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Carbon monoxide detection and remote monitoring: A novel design approach

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Abstract: Pollutants like Carbon-Monoxide (CO) create a lot of health hazards in the life of human beings and animals for which a portable, less-expensive, easy to use device with remote data visualization is required for fabrication. There are several instruments that can measure the concentration of CO. Instruments based on infrared radiation adsorption are bulky, costly and not portable. Instruments based on electrochemical have limited lifespan. Our approach is based on metal oxide semiconductor-based sensors which are low cost and have a longer lifespan. Our design integrated the sensor with a wi-fi microcontroller to transmit the data and monitor the data remotely. The main component of this setup is Raspberry Pi PICO W micro controller with onboard Wi-Fi capability and metal oxide semiconductor-based sensor. Additional devices like an OLED unit have been used as a display unit during the course of data acquisition.

Keywords: Carbon Monoxide (CO), microcontroller (Raspberry Pi PICO W), MQ7, Micro python.

1. Introduction

Carbon monoxide (CO) is an odorless, colorless and toxic gas. The effect of the toxicity depends on concentration and duration of exposure of the gas. Familiar sources of CO are from incomplete combustions of wood, kerosene, cooking gas, gasoline products, smoking tobacco, automobile exhaust, etc. Some common issues observed due to prolonged exposure to CO gases are fatigue, chest pain, reduced blood flow to the heart, impaired vision, and reduced brain function. If the concentration is high, then it leads to headache, dizziness, confusion, nausea, flu-like symptoms, or even death. The impact of CO toxicity on the health and wellness of human beings is a matter of grave concern[1]. As per guidelines of the World Health Organization, the carboxyhemoglobin (COHb) levels in human blood should be less than 2.5%. If the COHb concentration level persists within 2–20%, it might affect visual, auditory, motor, and many neuro-related problems [2]. The remote monitoring of toxic gas will help people take preventive measures for their health. There are many works related to CO monitoring. Suyuti, A., et al., proposed a design of a CO gas detector with a microcontroller connected with a computer monitor via serial communication interface [3]. It can be used for real-time monitoring of CO, but the overall design includes a computer and hence is not portable. M. K. Zaman M. Zaiedi et al designed a CO detection system that uses TGS2600 sensor with PIC16F877A microcontroller. The PIC16F877A microcontroller is based on assembly language instruction code that requires a longer learning curve and is difficult to accommodate new functionality[4]. Ahmed Abdullah Ibrahim et al designed CO Level Detector using MQ-7 & Arduino Uno microcontroller [5] . The system displays the CO level using an LCD display, requiring the user to be very close to the toxic environment. Kumar, S. et al proposed an air quality monitoring system based on IoT using Raspberry Pi, Arduino Uno & cloud server[6]. Other CO detection techniques include electrochemical and optical-chemical sensors [7-9].

Our approach focuses on a portable, long-life span, low-cost device that detects CO and displays the data in a web browser using Wi-Fi protocol. We have used a metal oxide-based semiconductor sensor called MQ-7 from Henan Hanwei Electronics Co., commonly available in the market. The MQ-7 has properties like robustness, stability & cost-effectiveness concerning other sensors and can be easily integrated into any microcontroller [10-11] . The sensor uses SnO_2 as the metal oxide semiconducting sensing layer, with the gold/ platinum interdigitated electrodes heated by a micro heater to provide activation energy. The sensor is connected to the Raspberry Pi Pico W microcontroller, which converts the sensor's analog voltage level into a digital value. The digital data is stored in a micro-SD card through a serial peripheral interface, giving us a historical perspective of the toxicity level. The device uses wireless Wi-Fi protocol to send the data to a web browser using HTML in a client-server architecture mechanism.

2. Assembly

The device for sensing CO is assembled by using commercially available accessories that includes MQ-7 CO Sensor, Microcontroller, RTC module, Memory Module, Micro Secure Digital (SD) card, Buzzer, Jumper wires, Breadboard & Battery.

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2.1 Specifications

The device hardware and software specifications are listed below.

2.2 Hardware specifications

The hardware (technical) specifications of microcontroller unit (MCU), Real Time Clock (RTC) Module & Carbon Monoxide Sensor are represented in the Table-1.

Table 1: Hardware Specifications of the proposed CO detector.

Sl. No	Device Name	
1	**MCU: Raspberry Pi PICO W**	
a	Processor	Dual-core Arm Cortex M0+ processor with 133 MHz clock frequency
b	Input Voltage	1.8 to 5.5V DC
c	Pins	23 Digital I/O Pins, 3 Analog Pins
d	Memory	2048 KB Flash Memory, 264KB SRAM &16KB Cache Memory
e	Wireless	2.4GHz wireless interface
2	**RTC: DS3231 Module**	
a	Input Voltage	3.3 to 5.5 V DC
b	Communication	Inter-Integrated Circuit synchronous serial communication (I2C) bus protocol.
c	Temperature Ranges	Commercial (0°C to +70°C) and Industrial (-40°C to +85°C)
3	**Carbon Monoxide Sensor:MQ7**	
a	Operating voltage	5V DC
b	Sensibility	CO
c	Range	10-1000 ppm

2.3 Software specifications

The MCU uses Micro-Python Programming language to manage all the operations. Micro-Python is implemented with Python-3 programming language and consists of a few standard libraries to be run on MCU. It uses an integrated development environment (IDE) like Thonny for managing & developing the code. The USB Flashing Format (UF2) file is used to control the MCU from the PC. The UF2 file is downloaded from the official Raspberry Pi site and put in the RPI-RP2 volume of the MCU.

2.4 Design

The design of the CO detector is given as per the block diagram in Figure 1. The heart of the CO detector is the metal oxide (MOX) SnO_2 sensor sensitive to CO. The sensor's output is a voltage proportional to the CO gas concentration, which is detected by the ADC port of the microcontroller. The microcontroller reads the value of the sensor, processes it, stores it in the SD card, and transmits it using the device's onboard Wi-Fi.

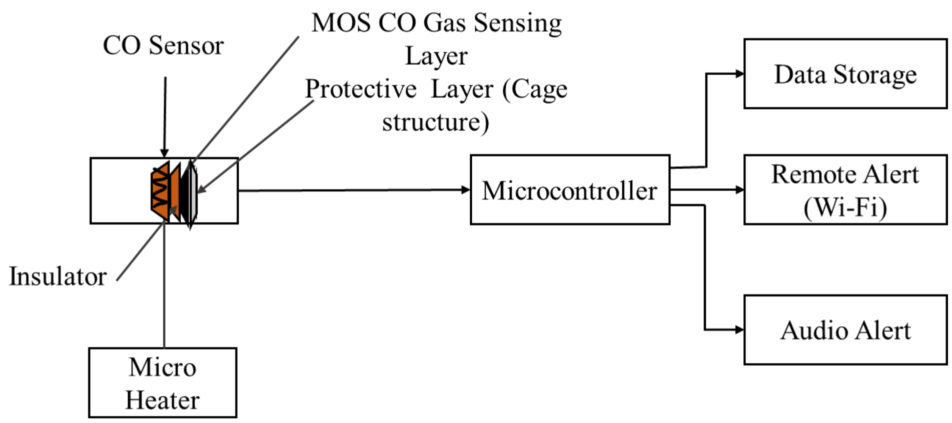

Figure 1: Block Diagram CO Detection System.

2.5 Sensor Design

Metal Oxide Semiconductor based CO sensor was first proposed by Taguchi. The schematic diagram of the metal oxide semiconductor sensor is given by the Figure. 2. There is a tiny heater which is insulated by a ceramic layer from the interdigitated electrode and the gas sensing layer. The entire system is enclosed inside a metal cage like structure so that there will not be any kind of physical damage to the structure during handling [12-13].

The principle of gas-sensing process involves surface adsorption on the sensing layer of SnO_2 which is a n-type semiconductor. With activation energy obtained from the heater, at the surface of the semiconductor, gas is dissociated to charged ions which results a change in the availability of electrons. The interaction happens at the surface, so atoms residing in grain boundaries (GBs) and the interface determines the effectiveness of the sensor. With carbon monoxide and hydrogen, that reacts with the surface-adsorbed oxygen and electrons are available in the conduction band with an increase in conductance as shown in Figure 3. This property is used for the detection of inflammable and toxic gases[14]

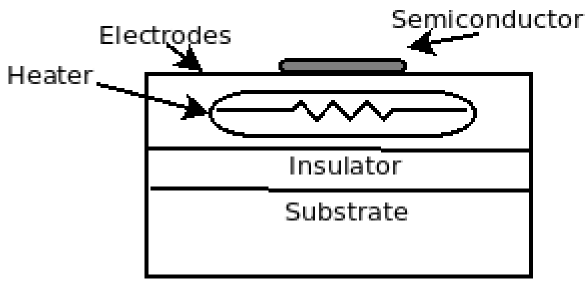

Figure 2: Schematic diagram of metal oxide semiconductor sensor.

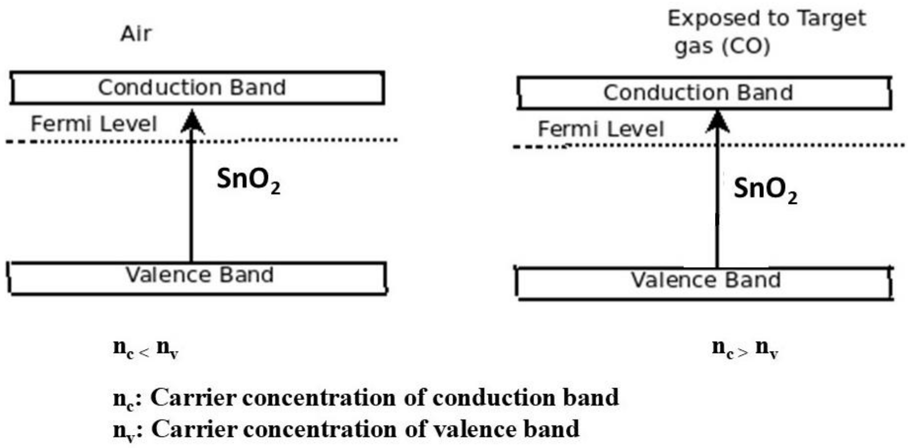

Figure 3: Mechanism of Sensor when exposed to air and target gas.

2.6 Prototype development

The prototype of the device is given in Figure 4 where MCU, Sensor and SD Adaptor with SD card are mounted on a breadboard circuit. The data from SD card are exchanged with the microcontroller by using the Chip Select (CS), Serial Clock (SCK), Master Out Slave In (MOSI) & Master in Slave Out (MISO) Pins to their corresponding General Purpose Input Output (GPIO) pins of GPIO-1, GPIO-2, GPIO-3 and GPIO-0 of the MCU respectively. The data communication between the MCU & SD card happens through Synchronous Serial communication mechanism known as Serial Peripheral Interface (SPI) protocol. The organic light emitting diode (OLED) is used during the development process of the device. The OLED communicates by I2C protocols through their serial data pin (SDA) and serial clock pin (SCL) pins to that of GPIO-8 and GPIO-9 of the MCU. The DS3231 communicates by inter-integrated-circuit (I2C) protocols through their serial data pin (SDA) & serial clock pin (SCL) pins to that of GPIO-6 and GPIO-7 of the MCU. The sensor output is connected to the ADC pin (GPIO26) & buzzer is connected to GPIO-21 pin of the MCU. The onboard Wi-Fi connectivity has opened wireless monitoring of the data by using any browser enabled device connected with the same Wi-Fi. The equivalent electrical circuit diagram of the MQ 7 sensor is represented in Figure 5.

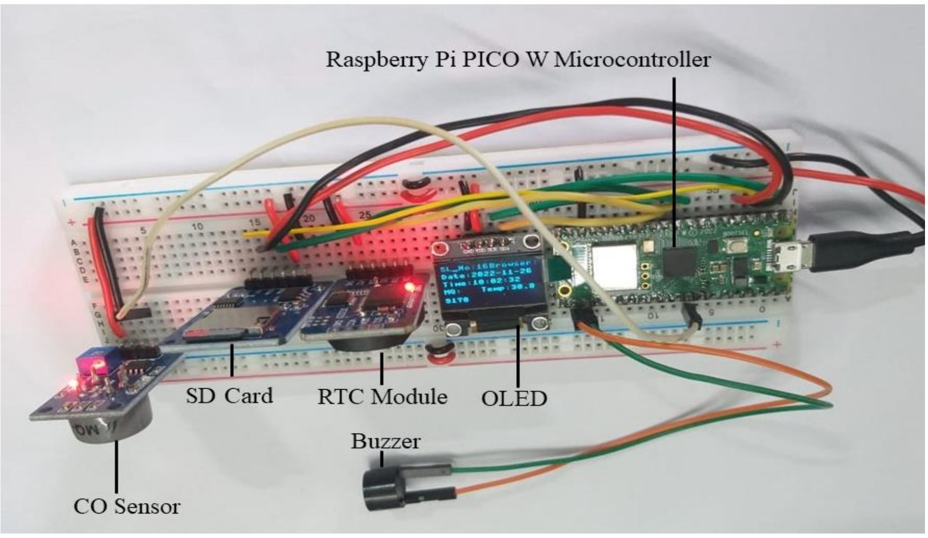

Figure. 4: Prototype of CO Sensor.

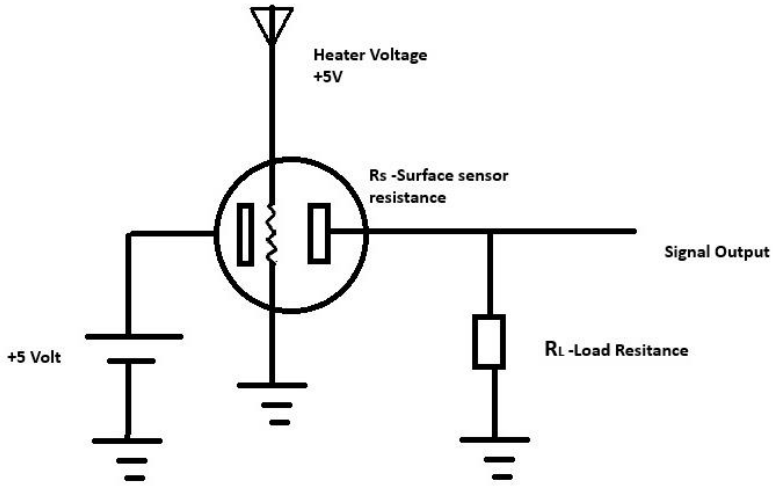

Figure 5: Equivalent electrical circuit of MQ7 sensor.

2.7 Working procedure

The sensor, SD-card, OLED & remote access via browser is shown as per the flow chart given in Figure 6. Here the ds3231_i2c, ssd1306 & SD card library files are used to manage the DS3231 RTC module, display and SD memory card respectively. We have implemented the integration of the sensor with a Wi-Fi microcontroller so as to transmit the data and monitor the data remotely. In our case we are able to see the data in the browser of a mobile phone or any computers.

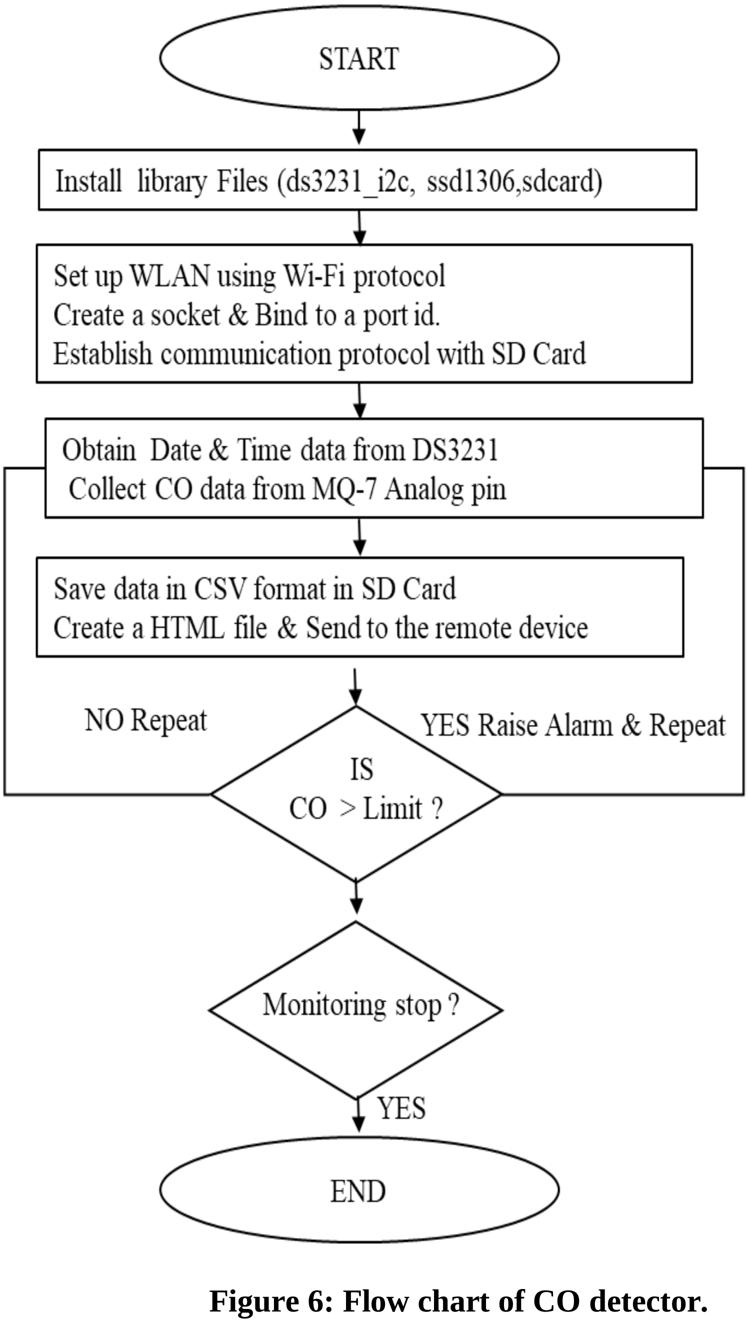

Figure 6: Flow chart of CO detector.

2.8 Calibration of the sensor

Using the electrical circuit diagram of the MQ7 sensor and applying the voltage divider rule we will get

$$V_{RL} = V_{CC}\left(\frac{R_L}{R_L + R_s}\right) \tag{1}$$

Where V_{RL} is the voltage across the load resistor R_L which is captured by the ADC converter, R_L is the load resistance and, in our case, it is 10 kilo ohms, and R_S is the surface sensor resistance to be determined. This resistance R_S varies with respect to the CO gas and that will be reflected in the value of V_{RL}. At clean air with 100 ppm of CO gas the sensor resistance is standardized to a reference resistance known as R_O. The manufacturer of the MQ7 sensor has provided the datasheet having the concentration of CO gas in X-axis to that of ratio of R_S / R_O in y-axis. Here both the x-axis and y-axis are represented in logarithmic scale.

From equation (1) we can get the value of R_S as

$$R_s = \left(\frac{V_{cc}}{V_{RL}} - 1\right) R_L \tag{2}$$

From the datasheet in the Figure 7 it is observed that the CO line is almost a straight line and a straight-line equation as [15-16].

$$y = mx + c \tag{3}$$

Where $y = Log_{10}\frac{R_s}{R_o}$ $and\ x = Log_{10}\,(PPM)$ and the slope m is calculated as

$$m = \frac{Log_{10}\left(\frac{R_s}{R_o}\right)_{4000\,PPM} - Log_{10}\left(\frac{R_s}{R_o}\right)_{100\,PPM}}{log_{10}(4000) - log_{10}(100)} \tag{4}$$

$$m = \frac{Log_{10}\,0.09 - Log_{10}\,1}{log_{10}(4000) - log_{10}(100)} = \frac{-1.04575}{3.6 - 2} = -0.66 \tag{5}$$

And

$$c = y - mx = log_{10}\,\frac{R_s}{R_o} - mLog_{10}\,(PPM) \tag{6}$$

At x=100 PPM of CO y=1 and m= -0.66 c calculated as

$$c = Log_{10}\,1 - (-0.66) * Log_{10}\,100) = 1.32 \tag{7}$$

This value can be used in the linear equation to find the value of x from $y = mx + c$

$$x = \frac{1}{m}(y - c) \tag{8}$$

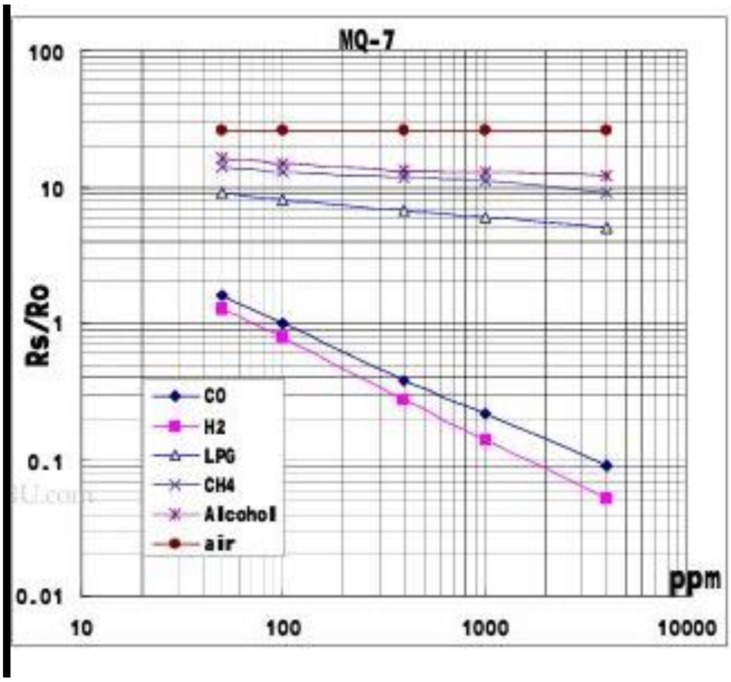

Figure 7: Sensitivity characteristics of the MQ-7 from the datasheet {*reproduced from Ref. [17]*}.

From equation (5) and (7) the value of m and c is found to be -0.66 and 1.32, respectively and using equation (8) and putting the values of x and y we will get

$$Log_{10}\,(CO\ inPPM) = \frac{1}{-0.66}\left(Log_{10}\frac{R_s}{R_o} - 1.32\right) \tag{9}$$

$$Log_{10}\,(CO\ in\ PPM) = \frac{1.32 - Log_{10}\frac{R_s}{R_o}}{0.66} \tag{10}$$

$$CO\ in\ PPM = 10^{\frac{1.32 - Log_{10}\frac{R_s}{R_o}}{0.66}} \tag{11}$$

This equation (11) is used to quantify the CO level produced from various sources. All above equations are reproduced from reference [16] and Figure 7 {reproduced from Ref. [17]}.

3. Results and discussion

The CO detector is deployed in a test environment and the data is recorded in the SD card in CSV format and a line chart is prepared. The Figure 8 shows the CO level present in smoke from cigarette, smoke from vehicle exhaust and smoke from mosquito coil and its variation with respect to time. However, the smoke produced from various sources considered in this study are uncontrolled and the variation of the intensity is occurred according to the environmental condition and dispersion of smoke with time. The data are transmitted to other devices connected with the Wi-Fi. In our test environment, the data are collected and displayed in the smart phone browser as shown in Figure 9. The CO data shown in the figure is just an empirical value which is not standardized as per the air quality index. The obtained color scheme in the Figure 9 warns the quality of the environment at where the living beings are exposed.

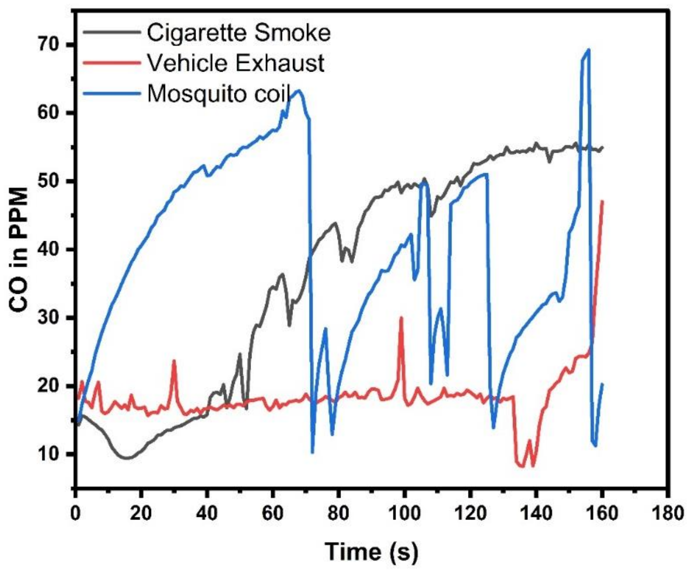

Figure 8: CO Level of cigarette smoke, vehicle exhaust and mosquito coil smoke.

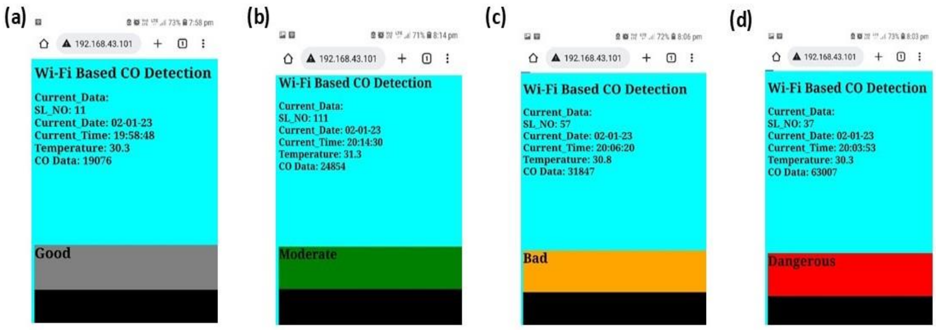

Figure 9: CO Data as displayed in the browser.

The presence of carbon monoxide in the presence of cigarette smoke, mosquito coil smoke and vehicle exhaust is quantified in by this model. The impact of long term exposure of carbon monoxide from these sources cane be objectively monitored by this model and can be used at various location of the city as large number of people stay long hours close to the traffic junctions, parking stations, vehicle service stations etc.

4. Conclusion

A low cost, portable CO sensor device prototype is developed by using commercially available accessories and the software is designed and developed by the authors. The system is tested at various levels of hardware and software module. In the current design the device is meant for room temperature operation. To make this device more effective, it is planned to have multiple sensors and calibration the feasible region of operation.

Conflict of interest

The authors declare that they do not have any conflict of interest in this work.

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