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Design and Development of a Wireless Communication Network Based Ambient Air Quality Monitoring System for Metropolitan Cities

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Abstract

Air pollution poses a severe threat to humans and the natural environment. High levels of air pollution are linked to respiratory problems, mental illness, skin diseases etc. Monitoring air pollution to report, study and take appropriate actions to curb it is an important agenda on many civic and government institutions. This work aims to develop a capable system to cover these grounds. The system is cost effective, portable, and accurate for providing warnings in case life threatening levels of pollutants is discovered. These specifications were responsible in the selection of ATmega32 processor with Arduino UNO development board for the main air pollution monitoring unit. It is a low power controller and can be powered by solar panels. The sensors are capable of detecting CO, CO_2, Methane, dust of PM 1.0, PM 10.0 and temperature and humidity are passed through a conditioning circuit and are then interfaced to the main control unit. The signals are calibrated initially to reduce erroneous detections. Short messaging service or SMS is used to wirelessly transmit data to a base station which is capable of alerting in case of a hazard. Wireless networks eliminate many limitations posed by wired networks, mainly costs related to wiring infrastructure.

Keywords: GSM; Metal Oxide; Sensor network; DHT1;, DS130; Dust sensor; Sensitivity; Selectivity; Calibration

Introduction

December 2015, marks the 32nd anniversary of the gas tragedy in Bhopal, India. Stagnant weather conditions caused a sharp increase in fatalities and for more than a year almost four people died each day leading an unexpected death toll over 4000 due to the release of 42 tons of toxic Methyl Isocyanate gas. This event is not an isolated incident that affected humans and the environment, as there have been many similar events such as Meuse valley, Belgium, London Smog event etc. Particulate air pollution has been conventionally measured by passing air through a particular filter paper and determining the density of black stain, known as "black smoke method". Most metropolitan cities are seeing a significant increase in their vehicular registration count and have increased the black exhaust containing CO and other harmful gases along with particulate matter, thus rendering the black smoke method obsolete.

The need for a simpler approach to detect and monitor these disease causing harmful pollutants in every polluted area with more concentration over metropolitan cities has never been so imperative and necessitated.

Literature Review

Ambient outdoor air pollution is renowned as a very thoughtful and top global public health issue, both in developed and developing countries. Most of the countries across Asia, Europe and America have failed, to a high degree, to maintain air pollution levels in urban or metro cities within the limit of WHO guidelines. The utmost populous country, China has shown a significant increase in the air pollution. The influence of air pollution on human and animal's health is abundant. Research over this has shown relations between air pollution and pre-mature mortality because of cardio-respiratory disorders and cancers and heart attacks. Even the smaller behaviour of humans like anxiety and anger is linked to air pollution.

With all these diseases, research people came up with solutions and systems to measure air quality monitoring systems. A system designed with a network of tin oxide sensors for indoor and outdoor air quality monitoring [1]. In this paper, innovative processing based on multiple-input-multiple –output neural networks is applied at the network sensing node to obtain temperature and humidity compensated gas concentration values. Some researchers also concentrated on particular area/room air pollution like air quality control for health centres and schools etc., like a system designed for air quality control for health centres [2]. The designed system is based on a set of low cost sensors fortified with a communication module. A multi agent system is used to handle various features of the monitoring system such as: data integration, data analysis, user cantered interfaces, etc... In the same manner, a system for ambient air quality measurement for School area based off the ZigBee wireless network. The system designed measures CO, NO_2 and dust particles [3]. Some researchers designed and proposed systems to measure air quality check by monitoring vehicular emission in traffic signals. The quality of emission of each vehicle is analyzed and recorded individually. If the emission is found to be below the ideals then the number plate will be captured using the installed camera and the information is sent to the nearby traffic police. The complete simulation is carried out on OMRON PLCK [4]. Some researchers have only concentrated on indoor environment air quality check measures [5]. There are multiple papers where authors have concentrated on particular disease causing pollutants like asthma caused due to entry of dust particles in the human body through respiration [6].

Motivation

In order to monitor particular gases that are hazardous to humans

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like ozone, carbon monoxide, sulphur dioxide, nitrogen dioxide, methane, lead, particulate matter and other gases, it is crucial that a stand-alone system is to be designed, implemented and deployed. Currently in India, air pollution is monitored by independent third party environmental agencies, academic institutions or the government. It is often seen that severe injuries or fatalities occur even before these agencies and institutions have performed tests and released public reports warning about these hazards.

This work proposes a system aimed at designing an ideal low cost ambient air quality monitoring module which will communicate based on wireless communication networks. The designed system will be able to notify residents and pedestrians in that particular area with the air quality level.

Proposed System Overview

The design described here is a wireless communication network based ambient air quality monitoring system. It mainly consists of two major subsystems as shown in Figure 1, namely:

1. The air quality monitoring module
2. The base station

The design is derived based on the necessity of an autonomous and ubiquitous system to allow for large scale data collection, which can be studied and used to issue alert automatically in case of unusually high levels of pollutants. A wireless system is chosen in order to facilitate real time data collection without the need for human intervention. A wired system would increase infrastructural cost, especially towards physically wiring a large number of devices to a centralized server. It has no tangible benefits when compared to a wireless setup.

The air quality monitoring module

The air quality monitoring module is responsible for detecting the CO, CO_2, and CH_4 gases present in the environment along with the temperature and humidity of the corresponding location and communicate with the air quality data monitoring base station as show in Figure 2.

The base station

The base station is responsible for receiving the distress messages from the air quality monitoring module.

The base station forms the back end of the system, receiving data from multiple measurement modules and taking an intelligent decision based on the collective data as shown in Figure 3.

Methodology

The system design simulation is carried out in Proteus ISIS Professional v 8.1 SPI for Arduino UNO development board. Proteus combines mixed mode SPICE circuit simulation, microprocessor models and animated components to simulate microcontroller based designs. Proteus helps simulate the design without the need to actually setup the physical components. This helps in prototyping and testing the design without physically implementing it, thus saving a lot of time in case there is a bug in the design. The system is initialized by powering it on. Upon power up, the peripherals are then prepped and initialized for use. The various sensors which are connected to the MCU are then read. The values from the Carbon Monoxide (CO), Carbon Di-Oxide (CO_2), and Methane (CH_4) and dust particles are then retrieved from the sensors along with temperature and humidity readings from their respective sensors. The control unit then checks the humidity to see if it lies between 30% RH and 45% RH. This is done because the values of the carbon monoxide, carbon dioxide and methane to determine their concentration in parts per million (ppm) depends on humidity. In this case, if the humidity is between 35% RH and 45% RH, the concentration in ppm is determined by formula set 1.

The controller then checks the real time clock continuously to determine the current time. At predetermined regular intervals determined by the real time clock, the controller sends an SMS to the base station with the values of the pollutants. However, if the humidity is not between 35% RH and 45% RH in the first conditional check, the humidity is checked to see if it lays between 46% RH and 65% RH. If

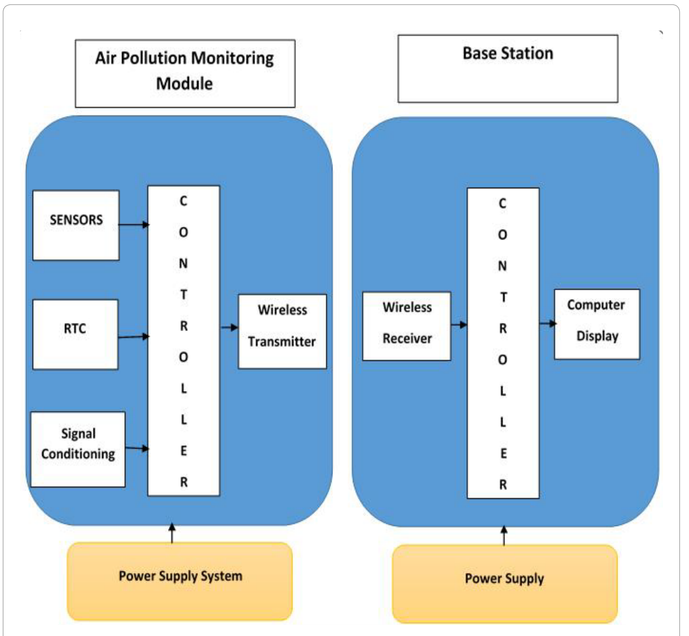

Figure 1: Proposed system block diagram.

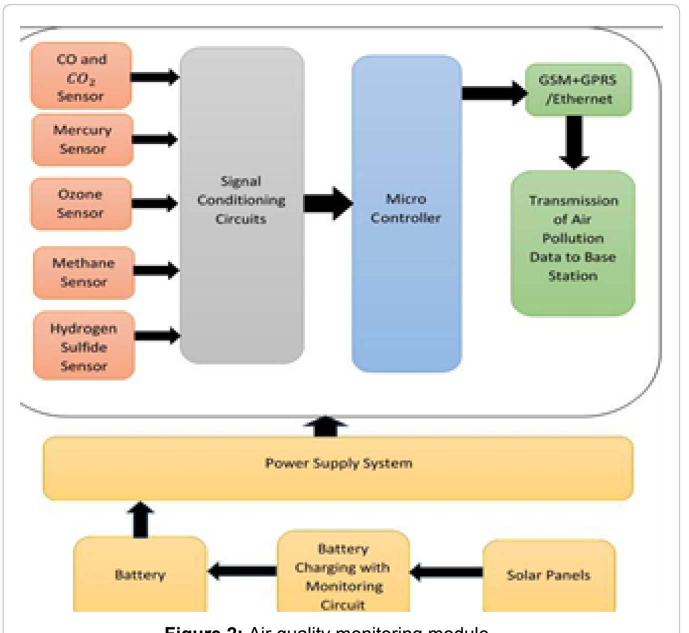

Figure 2: Air quality monitoring module.

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it lies between 46% RH and 65% RH, then formula set 2 is used, else formula set 3 is used. The controller then checks the real time clock to determine whether to send an SMS to the base station. If it determines that not enough time has elapsed since the last transmission, the controller reads renewed values from the sensors and repeats the entire process as shown in Figure 4. If an SMS is sent, the controller again starts reading new values and continues the process explained above.

Calibration of MQ sensors

In order to calibrate a sensor, measure the sensor output and then calculate the R_O value

Where, $$R_O = \frac{R_S}{R_{O\_clean\_air\_factor}} \quad (1)$$

$$R_{O\_clean\_air\_factor} = 10K\Omega$$

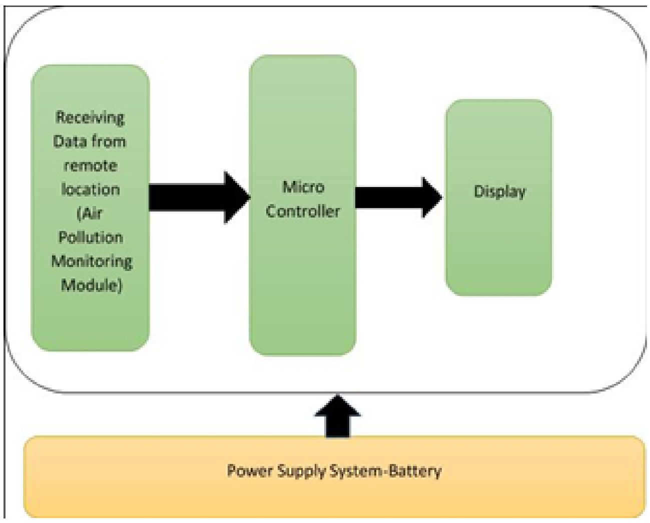

Figure 3: The base station.

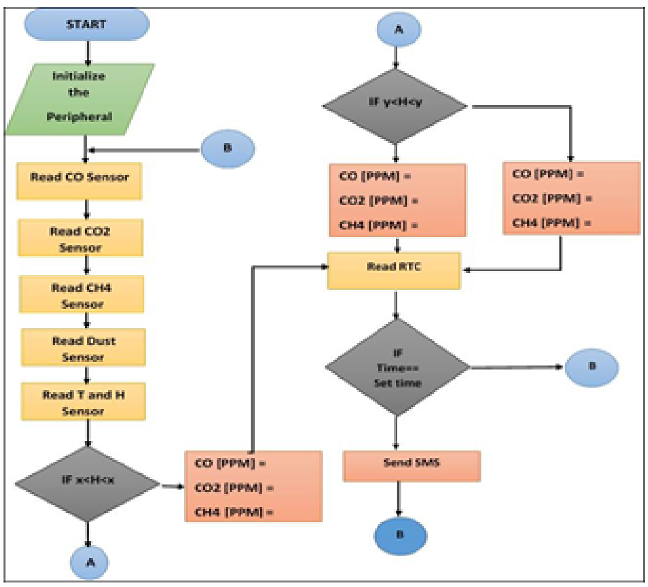

Figure 4: System level flow chart.

Where, $$R_S = \frac{(V_{in}-V_O)\times R_L}{V_O} \quad (2)$$

Where, R_S = Sensor

R_L = Load Resistance

V_{in} = Supply Voltage

V_O = Output Voltage

Substituting R_S in the Equation (1),

$$R_O = \frac{\frac{(V_{in}-V_O)\times R_L}{V_O}}{R_{O\_clean\_air\_factor}} \quad (3)$$

Computing the R_O values and plotting the $\frac{R_S}{R_o}$ against the obtained PPM, a sensor will be calibrated.

Results and Validation

The graph on the left side indicates values calculated from the data sheet for CO_2, whereas the one on the right shows experimental values for CO_2. As seen above, the values of R^2 are 0.9961 and 0.8876, which are approximately the same from Figures 5 and 6 respectively.

For CO, the calculated theoretical values on the left show an R^2 value of 0.9825 and the experimental value of R^2 of 0.8503, which are equal within the practical limits of error as shown in Figures 7 and 8 respectively.

Plot from Experimental Values for Dust Sensor Similarly, the dust

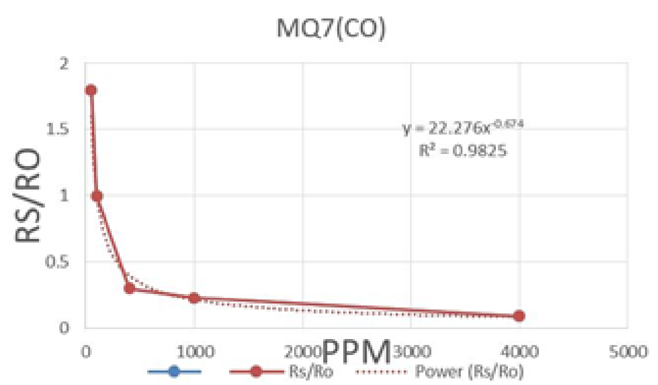

Figure 5: Plot from datasheet values for MQ7 sensor.

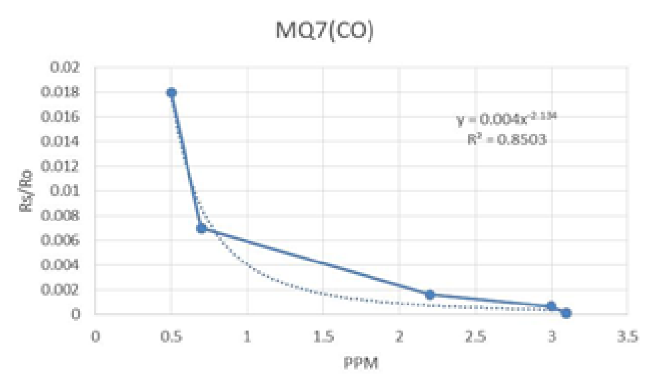

Figure 6: Plot experimental values for MQ7 sensor.

sensor also shows high congruity between the values of calculated data sheet and experimental values of R^2 at 0.9105 and 0.998 respectively. These readings indicate that the sensors are working within a reasonable range of error as shown in Figures 9 and 10 respectively.

The Table 1 shows the typical values of CO and CO_2 and the experimental results obtained. For CO, the typical value expected in a residential environment is 0-5 ppm, and the experimental detection in clean air is well within the limits. Similarly the experimental values of an incense stick and vehicle exhaust approximate the typical values of a gas stove and vehicle exhaust as shown in Table 1. Next, the table for CO_2 shows the typical values found in the air outdoors and in residential complexes. The experimental values are found to be within reasonable limits as shown in the table above under detection in clean air, incense stick and vehicle exhaust. Thus, the system is found to be accurate enough to give reliable readings (Table 2).

Future Work

1. An application can be developed in PC to display the plot of the obtained data daily, weekly, monthly and yearly basis.
2. More number of sensors can be interfaced like to detect mercury, sulphur etc.
3. Calibration of MQ sensors can be done in two ways, one way is being carried out here by calculating R_s/R_o can also be done by injecting known amount of gas into the vacuum chamber.

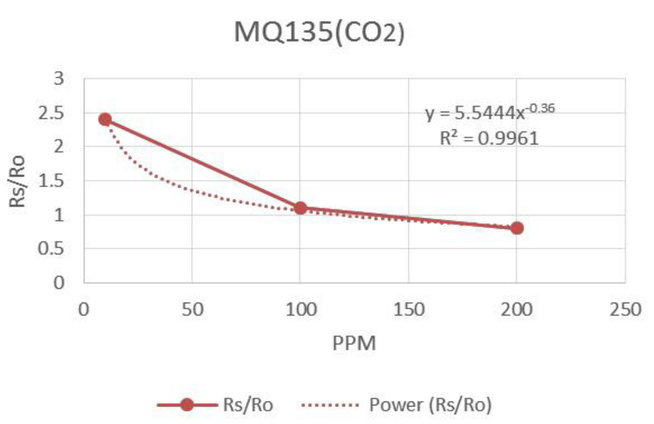

Figure 7: Plot from datasheet values for MQ135 sensor.

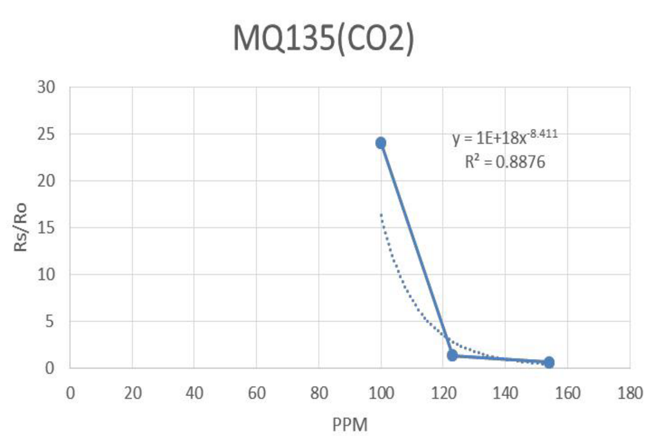

Figure 8: Plot from experimental values for CO_2 from MQ135 sensor.

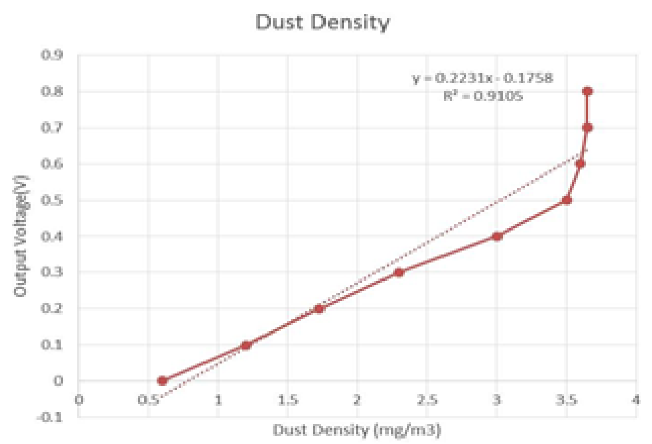

Figure 9: Plot from datasheet values for dust sensor.

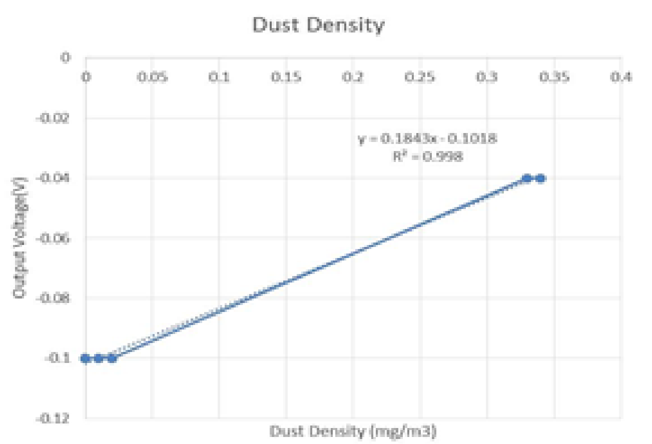

Figure 10: Plot from experimental values for dust sensor.

Carbon Monoxide Detection		
Detected in clean air	Detected incense with stick	Detected at vehicle exhaust
0-3.1 ppm	4-7 ppm	100-170 ppm
Carbon Di-oxide Detection		
Detected in clean air	Detected with incense stick	Detected at vehicle exhaust
100-154 ppm	223-280 ppm	450-800 ppm

Table 1: Results obtained.

S No	CO	CO_2
Emission Test	114 ppm	315 ppm
Machine		
Developed	100-17 ppm	450-800 ppm
Design		

Table 2: Comparison of results with standard emission test machine.

Conclusion

This paper suggest the design, development and implementation of a wireless communication network based ambient air quality monitoring system for metropolitan cities, as an alternative to the existing traditional air quality monitoring systems facing issues in the area of portability and calibration part.

The system consists of two main blocks

1. The air pollution quality monitoring unit with all the measuring sensors, which continuously monitors the respective areas air quality and keeps logging it and send a message to the base station at the particular instant of time.

2. A base station, which receives the messages from the air quality monitoring modules placed at different locations and keeps a record of each module on yearly, monthly, weekly and daily bases.

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