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Design and Implementation of an IoT-Enabled Remote Air Quality Monitoring System for Ambient Air Quality Assess-Ment

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Abstract: Today, many advanced systems and techniques are available to monitor ambient air quality, but these systems are not accessible by every nation in the world. Pakistan is the fifth most populated country in the world, with a population of around 212.2 million, which requires a vast quantity of industrial resources and causes air pollution, which needs excellent attention by the nation. Still, Pakistan's air quality is worsening due to a lack of data, knowledge, and supervision. To remove this obstacle in data monitoring, an innovative, cutting-edge, and emerging technology is proposed (IoT-Enabled Remote Air Quality Monitoring System), which monitors the ambient air quality remotely. The system consists of 3 sensors (MQ-135, DHT-11, and Gp2y1010au0f), which monitor CO, CO_2, Temperature, and Humidity present in the surrounding and transfer this data to the microprocessor, which analyze the data and transmit the data on thing speak channel named (IoT-Enabled Remote Air Quality Monitoring System) where the graphs are generated separately for each parameter between time and concentration in their respective unit (PPM, ug/m^3, and ^{o}C). In this study, the air quality of Jamshoro city was determined by selecting two sites, “Main gate of MUET” and “Phase one Residential Society,” which revealed that the concentration of Particulate matter, CO, and CO_2 exceeded the WHO and NAAQS standards.

Keywords: Air pollution monitoring; Humidity sensor; Temperature sensor; carbon dioxide (CO_2) sensor; Carbon monoxide (CO) sensor; Gas detectors; Wireless sensor

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1. Introduction

Clean air is one of the most critical aspects for the survival of human beings. Still, it is becoming more adverse daily, and every nation faces severe consequences of air pollution because of the revolutionization of industries, transportation, and human comforts. The air quality is changing, and there is no one denying it. It causes the death of every child in a group of 10 under five years. It leads to the end of 1.3 million people annually, ultimately causing global environmental change. Throughout the world, the majority of the population is inhaling polluted air, which surpasses the WHO guidelines [1]. The improper planning and poor enforcement of rules and regulation throughout the globe has led to the release of harmful emissions, i.e., Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NO_X), Sulphur Oxides (SO_X), Lead and other heavy metals into the atmosphere and causing various human health effects in respiratory and heart diseases leading to susceptibility of the immune system to microbial infections. Different research and organizations have stated that if the atmospheric CO_2 concentration exceeds the limit of 450 PPM, then the whole world will suffer significant environmental and health impacts (global warming, greenhouse effect, asthma, cancer, acute and chronic pulmonary disorders, respiratory infections, and cardiovascular disease). We are getting near it daily since the atmospheric CO_2 concentration in 2021 was 417 PPM [2].

Today, many developed and developing countries have installed various air quality stationary stations that monitor different air quality parameters and send data to the competent authorities so they can act according to it. Still, these monitoring stations cover only a tiny portion of the country's populated area, leaving some uncertainty regarding data [3]. This research aims to provide a fully functional, low-cost, environment-friendly remote air quality monitoring system, which monitors the air quality of various areas remotely and transfers the data over the cloud server 24 hours daily in any weather so that end users can see it and act according to it.

1.1. Background and Purpose

Pakistan is the 33rd largest country by area in the world and home to 212.2 million people from various religions, which requires abundant industrial resources, puts pressure on environmental resources, and leads to air pollution. A recent WHO report mentioned that the annual mean concentration of $PM_{2.5}$ in Pakistan was 58 μg/m3, exceeding the 10 μg/m^3 limit. It was due to improper planning, vehicle emissions, and open burning, and it was influenced by seasonal variations, mainly in winter (December to March) [4]. Pakistan ranks second in polluted countries worldwide and has caused 50,000 premature deaths, and 35% of total deaths occur due to lung-related diseases [5].

Jamshoro, the city of wind, is located on the left bank of the river Indus and is home to the three most prominent universities in Sindh. The town is 18 km from Hyderabad and is home to around 34,420 people. Temperature variation between 45°C to 7°C and wind speed variation between 4 to 3 mph from summer to winter, respectively. The primary pollution sources of the city are the Jamshoro power plant, located in the north area of the town, and the other M9 motorway, which is in the South direction. From both these sources, pollutants emitted are PM, CO, and CO_2. The city has the worst AQI, and the $PM_{2.5}$ concentration is 64 ug/m^3, higher than the WHO guidelines due to continuous vehicle movement and increased construction of new buildings.

Due to the absence and lack of a real-time remote monitoring system, air quality monitoring is complex, and there is a need to develop a real-time sensor-based air quality monitoring system. To overcome this difficulty, a remote air quality monitoring system operates on IOT protocols and analyzes various air quality parameters. The method comprises three components: a sensing unit, a microprocessor, and a webpage. The sensing unit consists of three sensors, MQ-135, DHT-11, and Gp2y1010au0f, which analyze CO, CO_2, Temperature, and Humidity, respectively [6]. The data collected from the sensors is transferred to the microprocessor ESP-32, which processes the data and applies a set of coding to convert the data into a human-readable form and uploads it over the server on Thing Speak Channel named "IoT-Enabled Remote Air Quality Monitoring System" from where the accessed user obtain it and act according to it shown in Figure 1.

Figure 1. Represents the Flow chart of the IoT-Enabled Remote Air Quality Monitoring System.

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1.2. Site Selection

For the data analysis, two sites were selected, located in Jamshoro city. The first site chosen for the analysis was "Main gate of the Mehran University Engineering Technology," which links with Indu's highway section "N55" and is shown in Figure 2. The second site selected was "Phase One Residential Society" beside Aptech Center, shown in Figure 3.

Figure 2. Represents Sampling Point 1.

Figure 3. Represents Sampling Point 2.

2. Materials and Methods

In this study, two major air pollutants, CO and CO_2, were considered and monitored to determine the ambient air quality and associated risk to the residents of Jamshoro city selected by the coping with WHO and NEQS guidelines. Along with these parameters, another two parameters, Temperature, and Humidity, were analyzed because they play a chief role in changing the concentration of these air pollutants. The daily permissible limits of these pollutants in outdoor environments by the WHO [7] and NEQS [8] are mentioned below in Table 1.

Table 1. Represents the guidelines of WHO & NEQS for Ambient Air Quality.

Pollutants	WHO	NEQS
CO	9 PPM	9 PPM
CO_2	350-450 PPM for 1 year	350-450 PPM for 1 year

2.1. System Requirements

The developed air quality monitoring system consists of three sensors and one microcontroller, namely DHT-11, MQ-135, Gp2y1010au0f, and ESP-32. Out of three sensors, two sensors, MQ-135 and Gp2y1010au0f, analyzed CO and CO_2, and DHT-11 analyzed the temperature and humidity of the atmosphere [9]. The data was sent to a microcontroller, which was analyzed and uploaded over a server on Thing Speak from where the end-user observed it, as shown in Figure 4.

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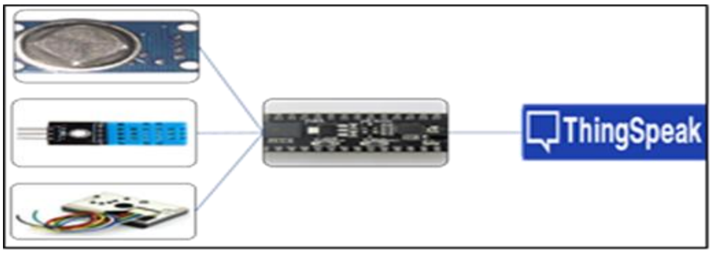

Figure 4. Represents a working diagram of the IoT-Enabled Remote Air Quality Monitoring System.

2.2. Working Mechanism

The project consists of multiple air quality sensors connected to a 5v power bank and uses the Wireless sensing network to detect the presence of harmful pollutants in the surroundings. Toxic pollutants like CO, CO2, percentile humidity, and temperature in the ambient air are sensed by MQ-135, Gp2y1010au0f, and DHT-11 sensors, respectively, and their corresponding values are recorded [10, 11]. The detected sensor values are transmitted to the microprocessor, which is integrated into the PCB board. After receiving the data from particular sensors, the microcontroller processes the data. It applies a set of coding so that the digital data is converted into analog values of respective units (PPM, ug/m^3,^{o}C). After converting the data, the microprocessor transfers the data over the thing speak portal through IOT protocols, and the final data output can be seen on the "IoT-Enabled Remote Air Quality Monitoring System" channel [12].

3. Materials and Methods

The concentration of air pollutants in the ambient air was measured using an IoT-Enabled Remote Air Quality Monitoring System. The system detected the presence of harmful contaminants like CO, CO_2, percentile humidity, and temperature in the selected two sampling stations and transferred the concentration data, changing with time over the Thingspeak channel, where the graphs were generated of all the parameters separately.

3.1. Location 1 (Main Gate MUET)

The data for site 1, "Main Gate MUET," was collected from 03.20 to 04.20 p.m.; during these hours, there was less traffic flow and fresh breeze in the surroundings.

3.1.1. Humidity

Figure 5 shows that from 03:20 to 04:20 p.m., there was a significant variation in humidity. The variation in humidity was because of the change in surrounding temperature and wind flow. It was observed the humidity decreased as time passed.

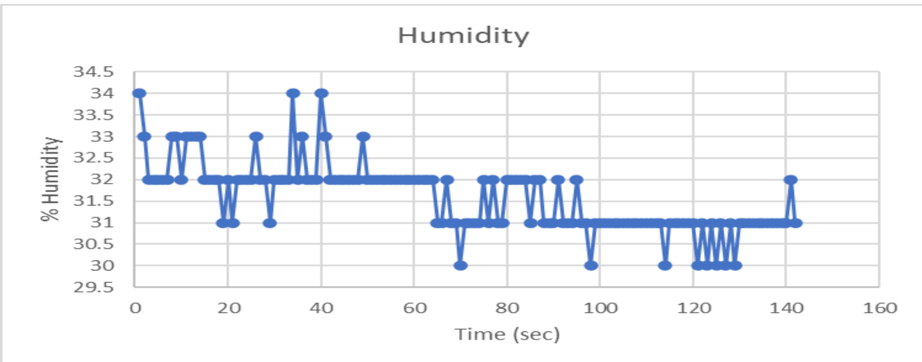

Figure 5. Represents the change in Humidity with Time at The Main Gate of MUET.

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3.1.2. Temperature

Figure 6 shows that the surrounding temperature increased from 03:20 to 04:20 p.m.. The increase in temperature was because as time passed, more solar radiation fell on the earth's surface; heat was also dissipated in the atmosphere from vehicles and generators.

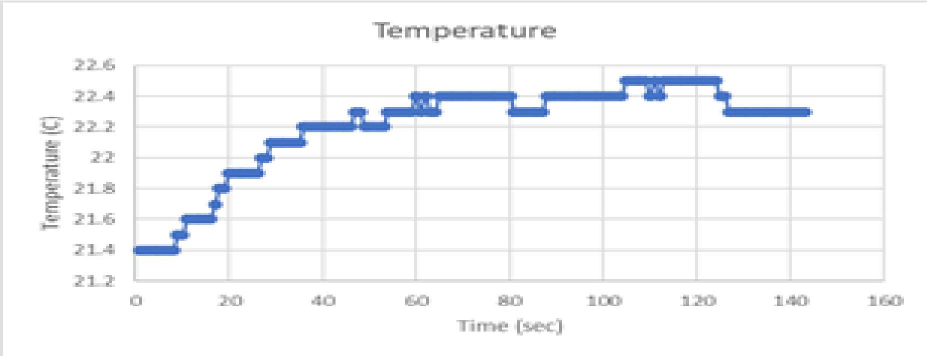

Figure 6. Represents the change in Temperature with Time at The Main Gate of MUET.

3.1.3. Carbon Dioxide (CO_2)

Figure 7 shows that from 03:20 to 04:20 p.m., the concentration of carbon dioxide started to decrease in the atmosphere. The reduction in the concentration of CO_2 was because the movement of vehicles slowed, and generators running in the surroundings were stopped as electricity came back.

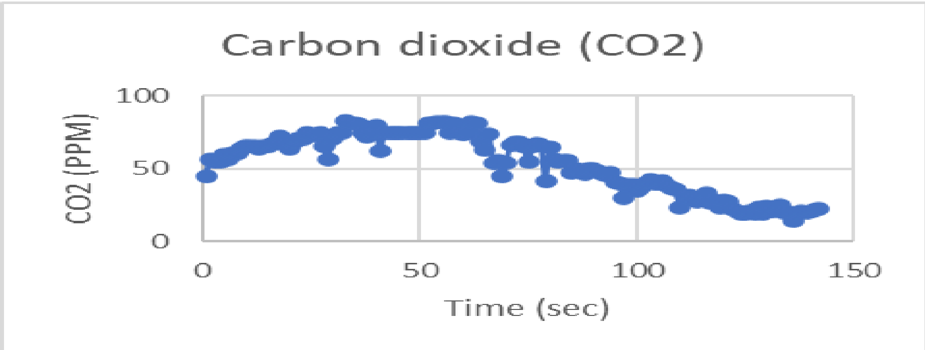

Figure 7. Represents the change in CO_2 with Time at The Main Gate of MUET.

3.1.4. Carbon Monoxide (CO)

Figure 6 shows that from 03:20 to 04:20 p.m., the concentration of carbon monoxide increased in the surroundings. This increase in the concentration of carbon monoxide was because vehicles and generators burned fuel and released CO into the environment, which remained for a long duration in the atmosphere, making the air toxic for breathing.

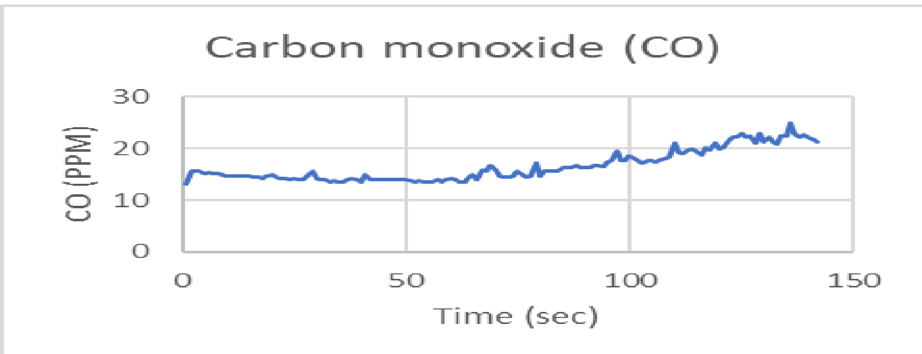

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Figure 7. Represents the change in CO with Time at The Main Gate of MUET.

3.2. Location 2 (Phase One Residential Society)

The data for site 2, "Phase One Residential Society," was collected from 5:15 to 6:15 p.m., when the temperature dropped significantly because of the winter season. At this time, most of the residents came out for a cup of tea and an evening walk.

3.2.1. Carbon Dioxide (CO_2)

Figure 8 shows that from 05:15 to 06:15 p.m., the concentration of carbon dioxide started to vary. This slight variation in CO2 concentration was due to the passage of vehicles and the burning of wood at tea stalls. During this hour, the CO_2 level in the atmosphere was safe.

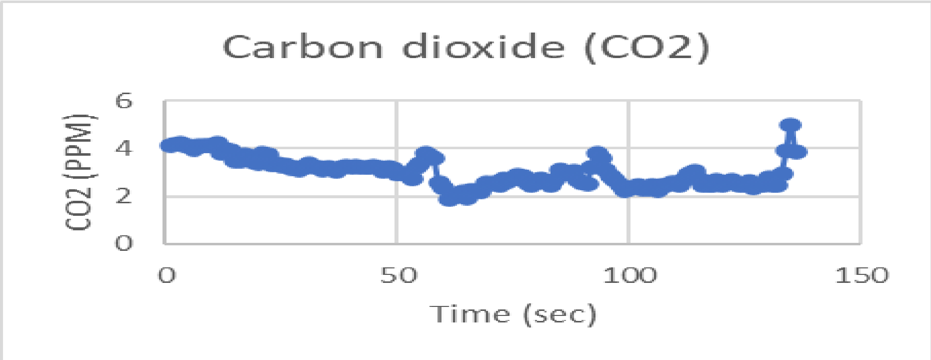

Figure 8. Represents the change in CO_2 with Time at Phase One Residential Society.

3.2.2. Carbon Monoxide

Figure 9 shows that from 05:15 to 06:15 p.m., the concentration of carbon monoxide in the atmosphere was high. This high concentration of carbon monoxide in the atmosphere was due to the burning of fuel and vehicle movement.

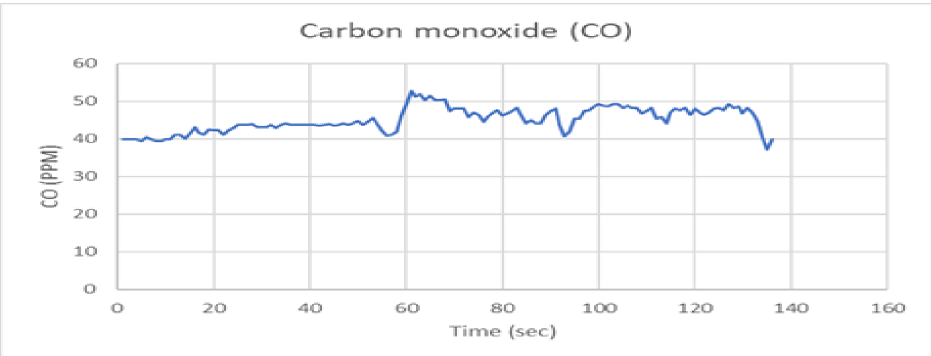

Figure 9. Represents the change in CO with Time at Phase One Residential Society.

4. Conclusion

The study found that the ambient air quality of Jamshoro City was bad in terms of CO_2 and CO in the atmosphere. Two sites were selected to determine the side effects on human health associated with air pollutants: "Main Gate MUET" & "Phase One Residential Society." The pollution level of both sites was collected for 1 hour each from 03:20 to 04:20 p.m. and 5:15 to 6:15 p.m., respectively.

It was found out the mean concentration of CO at both sites, "Main Gate MUET" and "Phase One Residential Society," was 45 PPM for 1 hour, which was significantly higher than standards due to open burning of fuel, movement of vehicles, construction, and

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unpaved roads which may lead to asthma, acute and chronic pulmonary disorders, respiratory infections, and cardiovascular disease.

5. Recommendations

From the data collected, it is recommended that the vehicles and generators should be adequately maintained, open waste burning should be stopped, and the construction should be carried out well. Air quality monitoring systems can be improved if pollutants like SO_2, NO_2, and ground-level ozone are monitored. Furthermore, there is a need for long-term monitoring of air pollutants to identify the reasons for their rise and change in their behavior [13].

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Conflicts of Interest: The authors declare no conflict of interest.

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