Air Pollution Monitoring based Fuzzy Controller with Embedded System

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Abstract. Air pollution has a wide and great influence on the concentration of constituents of the atmosphere, which leads to many effects such as acid rains and global warming. In order to avoid such unwanted adverse imbalances in the nature, designing an air pollution monitoring system (APMS) is very important. This paper discussed the development of an effective solution for monitoring the air pollution by making an Arduino-Based Air Pollution Monitoring System (APMS). Carbon monoxide and Carbon Dioxide concentration levels in air were measured and monitored using MQ4 and MQ7 gas sensors and Arduino atmega microcontroller. These sensors can detect many harmful gases and can be used for measuring their amount very accurately. The concentrations of CO and CO2 in particle per million (PPM) will be monitored and displayed on the LCD very easily. Based on these measurements the pollution level could be monitored, determined, and displayed. The experiments were carried out using the developed wireless APMS under various physical conditions. The results showed that the designed system collects reliable and reasonable real time pollution data. Three hour sampling time was executed in each location. One of the logical functions that are widely used is fuzzy logic. A fuzzy logic artificial intelligence for gas sensors is used which clarifies the presence as well as the concentration of CO and CO2 efficiently. Fuzzy logic will gives the decision about whether the air is polluted or unpolluted. This logic function we can process some existing data into a form of output which can be in the form of a status or state of action that will be performed by a tool. This proposed system will contribute in the construction of an APMS in the outdoor or even in the indoor environment.

Keywords: Air pollution, Carbon monoxide, Carbon dioxide, Arduino, Gas sensors, Fuzzy Logic, Membership Function

1. Introduction.
One of the world’s unembellished environment issues is air pollution. World Health Organization (WHO) reported that, in developing countries there are about 3 million people died annually due to air pollution [1]. The emergence of air pollution in many countries all over the world is a result of the industrial growth and road transport [2]. Air pollution contributes in the climate change. Exposure to CO gas leads to various and different health effects. This gas affects the central nervous systems, the cardiovascular system, blood, and lungs [2]. Effect of CO depends on the physiological status, the health of exposed person, exposure time and the pollutant concentration [3]. On the other hand CO2 gas can be considered as a basic indication for air quality. The concentration of CO2 is about 350 PPM.
in the outdoor atmosphere [4]. The main profits of APMS are improving the environment, reducing costs, better risk control, better pollution detection, and reduced errors. The main artificial intelligence methods of soft computing namely fuzzy logic, neural network and genetic algorithm have shown great ability in solving complex non-linear system identification and control problems. Several research efforts have been expended to use evolutionary methods as effective tools for system identification. Among these methodologies, fuzzy rule based systems have been an active research field for their unique ability to build models based on experimental data [4]. This paper is arranged as follows: Section 2 contains the related works and Section 3 explains background theory. It also explains the implementation of the system. Section 4 presents, demonstrates, and discusses the results obtained from the developed system while Section 5 presents the conclusions of this proposed system.

2. Related works:
There are many studies and researches that have been proposed, analyzed, and published on the subject of air pollution monitoring systems (APMS), such as [3], where concentrations of carbon monoxide in indoor and outdoor air of Ghalyun cafes were measured using a portable gas meter (Honeywell BW MAX XTII, Brandt Instruments, Inc. Canada). In [5], shows a Novel Fuzzy Logic Model for Multiple Gas Sensor Array where the outputs from an integrated multiple gas sensor was used to specifically select the presence and concentration of four gases namely Hydrogen, methane, LPG and Carbon monoxide. In [6], the concept of IoT is used to monitor the air pollution using MQ135 Gas sensor through Arduino Uno. In [7], the author attempts to develop an effective solution for pollution monitoring using wireless sensor networks (WSN) on a real time basis namely real time wireless air pollution monitoring system. Each of these studies has different methods, number of sensors, types of machine learning, microcontrollers to realize the APMS. In this paper, the carbon dioxide (CO$_2$) concentration and carbon monoxide (CO) concentration were monitored, and then the readings were analyzed using fuzzy logic with several rules and memberships to decide the degree of risk according to air pollution, and display the results and measurements of CO and CO$_2$ and the output of fuzzy logic. The Atmega microcontroller was used in this system. This proposed APMS may participate in the development process of a comprehensive outdoor air pollution monitoring systems in the future. It may also support indoor air pollution monitoring.

3. Background theory

3.1. Carbon monoxide (CO): It is a non–irritating, colorless, odorless, tasteless, poisonous and Pollutant gas [7][8]. It may be emitted by anthropogenic or natural sources into the environment [3]. It is formed when carbon (C) in fuels such as petrol, wood, coal, and natural gas hasn't burned completely. Air quality may be affected by emitting sources of CO such as tobacco smoke, gas stoves, fireplaces, and other types of fuel burners [2]. CO produces carboxyhemoglobin (COHb) through reacting with blood hemoglobin molecules; this will reduce oxygen (O$_2$) supplied to the body organs. The concentration of COHb in blood is considered as an indicator for exposure to CO [2][9]. In this article CO concentrations had been surveyed in the outdoor air in Baghdad; the capital of Iraq.

3.2. Carbon dioxide (CO$_2$): It is a non-toxic, non-flammable, colorless, odorless, and non-reactive gas. It is a naturally sub product of cellular respirational process and a as a result of burning the fossil fuels. Exposure to high concentrations of CO$_2$ may cause a risk to life [7]. In this article CO$_2$ concentrations had been surveyed in the outdoor air in Baghdad; the capital of Iraq.

3.3. MQ7 Gas Sensor (CO Sensor): This is a low cost, simply used with extremely high sensitivity for sensing Carbon Monoxide (CO) concentrations in the air. This sensor has the ability to sense and detect CO-gas concentrations within a range from 20 to 2000 PPM wherever the sensor is placed. MQ7 has fast time of response. The output of the sensor is the analog resistance of it. MQ7 sensor consumes not more than 150 mA at a voltage of 5 V. It is very stable sensor with the characteristic of long life. It is an ideal sensor to use for a CO alarm [7]. MQ7 Gas Sensor is shown in fig.1.
The sensitive material of MQ7 is SnO$_2$ is. It has a low conductivity in the clean air. MQ7 can detect CO at low temperatures when heated by 1.5V. The conductivity of MQ7 sensor is high along whenever the gas concentration is rising. At high temperatures when the sensor is heated by 5.0V, it will clean the gases which had been adsorbed at low temperatures. MQ7 can detect various gases that contains CO. This sensor is very suitable to use for different applications [7].

3.4. MQ4 Gas Sensor (CO$_2$ Sensor): The MQ4 gas sensor is using SnO$_2$ as a sensitive material to sense and detect combustible gasses which includes methane, propane, and butane. This gas sensor can detect concentrations of methane / natural gas in the range of 200 PPM to 10,000 PPM. This range is very suitable to detect gas leaks. MQ4 is simple and analog voltage interface that requires one analog input pin only from the microcontroller. MQ4 is a perfect gas sensor for Air Pollution Monitoring System (APMS) can sense CO$_2$, smoke, NH$_3$, Benzene, alcohol, and other gases. MQ4 is a low cost gas sensor and it's suitable for many different applications [7]. MQ4 Gas Sensor is shown in fig.2.

MQ4 is a sensitive gas sensor to the changes in temperature. The variations in the readings of CO$_2$ are small if it happened according to temperature changes. It's (<100 PPM) on the low range, and it's (<1000 PPM) on the high range. These variations in the readings of CO$_2$ due to the change in temperature may become negligible as compared to the whole changes in concentration of CO$_2$ if the design was good. Sensor's accuracy can be improved to make the entire experiments in a constant temperature if the sensor is calibrated at the desired temperature. MQ4 operates in temperatures within the range 20-30°C, but it may be used outside this range [5].

3.5 Arduino:
Arduino is a flexible micro-controller and a development environment that is used for controlling devices and reading data from all types and categories of sensors. It's simple, extensible; also it has a great success, wide adoption and spread between users. The previous properties of Arduino lead to continuous development of several software libraries and hardware extensions which enable it to
communicate wirelessly as well as using wires with the Internet. Arduino is an open hardware platform. Sensors do the function of collecting data from the surrounded environment and generating information to raise awareness about the context by monitoring any change in the environment, then the corresponding things will make the needed responses. Here, using the MQ4 and MQ7 gas sensor gives the ability to monitor various kinds of dangerous gases and Arduino mega 2560 microcontroller considered as the heart of Air Pollution Monitoring System (APMS) because it controls the entire monitoring process. Arduino mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input / output pins where 15 of them can be used as PWM outputs, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a power jack, a USB connection, an ICSP header as well as a reset button. Arduino contains all the things that are needed for supporting the microcontroller. It can be connected simply and easily to a computer using a USB cable. Arduino also can be powered with a battery or an AC-to-DC adapter to get started [6]. The tracking APMS was developed in order to monitor air pollution even at the remote and far sites accurately. APMS is very helpful for those who are involved in monitoring the environment. Arduino-Based APMS uses the required data to adjust air parameters on time and to update the risk of environmental parameters during the standard period of time. In addition to that, Arduino-Based APMS and its sensors readings of measurements relevant to environmental parameters can be employed in a very efficient manner to detect the carbon monoxide concentration (CO) and carbon dioxide concentration (CO₂). Arduino Mega is shown in fig.3.

Figure 3 Arduino Mega

3.6. Fuzzy Logic:
The approach of Fuzzy logic (FL) has been introduced by the artificial intelligence researcher Lotfi A. Zadeh in 1965. FL methodology focuses on the purpose of making a decision for deficient data with a concept named true or false and the degrees of truth. The fuzzy logic set includes the classical set [9][10]. The fuzziness of elements had been implemented using membership functions in the set of solution which is based on experiment regardless knowledge. The membership function is implemented using the methodology of weighted rate inside fuzzy logic interference system [11][12][13].

4. The designed system and implementation

4.1 Proposed system architecture:
In this paper an Arduino-Based Air Pollution Monitoring System (Arduino-Based APMS) was designed and implemented with the use of Fuzzy logic as a type of artificial intelligence as shown in Fig 4. The data collected using MQ4 and MQ7 sensors is analyzed by the method of FL and graphs based on the fuzzy inferences had been also generated using this method. Using FL has many advantages like there isn’t any need for many data sets for analyzing the collected data. The second advantage of using FL is its power of interpretation as well as its simplicity [10][14][15]. The approach of
Mamdani Fuzzy Inference (MFI) is a simple and a commonly used Fuzzy methodology\[13\]. The MFI structure depends on the operations of min-max. MFI method has a wide spread acceptance. It is a well suited method for human inputs. The output of MFI can be transferred easily to a linguistic form\[13\]. In this system we can monitor air pollution using Arduino and gas sensors that available locally to monitor gases such as Carbon monoxide (CO) and Carbon dioxide (CO₂) which considered so dangerous and harmful gases to people. This APMS will display the concentration of CO and CO₂ in PPM on LCD so we can observe and monitor them very easily. Measurements of CO and CO₂ concentration levels were taken in the Iraqi capital, Baghdad. Different measurements were made within different times during day and night. The reading were recorded and displayed such that there is 2 minutes between each reading and another. The information obtained from these gas sensors is recorded then will be sending to the destination device through the Arduino atmega microcontroller. The level of air pollution can be viewed by people wirelessly using this method. APMS will reduce cost, it’s reliable and a very comfortable system to use it for any place to monitor these gases.

In this paper the outputs were produced using a fuzzy rule based system according to the inputs for the system. Two input parameters had been entered to the APMS. The first input is CO concentration and it consists of 2 membership functions. The second input is CO₂ concentration and it consists of 3 membership functions. The output of APMS is the degree of pollution and it consists of 3 membership functions.

All the membership functions of inputs and output were graphed in Matlab using the trapezoidal function. The membership function for CO concentration is demonstrated in Fig. 5 with the parameters low and high to analyze CO concentration whereas Fig. 6 shows the membership function for CO₂ concentration with the parameters low, medium and high for analyzing CO₂ concentration. In Fig. 7 the membership function for output is shown with the parameters low, medium and high to analyze it.

![Figure 4 APMS architecture](image)

![Figure 5 membership function of CO concentration](image)
The number of fuzzy rules that governed the APMS is 6 and it's determined according to the given membership function of the parameters as shown in Table 1.

Table 1. Fuzzy rules of the APMS input and output parameters

| No. | Input | Output         |
|-----|-------|----------------|
|     | CO concentration | CO₂ concentration | degree of pollution |
| 1   | Low   | Low            | Low (Normal air)    |
| 2   | High  | Low            | High (Low level of pollution) |
| 3   | Low   | Medium         | Medium (Low level of pollution) |
| 4   | High  | Medium         | High (Air is polluted) |
| 5   | Low   | High           | High (Low level of pollution) |
| 6   | High  | High           | High (Air is polluted) |

Fig. 8 shows the Fuzzy Logic Inference System where CO and CO₂ concentrations are the inputs of the system. Fuzzification and Defuzzification methods were carried out and the degree of pollution is the output of APMS.
Figure 8 Fuzzy Inference System

4.2 Implementation of APMS:
Figure 9 shows the connections between of the LCD and the Arduino microcontroller board through the VCC, GND, SDA and SCL pins also the figure shows how to connect the sensors MQ4 and MQ7 to the power (5v) and ground through wires, while the wire that transfers information of the CO concentration sensor was connected to one of the analog pins (A0) and the information wire of the CO2 concentration sensor was connected by wire to the analog pin (A1) of the Arduino. The power of the Arduino microcontroller can be supplied in the following three ways, the 1\textsuperscript{st} way is by laptop using the USB port and the 2\textsuperscript{nd} way is by using an external adapter which connected to the power jack in the microcontroller and the 3\textsuperscript{rd} way is by using batteries that are connected to Vin port.

Figure 9 Installation of Arduino-Based APMS circuit
5. Results and discussion.
The developed Arduino-Based Air Pollution Monitoring System (APMS) is checked using different measurements in different situations and conditions from normal and common states to abnormal and uncommon states of air. These different tests and results shows minimum error rate and high accuracy in sensing CO and CO₂.

Through the experiments that had been carried in several times and conditions, it had been noticed that when the levels of air pollutions (CO and CO₂ concentrations) are within the normal range, APMS gives a low risk notification whereas if one of the levels of CO and CO₂ concentrations is not within the normal range and the pollution is in risky levels, APMS will give a risk notification which is appropriate to the data as shown in fig.10, so people who involves with air pollution will be able to know how dangerous the situation is, in very easy and high speed way, in order to do the necessary measurements.

![Figure 10 Implementation of Arduino-Based APMS circuit](image)

6. Conclusion and future work.
The risk of environmental pollution can be reduced when Arduino and gas sensors are used in detecting air pollution with the aid of an intelligent fuzzy logic system. Arduino can enable easy and simple integration with air pollution monitoring sensors (MQ4 and MQ7 gas sensors). This paper demonstrates a very simple and easy-to-use system. The libraries of fuzzy logic system which is found in the Arduino mega microcontroller software was used to analyze the data and information recorded from MQ4 and MQ7 sensors, and then it gives the decision about the risk directly. Using Arduino made the information of the APMS to be recorded for all of those who are involved with environmental monitoring. It's appeared from this experiment that using APMS gives good results that one can rely on it. APMS is easy, quick, and accurate system. It can be used for monitoring everywhere and for any period of time without any obstacles or problems.

Acknowledgement.
The authors would like to thank Al-Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad-Iraq for supporting the present work.
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