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Novel approach for Asthma Detection Using Carbon Monoxide Sensor †

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Abstract: Around 339 million people are suffering from asthma worldwide. An acute asthma attack causes difficulties in daily life activities and sometimes it can be fatal. The unnecessary challenges faced by asthmatics signifies the need for a device that helps people monitor and control asthma to prevent possible attacks. A number of studies have reported an elevation of carbon monoxide in exhaled breath (eCO) of asthma patients and suggests it as an effective bio-marker of lung inflammation. By making use of the reported results, this projects aims to make use of the eCO bio-marker to design a carbon monoxide (CO) asthma monitoring system. The system consists of raspberry Pi 3 microcontroller and a MQ 7 CO sensor for processing and detecting the carbon monoxide concentration in parts per million. For accurate results a face mask is attached to the sensor to neglect the environmental CO. The working of the sensor circuit is validated using carbon monoxide source. With more researchers on the threshold level of CO for an imminent asthma attack this CO sensor could eventually save lives and improves the standard of living while being an affordable and user friendly device for active lifestyle.

Keywords: Asthma monitor; Exhaled Carbon Monoxide (eCO); CO sensor; raspberry Pi 3

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1. Introduction

Asthma a respiratory ailment, is categorized by chronic inflammation caused in the pulmonary airways, along with oxidative stress in the bronchial tubes. A significant characteristic is the swelling in both proximal & distal lung airways [1]. An asthma patient can get sudden or unexpected asthma attack that can be triggered by any factor and the factors varies from person to person. The intensity of an acute asthma attack is unforeseeable and has the possibility to be fatal [2].

Asthma affect human beings of all ages, and it generally begins in childhood. Asthma is a raising medical issue infecting people globally. As reported by the Global Asthma report 2018 it was believed that around 339 million people had asthma universally and there were 417,918 demise due to asthma worldwide [3]. India has around 15–20 million asthmatics in which 6% are children & 2% of adults. The phase 3 International Study of Asthma & Allergy in Children (ISAAC) investigated a nationwide predominance of present wheeze of 7% in Indian children age between 6–7 years and age between 13–14 years. Certainly, more than 50% of the people had terrible asthma [4].

Asthma is an incurable disease. While some asthma cases are mortal, the maximum are less serious and causes hardships in day to day life. It is very challenging for an asthmatic to maintain a healthy lifestyle since most of the people with asthma encounter symptoms of exercise induced lung constriction while doing exercises in which engaging themselves in exercise and sports are very burdensome and sometimes it may even be dangerous. The inability to participate in daily life activities can make them inactive and affects their social well-being which leads to stress, sleep deprivation, depression etc [5].

Spirometry, Peak Expiratory Flow are employed in diagnosing and monitoring severity of asthma exacerbation. But physician's supervision is mandatory for both the techniques, yet visiting healthcare center is impracticable and tiresome for asthmatics. This inefficacy paved the gateway for advance technology portable devices [6]. These portable devices assists in diagnosing and continuous monitoring of the disease symptoms at earlier stage and reduces unnecessary hospitalization cost, allows remote monitoring and helps in maintaining better patient to doctor ratio.

In recent times, chemical bio-markers like exhaled nitric oxide (eNO) and exhaled carbon monoxide (eCO) are employed by health care professionals as an another capable device to help analyze, evaluate and frame asthma treatment plans [2]. Carbon monoxide (CO) is a bio-marker of oxidative stress, induced by the stress protein heme-oxygenase [(HO)- 1] and also due to inflammation [1]. Exhaled CO (eCO) is alike exhaled NO which is assessed as a candidate breath biomarker of pathophysiological states that elevates in asthmatics & decreases with steroid therapies. As mentioned in [1], NO has airway origin whereas the CO has alveoli origin. The main advantage of utilizing eCO as a breath biomarker is that it is observed in greater concentration than nitric oxide (NO). This allows less sophisticated and more reliable monitoring device [7]. Many of currently available asthma monitoring devices are either unaffordable, unreliable or not suitable for an active lifestyle [5].

When a person is experiencing an asthma attack, the body might be triggered by a stimuli which is results in bronchial inflammation. One method to detect these phenomenon is by monitoring eCO concentration before, during & after an acute attack [5]. Prior studies [8–10,12–15] have proven that CO level increases during asthma attack. This project utilizes the result found in these studies to develop an asthma monitor using CO sensor.

Thus the detection of eCO could be an effortless non-invasive device for monitoring acute exacerbation of asthma. This study aims to develop a programmed device that monitor the eCO levels by using a CO sensor which could possibly reduce acute asthma attacks and helps to improve quality of life for asthmatics with varying lifestyles by reducing costs and extending portability that ultimately saves lives.

2. Literature Survey

The study conducted by Kiyoshi et al. (1997) shows an elevation of eCO in asthmatics that reduces with corticosteroid therapy and it further indicates the changes in the concentration of exhaled CO were remarkably associated to the number of eosinophil cell present in sputum [8]. P. Paredi et al. (1999) further inspected the possibility that allergen challenge can raise exhaled carbon monoxide (eCO) levels, as a indication of HO activation in 15 asthmatics and found out eCO increases in asthmatic reaction individually of the change in lung calibre [9]. The research conducted by M. Yamaya et al. (2001) has shown that eCO concentrations in people with unstable severe asthma were notably greater than those with stable condition. eCO concentrations in slight and non-extreme asthma patients did not differ appreciably from those patients who are controlled and doesn't have smoking habit ($p > 0.20$). The research further states a remarkable proportionality between eCO concentration and forced expiratory volume [10].

Susumu Sato et al. (2003) estimated the optimal cutoff level of exhaled CO concentration to differentiate actual smokers from nonsmokers among 161 asthmatics and 170 COPD patients. The result analysis demonstrates, in asthmatics and COPD patients the eCO level were potentially affected by underlying lung inflammation which lead to mis categorization of smoking status by exhaled CO. This shows CO level increases in asthma condition [11]. Ildiko Horvath et al. (2015) research indicates that, in the asthmatic lungs induction of HO-1 may cause increasing eCO concentrations suggesting it to be medically applicable as a diagnostic tool to evaluate asthma [12]. The prevalence of CO biomarker was studied by Yoichiro et al. (2016) and the result signifies exhaled CO levels in children were considerably increased while encountering asthma exacerbation and reduced after inhalation therapy with β2-agonist and SCG in those with intermittent asthma [13].

Amanda A. Pereira et al. (2018) speculated an increase in level of exhaled CO in asthmatic children, specifically in children with partially stable or unstable asthma and the mean adjusted eCO level was 0.56 ppm greater in asthmatic children suggesting that exhaled CO may serve as an inexpensive biomarker for asthma control [14]. Yoichiro et al. (2020) further stated that, in asthmatic infants and toddlers, asymptomatic asthma had exhaled CO of 2.0 (1.0–2.0) ppm and asthma attack had exhaled CO of 2.0 (2.0–3.25) ppm ($p < 0.0001$) [15].

3. Materials and Methods

3.1. Overall Architecture of the Implemented System

As shown in Figure 1, the proposed system consists of two working unit. One is the hardware architecture block & another is the software architecture block.

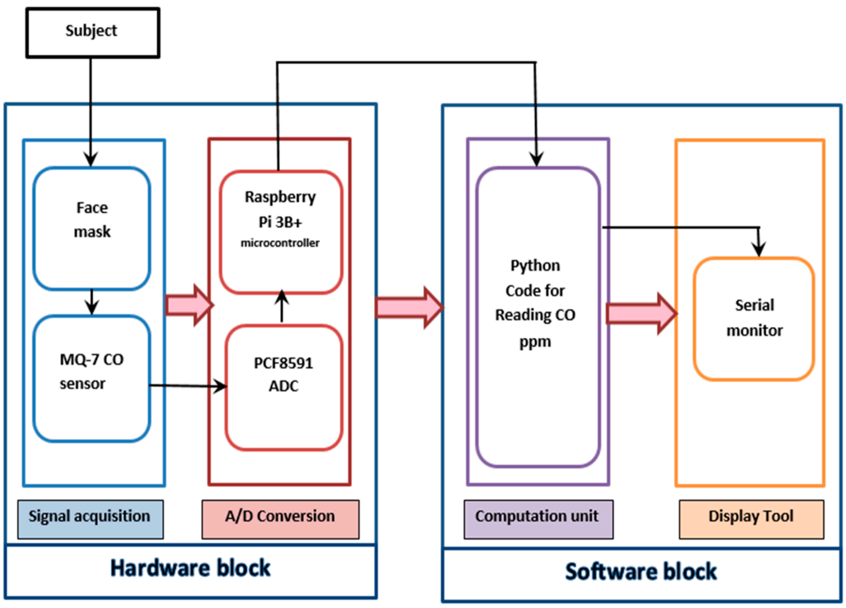

Figure 1. Block Diagram of the Proposed CO Monitoring.

3.2. Hardware Architecture

(1) Signal Acquisition Unit: Figure 2 shows a pictorial view of signal acquisition unit. For accurate & in order to avoid environmental CO, the sensor need to be held closely to the mouth. For this purpose a face mask is used. The MQ-7 sensor contains 4 –pin namely A0, D0, Vcc & GND. The A0 pin is connected to AIN0 of PCF8591, the Vcc & GND are connected to pin 2 & pin 6 of the raspberry Pi. The CO is acquired through MQ-7 and transmitted to PCF8591.Figure 3 shows the connection of MQ 7 sensor with raspberry pi 3b+ and PCF8591.

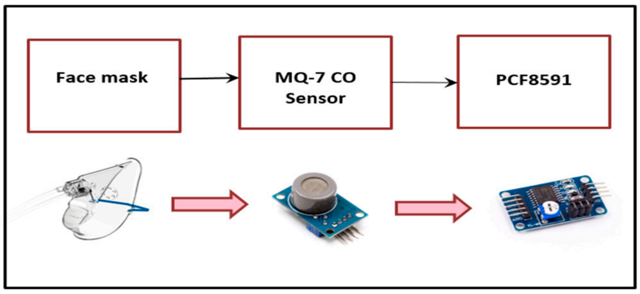

Figure 2. Signal Acquisition Unit.

(2) Analog to Digital Conversion: The MQ-7 sensor gives output in the form of analog values. These analog data are given to PCF8591 ADC. PCF8591 works on I2C communication.
The obtained Analog value is converted to digital volts by –

$$V_{OUT} = A_{OUT} \times 5/256 \quad (1)$$

A_{OUT}—Analog Value
V_{OUT}—Digital value in (0–5 V).

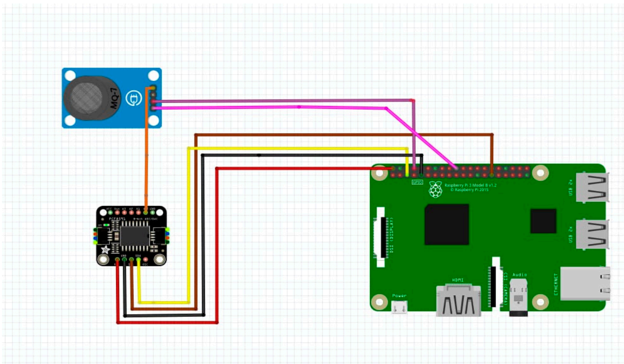

Figure 3. Schematic Diagram of the CO Sensing System.

3.3. Software Architecture

The concentration of CO in parts per million (ppm) is determined in accordance to the resistance ratio (RS /R0). RS is the estimated resistance altered when the sensing channel encounters gas and R0 is the stable sensor resistance in clean air or in absences of gas. Employing Ohm's law and sensor circuit diagram,

$$RS = VC - RL/V_{OUT} - RL \quad (2)$$

VC—voltage current (in this condition 5Volts from pi)
V_{OUT}—output voltage (calculated analog/digital value)
RL—Load resistance (here the value is 10K).
R0 can then be computed with the below equation,
R0 = RS/Fresh air ratio value from sensitivity graph of MQ-7.

For the purpose of transforming the digital signal values to CO concentration in ppm, MQ-7 datasheet [16] is used. The correlation coefficient (A & B) are found by performing a power regression. The sensitivity characteristic graph of the MQ-7 shown in Figure 4 is loaded on Web Plot Digitizer software. The obtained data points are then loaded to R script code to perform a power regression

(1) Calculation of CO ppm Concentration: To calculate the CO ppm concentration, two parts of codes are written. The first section of code is for calibrating the MQ-7 sensor

in fresh air to acquire RS & R0 values in atmospheric air and the second section of code is for sensing CO in testing environment. For the purpose of calibrating in clean air a mean of 500 values obtained by running the first part of code are taken into account. The initial value begins with 0 and allows adding up for every reading to each another till the given condition fails. Thus, from the mean value, the RS value in air & R0 value in fresh air are calculated. This code runs for single time

The next section of the code senses the presence of carbon monoxide, calculates the ratio & reads out the concentration of CO in ppm with respect to the change in voltage value. Figure 4 shows the flowchart for calculating CO concentration in real time.

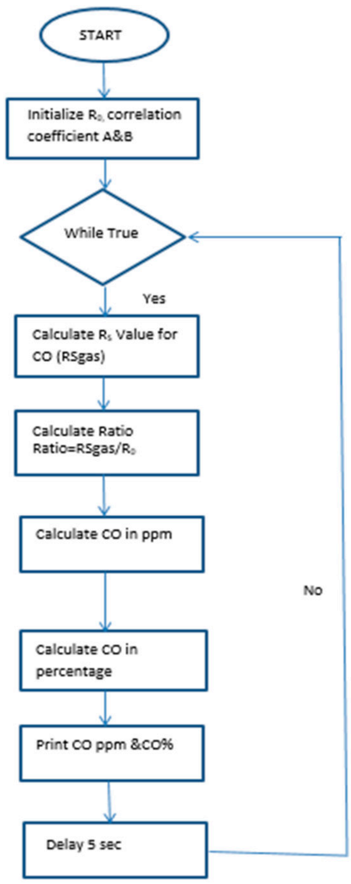

Figure 4. Flowchart for Detecting Presence of CO in Real Time.

Figure 5 shows the entire setup of the developed system with face mask attached to the sensor.

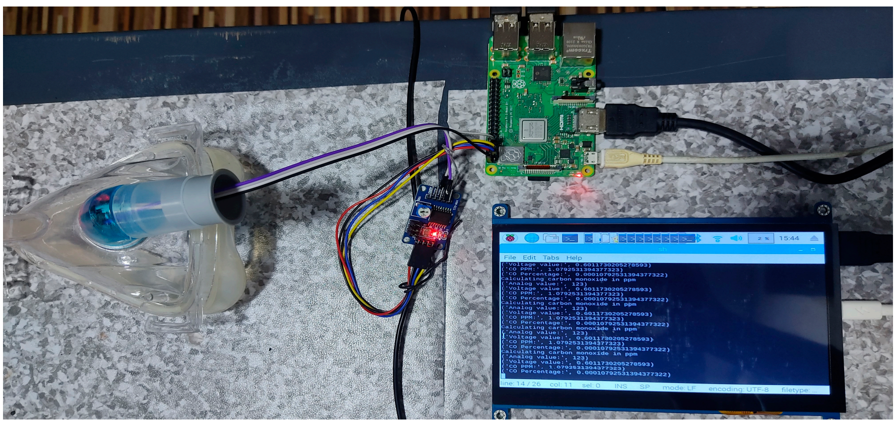

Figure 5. Proposed CO sensing System with Face Mask.

4. Results and discussion

The estimated values of correlation coefficient A & B using R-Script are found out to be 83.69 and −1.63 approximately. Sensitivity adjustment was done as given in [16]. The sensor was *calibrated to detect 40ppm CO in air*. The response from the sensor in terms of ppm as shown in Figure 6 is obtained for healthy (6 numbers) and chronic ashtma (3 numbers) patient and the level of CO was higher than the threshold for asthma patients, whereas for normal patient is is below the threshold. It shows the sensitivity of the designed system against CO sources. The below table shows the converted analog reading as shown above in terms of ppm.

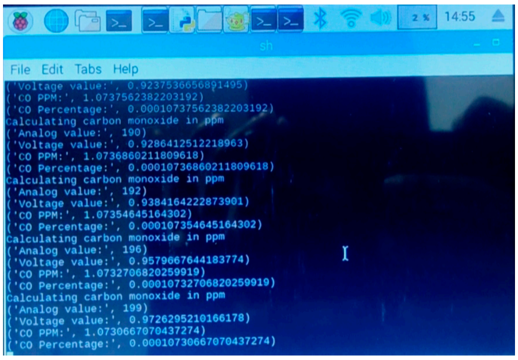

Figure 6. Result Of CO Concentration in ppm.

Table 1. Exhaled CO concentration in healthy and individual with Asthma.

S.No	Type of Subject	Exhaled CO Concentration Range in Ppm
1	Healthy	1.5 to 2.0
2	Asthma Patient	6.0 to 6.5

5. Conclusions and Future Scope

The designed CO sensor circuit shows high sensitivity to the CO sources. The target use of this system is to alert the patient to take precautions to avoid an asthma attack in the first place by monitoring the CO levels. Once the threshold level of CO that is dangerous to an asthma patient is found out by clinical trials, the system can alert the patients when the CO level crosses the threshold range. In addition, the design of the system can be enhanced further by reducing the size of the system as small as possible for handy use, travel ability and wearability. This project can be improved further by incorporating IoT structure which makes the physician access the data anywhere at any time to have an insight of the patient’s health condition. Tthis project idea can be further enhanced to develop an accurate and fully functional device that justifies the necessity of every asthmatics who makes use of it.

Author Contributions: M.B.N.M. and U.A. conceptualized the idea of this manuscript. D.D. and designed the model. A.F.F.M.J, S.P.M. and P.S.K.R.P. have contributed for the software and coding. D.D. and S.P.M. conducted the formal analysis. A.F.F.M.J conducted the investigation. M.B.N.M. and U.A. supervised the work. All authors have read and agreed to the published version of the manuscript.

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