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Smart Room Carbon Monoxide Monitoring and Control System

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Abstract: *Carbon Monoxide (CO) is the most abundant air pollutant gas and accumulates rapidly to dangerous concentrations even in areas that seem to be well ventilated. Carbon monoxide detectors/alarm systems exist but people who are old, hearing impaired, partially sighted or heavy sleepers may not get the warning or find it difficult to wake up and get out in the event of dangerous concentration of CO in their homes. This paper presents the development of a smart CO monitoring and control system to control the ventilation in a room when carbon monoxide concentration is at a level dangerous to human health. The system is comprised of a microcontroller interfaced with CO sensor (MQ-7) and ultrasonic distance sensor (HC-SR04) for CO concentration sampling and window state determination respectively. A third component interfaced with the controller is a DC motor, which accordingly control the window when the concentration of CO is high. A mechanism was provided to ensure that the fan in the room is ON and the window is completely open whenever CO concentration is high to ensure quick restoration of the air quality. Results from the performance evaluation of the system showed that it achieved an average response time of 6 seconds and consumed 321.62mW and 652.82mW of power during sampling and control respectively. The obtained results showed that the system is capable of responding quickly to dangerous concentration of CO, thus a desired attribute of CO monitoring systems hence, can adequately replace the existing systems with less power consumption.*

Keywords: *Carbon Monoxide (CO), Smart System, Control System, Air Quality*

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I. INTRODUCTION

The effects of human activities on their environment have gained important global consideration in the last decade. Air pollution is one of the significant effects which occur either due to increase in number of industries and industrial processes, vehicles for transportation systems or household-kitchen activities [1]. Many efforts have been proposed by individuals and institutions to tackle the problems related to air pollution control [2][3][4]. However, the encouragement of the use of vehicles with low carbon emission; the use of highly complex technology in filtering the gas exhausted from chimneys into the atmosphere are some of the major steps to reduce the concentration of polluting gases. Moreover, the use of Carbon Monoxide (CO) detectors/monitors in homes and the active campaign to promote green energy concepts, green city and green society has yielded positive results of clean air environment [1].

Carbon monoxide (CO) is a colourless, odourless, tasteless and poisonous gas produced when carbon-containing fuels are burned in the presence of oxygen. When CO is inhaled, it prevents haemoglobin from taking up oxygen in the red blood cells. Therefore, it impairs the oxygen-carrying capacity of the blood, cells and tissues [5]. CO accumulates rapidly (within minutes) to dangerous concentrations even in areas that seems to be well ventilated. Some effects of CO poisoning include: depression, light-headedness, confusion, headaches, nausea, memory loss, dizziness, vertigo, loss of consciousness, collapse and even death. The effects on the foetus of a pregnant woman is usually severe [6]. A dangerous level of CO (35 parts per million or over) causes heart problems, major organ dysfunction, brain damage, cognitive problems and some other permanent health problems [7]. The level of tolerance to carbon monoxide (CO) poisoning for an individual is determined by various factors such as, level of activity, ventilation rate, pre-existing cardiovascular and/or cerebral diseases, cardiac output, pregnancy, anaemia, age, sickle cell disease and some haematological disorders [8].

According to the World Health Organization (WHO), 41% of the world population is exposed to household air pollution resulting from cooking with polluting fuels and technologies [9]. In the developing world, CO is an indoor pollutant because firewood is used indoors for heating and cooking [10]. In the United States of America (USA), Consumer Product Safety Commission (CPSC) estimated that unintentional exposure to carbon monoxide accounts for about 500 deaths every year and that 8,000 to 15,000 people visit the emergency room of hospitals annually for carbon monoxide poisoning that is not related to fire. Similar report from the United Kingdom (UK), showed that, more than 200 people are hospitalized with suspected carbon monoxide poisoning and around 40 die annually [11]. Authors in [12] found out that emissions of carbon monoxide from domestic generators, in Nigeria, may be connected to the rate at which families are wiped out due to fumes from generators kept within or at an enclosure in places of residence. In similar context, authors in [13] discovered that trucks produced the highest concentration of carbon monoxide (at 289.64 ppm) when compared to another source's emission. Diesel-operated generators contributed about 116.23 ppm of carbon monoxide and firewood (used for cooking) produced the lowest concentration of carbon monoxide (at 5.75 ppm). These studies imply that the main sources of carbon monoxide in residential areas of Nigeria are automobiles and generators. The emissions from these sources are well above 100ppm. Hence, the need for carbon monoxide monitoring and control system, to be installed in every household that uses generator sets.

In this paper, a smart system that monitors the concentration of CO in a room and reacts accordingly to dangerous concentrations is proposed. A smart system is a system that has sensors and actuators that are either attached to or embedded in it as an integral part. The smart system and its components will act and/or react in a predicted manner, and therefore, emulate a biological function and the ideal smart system is the human body [14]. Generally, the control of carbon monoxide (CO), a pollutant that is primary in nature, is best achieved from the source [15].

The paper is organized into five sections: Section II provides the review of related works, detailed methodology is presented in section III, results and discussions, including performance evaluation are accomplished in section IV. Section V concludes and provides direction for future improvement.

II. RELATED WORKS

A number of related works in the area of CO monitoring exist. [1] proposed a design of a CO gas detector (based on microcontroller performance) which can display CO concentration on an LCD and a computer monitor via serial communication interface. The system can be used for real-time and continuous monitoring of CO concentration but cannot be used to control its concentration. In [18], a low-cost system that can detect and monitor air contaminants of CO and hydrogen for passive smokers with a standalone microcontroller for data acquisition and system control was presented. The system was cost effective and had an accuracy of 95%. However, it could not control the CO concentration. In the work of [2][3][4], a feasibility study of a wearable computing system to protect construction workers from carbon monoxide poisoning was proposed. Pulse oximetry sensor was integrated into a construction helmet for non-invasive and continuous monitoring of the blood-gas saturation levels of workers. Results of this study showed that the integration of an oximeter into a construction helmet can warn of impending CO poisoning with a probability of over 99%. The system uses an inexpensive and versatile mechanism for carbon monoxide sensing. However, it cannot be used in a room and was not designed to control CO concentration.

In [16], a carbon monoxide monitoring and alarm system based on MCS51 microcontroller was proposed. It was designed to raise an alarm when CO concentration is unsafe for humans inside automobiles. The system is cheap and simple. However, no mechanism for CO concentration control was incorporated.

In the work of [17], an innovative optical system for detection of CO was proposed. The system consists of a photodetector based on ultraviolet light source and Gallium Nitride (GaN). The structural properties of the photodetector allow it to operate at speed and temperature as high as 600oC in exhaust manifolds of combustion engines which make possible the real time measurement and control of the pollutant species generated by non-stationary combustion processes. However, it was not designed for rooms where CO concentration could be controlled.

Summarily, the existing CO monitoring systems did not incorporate a mechanism for controlling the gas in high concentration, which is the focus of this paper.

III. METHODOLOGY

The system components are divided into two categories; hardware and software components.

A. Hardware Design Considerations

The design of the system hardware consists of a power supply unit, the sensor unit, the microcontroller unit, the alert unit and the airflow control unit as shown in Fig. 1. Fig. 2 is the complete circuit diagram of the system.

1. Sensor Unit

The main component of this section is the carbon monoxide (CO) sensor, which is MQ-7, produced by Henan Hanwei Electronics Company Limited. It was used to obtain the value of carbon monoxide (CO) concentration. MQ-7 was selected because it is low-cost, long lasting and has a high sensitivity to carbon monoxide. Tin Dioxide (SnO_2) is the sensitive material of MQ-7 gas sensor which has a lower conductivity in clean air. When heated by 1.5V (low temperature), it detects CO and when heated by 5V (at high temperature), it cleans the other gases (like hydrogen and methane) adsorbed under low temperature. The sensor's conductivity increases with rise CO concentration. Table 1, gives a summary of the technical data of MQ-7.

Table 1: Technical Data of MQ-7

Heater voltage	5V(high) and 1.4V (low)
Heater consumption	Approximately 350mW
Heater time	60s (high) and 90(low)
Sensing resistance	2KOhm- 20KOhm
Preheat time	Over 48 hours

Fig. 4 shows the sensor sensitivity graph, Fig. 5, shows a power regression of sensor sensitivity and CO concentration (in PPM) obtained from the mathematical model of equations (1-4). Fig. 6, shows the basic loop test of the MQ-7 sensor. Rs is the sensor resistance in air under various conditions of temperature and humidity. Ro is measured sensor resistance in clean air. Rl is an adjustable load resistance used to calibrate the sensor and 10kΩ is used for this work.

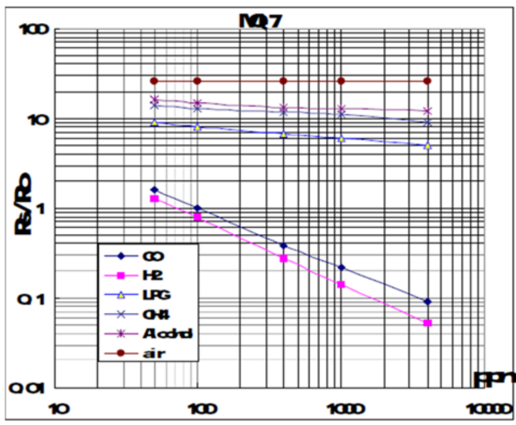

Fig 4: Sensor Sensitivity Graph

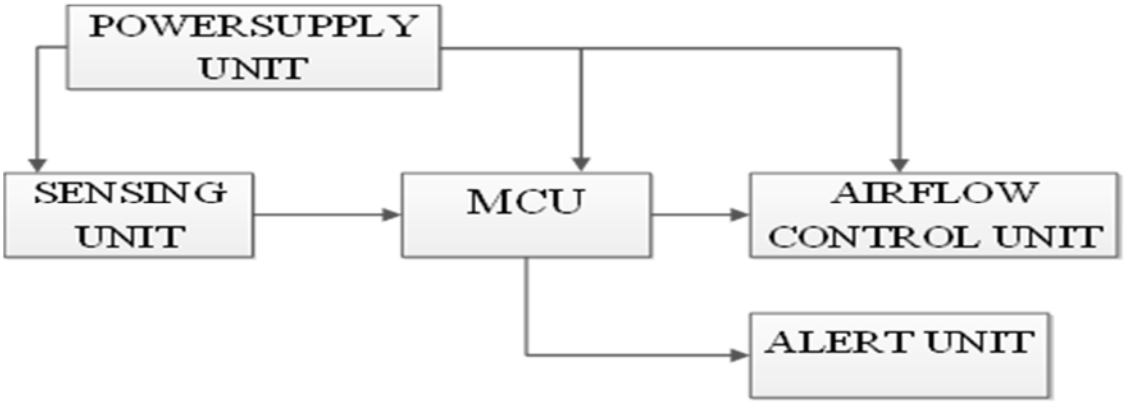

Fig. 1: Block Diagram of the CO Monitoring and Control System

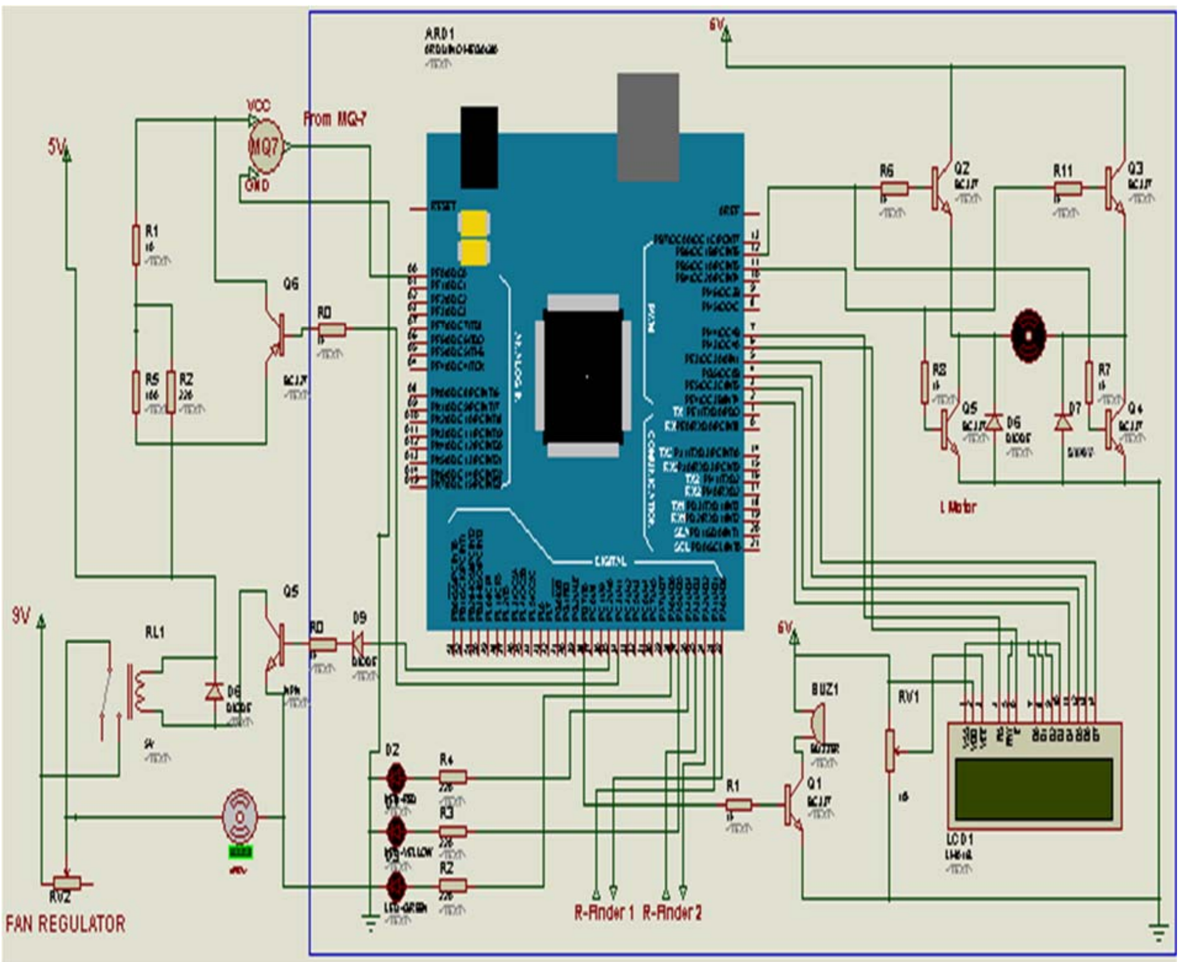

Fig. 2: Circuit Diagram of the Smart System

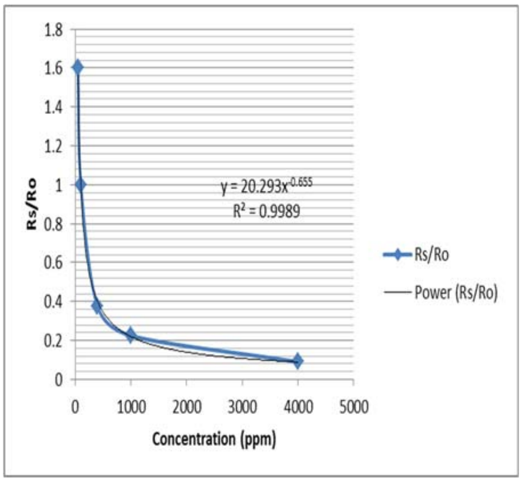

Fig. 5: Mathematical Modelling of Sensor Sensitivity Graph

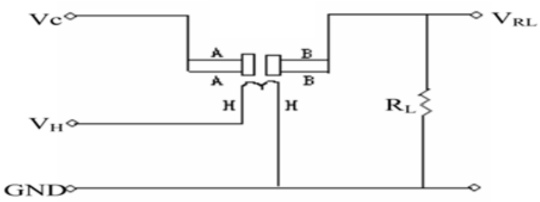

Fig. 6: Basic Loop Test of MQ-7 Sensor

Equations (1) and (2) were used to get the values of resistance and sensitivity ratio of the sensor respectively. Equation (3) shows the correlation between sensor sensitivity (Rs/Ro) and Concentration of CO in PPM. Equation (4) is used to get CO value in ppm and was implemented in the system software.

$$R_S = \left(\frac{Vc}{Vrl} - 1\right) Rl \quad (1)$$

$$\text{Sensitivity ratio} = \frac{Rs}{Ro} = y \quad (2)$$

$$y = kx^m \quad (3)$$

$$y = kx^m \quad (4)$$

Where Constant of approximation (k)= 20.293
Slope of sensor graph (m) = -0.655
x= CO concentration in PPM.

2. Microcontroller Unit

The microcontroller is the brain of the system. The Arduino mega is a microcontroller board based on the ATMega2568 which can be powered by 9V or 5V DC. It has 53 digital input/output pins (12 of which can be used for Pulse Width Modulation), 15 analogue inputs, an on-board resonator, a reset button, and holes for mounting pin headers. It performs the function of data acquisition from the sensor, manipulates the data and determines what control action to perform based on the concentration of CO using predefined software embedded in it.

3. Alert Unit

This unit consists of three LED (red, yellow and green) and a buzzer. The buzzer is used to give an audible alarm when CO concentration reaches a dangerous level. The LEDs give an indication of air quality based on the system software. A red LED when turned on indicates a hazardous CO concentration of 100 ppm or over, a yellow led indicates moderate CO level (above 34 ppm and below 100ppm) which can still cause harm and a green LED indicates that air quality in the room is safe or CO is at a level that is not dangerous to human health. An LCD displays the concentration of CO.

4. Airflow Control Unit

This unit consists of a relay, diodes, a DC fan (used as model of a standard AC fan) and DC motors which are used to implement Ventilation on Demand (VOD) in which the room is only ventilated when necessary. The VOD is, therefore, a power saving technique. The relay supply power to the DC fan depending on the concentration of CO in the room. The relay is connected in parallel to a diode to prevent the appearance of high voltage self-induction and similar to opto-couplers, there is no electrical contact between input and output circuits. This unit also consists of ultrasonic distance sensors to determine if the windows are open (and to what extent) or closed. The DC motor is used to open and close the windows by the microcontroller (using the system software) based on CO concentration. Basically because of the high current requirement the DC motor is driven by transistor which amplifies the current supplied to it. The microcontroller also controls the motors' speed by Pulse width modulation (PWM).

B. Software Design Consideration

The system software is basically the program code embedded into the microcontroller unit to perform the operation of data acquisition, data processing and control of the entire system. The code was written in C programming language through an Arduino Independent Development Environment (IDE). The IDE was used to upload the code into the microcontroller (ATMega2568). This gives the microcontroller the ability to take decisions (turn on the fan, open the window and give visual and audible alerts) based on the concentration of CO.

C. Working Principle of the System

The system monitors the air for the presence of carbon monoxide (CO) when the sensor is at a low temperature (heated by supply voltage of 1.4V) and if CO is detected, predefined control operation starts. In the event of dangerous CO concentration, the window state (opened or closed) is first determined using readings from the ultrasonic distance sensor. If CO is present and concentration is below 35 parts per million (ppm), the green LED is turned on. If CO is 35 ppm or more but less than 100 ppm, the fan and yellow LED are turned ON and the windows opened to about 50%. If CO is 100 ppm or more, the fan and red LED are turned ON and the windows opened totally (100%). When CO is no longer present in the room, the window is closed and the fan is turned OFF. Fig. 7, shows the flow of data and control in the system.

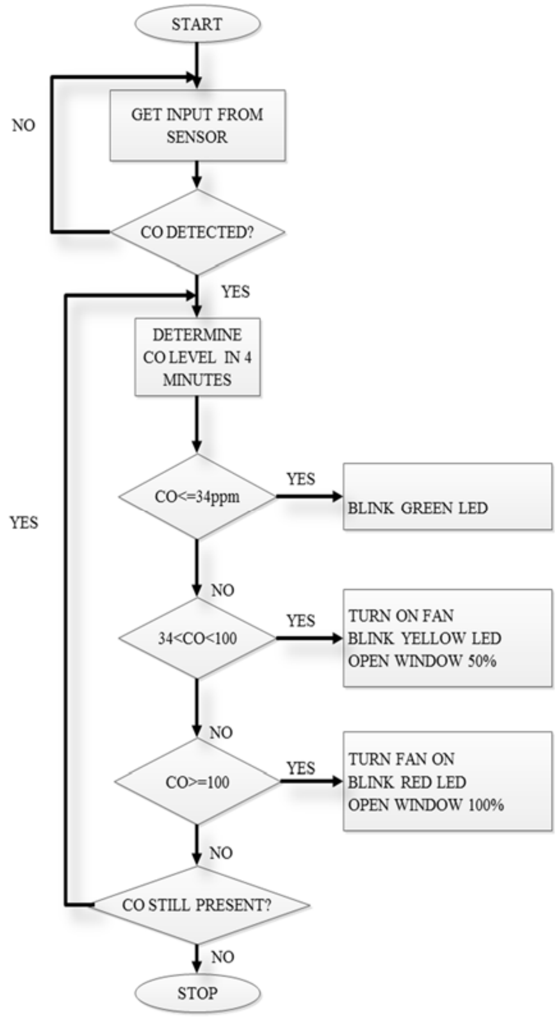

Fig. 7: Flow Diagram of the System

IV. RESULT AND DISCUSSION

The results obtained from system evaluation are presented in Tables 2 and 3. The system was evaluated by determining the response time and power consumed (by measuring the current drawn and voltage supplied) during the sensing and control phases. The sensing phase is the period when the microcontroller determines CO concentration while the control phase is the period when the microcontroller controls ventilation in a room.

From the results obtained, which is summarized in Table 4, the system consumes less power in the sensing phase (321.62mW) than in the control phase (652.82mW). This is because in the sensing phase, the microcontroller consumes a negligible amount of power, sensor unit is the only unit that consumes the bulk of the power and other units (alert and airflow control units) are inactive. In the control phase, however, the system consumes more power which can be attributed to the simultaneous control and sensing operation being carried out by the system in that period. The average response time of the system to a dangerous concentration of CO (35ppm and over) is 6 seconds. However, because the system only senses CO in the low voltage (1.4V) circle, the time it takes to determine the concentration of CO will generally vary. The overall performance of the system showed that, it responds adequately fast, which is critical in CO monitoring systems. The power consumption was also good; hence, the system is adequate for the application.

Table 2: System Response Time

S/N	CO Concentration (ppm)	Response Time (seconds)
1	40	1.15
2	36	4.44
3	38	5.00
4	35	18.74
5	37	2.40
6	37	4.73
	Average	6

Table 3: Power Consumption

S/N	Sensing Phase Power (mW)	Control Phase Power (mW)	Supply Voltage (V)
1	291.6	680.4	4.86
2	292.2	584.4	4.87
3	243.5	681.8	4.87
4	391.2	635.7	4.89
5	389.6	681.8	4.87
Average	321.62	652.82	4.87

Table 4: Summary of Performance Evaluation Results

S/N	Metric	Sensing Phase	Control Phase
1	Average power consumed	321.62mW	652.82mW
2	Average Response time	6 seconds	

V. CONCLUSION AND FUTURE WORK

In this work, a smart room carbon monoxide monitoring and control system has been successfully presented. The system was successful in the detection of hazardous concentration of carbon monoxide gas in a room and controls the ventilation in the room when carbon monoxide concentration is equal or above the dangerous level.

To achieve that, an MQ-7 sensor was used to detect CO concentration, DC motors were used to control windows, a relay was used to control the fan, while ultrasonic sensors were used to determine when the windows are closed or opened. The developed system achieved an average response time of 6 seconds and consumed 321.62 mW and 652.82 mW of power during sensing and control respectively. Quick response is very critical to monitoring applications especially CO monitoring in which the concentration can rise rapidly, as such, the developed system if adopted in homes will provide excellent air quality in the rooms without the occupants' knowledge of any abnormality. Also, the system does not interfere with user operation of the controlled ventilation means.

The developed system in its functionality performs adequately. Nevertheless, we intend to improve the system by integrating more sensors for the monitoring of general air quality in a home. The system will also be integrated to home automation systems as a sub-system.

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