

Portable Respiratory CO₂ Monitoring Device for Early Screening of Asthma

Sameen Ahmed Malik, Om Prakash Singh, Aimi Nurifhan, M. B. Malarvili

Abstract— This paper presents a portable and patient independent respiratory CO₂ monitoring device for early screening of asthma. The device is developed incorporation of hardware (Sprint IR CO₂ sensor with a sampling rate of 20 Hz, face mask, Atmega 328 microcontroller and graphical liquid crystal display-GLCD) and software (Arduino integrated development environment). The Transistor-Transistor Logic (TTL) communication was used to transmit and receive the signal from the host (microcontroller) to sensor and vice versa. Further, the computation and transmission algorithm was developed to process and display the CO₂ signal on GLCD. In addition, the signal processing techniques were used to discriminate mild stage of asthma and non-asthma condition. In this preliminary study, the developed device was tested on 20 subjects aged between 20 and 25 years. Out of those, 5 were suffering from mild asthma and 15 were without asthma. The performance of the developed prototype device was confirmed through statistical analysis using SPSS software which achieved 80% sensitivity and 90% specificity. The p-value of the developed device was 0.000. The result shows that it's statistically significant and able to differentiate asthma (mild) and non-asthma. However, the device will be tested further on a larger number of populations to generalize the finding.

Keywords— Asthma; Sprint IR CO₂ sensor; Arduino; GLCD;

I. Introduction

Asthma is one of the most common heterogeneous respiratory chronic diseases and has become the main reason to visit the emergency department and admission to the hospital setting every year [1]. It has been considered 14th most imperative illness in the world in terms of duration and extent of disability. In 2014, the global asthma report revealed that 334 million people were affected by the asthma throughout the world, of 14% children and 8.6% young adults (aged 18-45) [2], yet asthma will affect more than 100 million people until 2025 [3]. In addition, around 0.25 million people die each year prematurely due to improper management and lack of personal asthma monitoring tool. As well Kaitlin and Krull suggested that young adults (age 18-25) suffering from asthma should have a personal asthma monitoring device to assess their disease and decrease their risk of exacerbation and hospital admission [4]. Hence the early diagnosis of asthma and achieving acceptable asthma supervision at the right time remains evasive despite the existing methods.

There are two methods to diagnose asthma; firstly, through clinical investigation carried out by the specialized physician [5]; secondly, by applying diagnostic equipment such as Spirometer and peak flow meter [5-7]. However, the first method could be inaccurate sometimes due to manual and involvement of human. Whereas, the second method such as Spirometer have its own drawback like adult patients experience dizziness due to fully physical involvement, chest pain, coughing, bronchospasm and oxygen desaturation due to lack of oxygen. Indeed, it is difficult to get an accurate result if the patient is not able to understand the set of instructions, having chest pain forbidding a forceful effort, or not able to cooperate. It indicates that a successful test required full cooperation and wall chest pain-free [8]. In addition, the error rate of the spirometer may increase up to 24% of the otherwise normal subject due to the limitation of existing reference equation [9]. Similarly, the peak flow meter is highly patient-dependent and relatively insensitive which shows that unless giving a hard and fast expiratory effort, the true peak will be undervalued [5]. However, peak flow meter is easier than Spirometer. It requires only a short blow, not continued expiration until the lungs are completely emptied [10]. Naturally, the patient has to repeat it thrice and highest result of three attempts is the actual peak flow values. Hence both the methods required a full, deep breath in, and blast it out as hard as fast as a patient can until no more air exists in the lungs. Therefore, the aim of our research is to develop a patient-independent and home monitoring early screening asthmatic device that can be used by both asthmatic adult and children.

A Recent study shows that the capnograph can be considered as a new method to monitor the asthmatic condition [10-22]; as it uses an infrared technology to measure the concentration of carbon dioxide during exhalation and helps to understand the respiratory status of the patients including asthma [23]. However, most of the studies were offline. Furthermore, the existing capnograph is bulky, costly and cannot estimate components of physiological dead space as well as not able to distinguish the end of expiration from the beginning of inspiration [24-25]. Thus, we have developed a light weight, effort independent and portable asthma monitoring device that can measure the expired CO₂ concentrations and differentiate early stage of asthma.

This paper has been divided into four sections. Section I included the background study followed by material and methods in section II. Section III elucidated the result and discussion, whereas a conclusion and future work is made in section IV.

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II. Materials and Methods

A. Overview of Complete System

The block diagram of the complete system is shown in fig. 1. In general, the system is divided into 3 sub-systems; namely; signal acquisition for acquiring CO₂ from subjects, transmission and computation processing of the acquired CO₂ and finally display tool to display the CO₂ signal and the result whether asthma or non-asthma. Each sub-system is described in detail in following subsections.

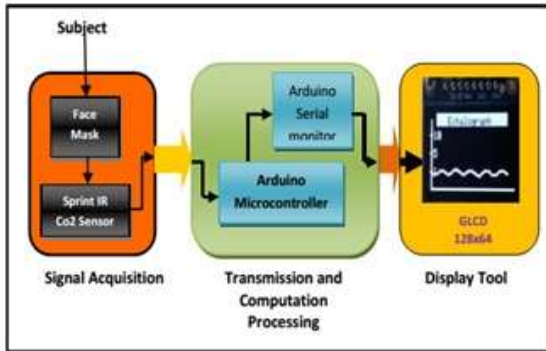


Figure 1. Block Diagram of proposed CO₂ monitoring system

B. Signal Acquisition Unit

Fig. 2 shows a pictorial view of the signal acquisition unit. The face mask is used to acquire CO₂ from the subject which transports the gasses to the Sprint IR sensor [26], where the sensor ignored all irrelevant gasses available in the received breath and except CO₂. Further, the data is transferred to Arduino through Transistor-Transistor Logic (TTL) cable. In this work, four pins namely Pin 1, Pin 3, Pin 5 and Pin 7 have been used for the purpose of recording CO₂ concentration from the sensor. The sensor is connected in similar fashion to the Arduino microcontroller. It is important to mention here that Sprint IR output can be received either using UART or analog pin. In UART, the data is transmitted and received over the serial communication. However, Pin 9 is typically used for accessing Sprint IR output over the analog channel. Analog voltage available on Pin 9 change with respect to CO₂ concentration detected but the process was quite tedious. Hence we prefer to use UART feature over analog.

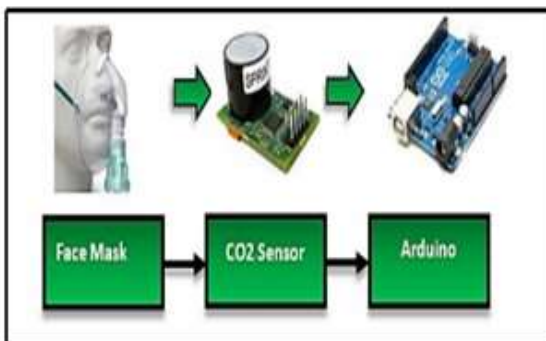


Figure 2. Signal Acquisition unit

C. Transmission and Computation Processing

Arduino Microcontroller

The reason for selecting Arduino microcontroller over other processor is that Arduino Uno R3 uses ATmega328P microcontroller and contains 14 digital pins which can be either made as input or output as shown in fig. 3. Out of these, 6 pins can also be used as Pulse Width Modulation (PWM). Arduino also has 6 analog pins which can be used as inputs. The microcontroller uses 16 MHz quartz crystal used to provide clock and it can run either on power adapter or battery as well. Arduino operates on very low DC voltage, 6 volts to 20 volt, which makes it applicable in portable applications. The total current used is around 40 mA per input/output pin which is relatively small when compared with other microcontrollers. Arduino also has UART feature which allows serial communication with other devices including a computer. In addition Plug and play, the feature allows instant programming and its real-time execution on Arduino board. One of the advantages of Arduino Uno has is its ability to be transformed into the standalone system in which no Arduino board is required to run the program on the Arduino chip. This particular feature reduces the cost and the overall power consumption significantly.



Figure 3. Arduino Uno R3 Microcontroller

Procedure to execute the algorithm

A summary of the whole Arduino program code developed in order to achieve real-time CO₂ concentration on serial monitor and to interface the information on GLCD screen is shown in the flowchart below in fig. 4.

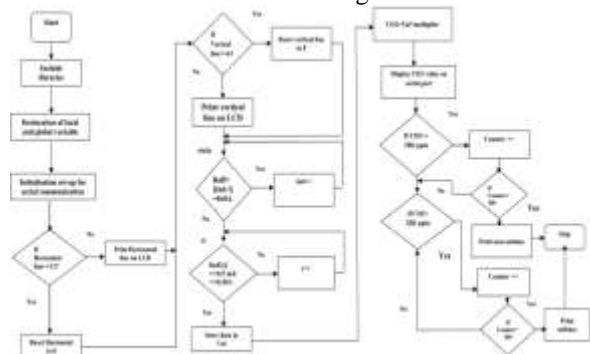


Figure 4. Flow Chart for CO₂ concentration classification and display module

To acquire and display the CO₂ signal on display module, the library, and the local variable was included into the software (Arduino IDE). In addition, the serial communication was made by assigning the baud rate (9600), data (8-bit), stop (1-bit) with no parity. Thereafter, the horizontal and vertical line was printing as per the specification of the display module (128x64). Hence, whenever there was an increase in the CO₂ values above to the size of the display, the output of the CO₂ was printed as a zero. Next, the CO₂ value was calculated by multiplying with a factor of 10 and stored in the variable named *Val* for further assessment.

Furthermore, the thresholding and window techniques were utilized to discriminate between asthma (mild) and non-asthma. For this purpose, the output of expired CO₂ value was limited to 28000 (2.8 % CO₂) ppm as a threshold and data were recorded for 5 seconds. Afterward, a window is selected with the width of 100 samples. Whenever the CO₂ values fall below the threshold within the width of the window for the stipulated time, the output is considered as mild asthma, however, if there is a change in one sample out of 100 during this, then the algorithm will look for another 100 samples until it follows the given condition.

D. Display Tool

The next step is to display the concentration in form of waveform on LCD screen. In order to do so, LCD screen was required. For our research GLCD, SSD136 (128x64), was selected since it has the ability to work efficiently while consuming extremely low power. In addition, image quality received by GLCD is considered much higher than LCD. GLCD slimmer size as well its greater screen refresh rate makes it ideal for portable applications. Mentioned above features were convincing to go for GLCD for this project.

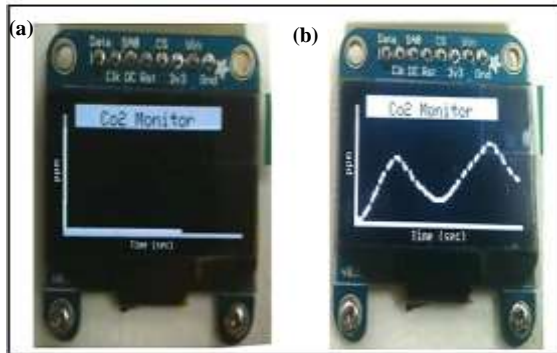


Figure 5. (a) Output during idle state (b) CO₂ waveform during Exhalation

Fig. 5 (a) represents the ideal state when there was no input line. In this, it shows continuous zero line indicating zero CO₂ concentration. Concentration in ppm was displayed on y-axis while time was shown over the x-axis. During the state when the device was being used by the user continuous waveform started appearing on the screen as shown in Fig. 5 (b).

E. Experiment Procedure

The developed prototype was tested on 20 subjects with the monitoring asthma and non-asthma using Convenience

sampling method [27]. After this, the same subjects were cross-verified through clinical investigation. To perform the experiment as shown in fig.6, the subjects were asked to sit with the relaxed condition and instructed to breathe as normal as possible unlike the traditional device (Spirometer). After that, the face mask was placed on the mouth of the patient for the acquisition of CO₂ concentrations. Further, the reading was recorded for 15-21 seconds for 5-7 breath as suggested by Yaron et.al [28] and the result was obtained. Asthma and non-asthma condition were identified based on the CO₂ values available in each breath using thresholding techniques. The experiment results are discussed in the following section.



Figure 6. Experiment set-up

III. Results and discussion

Fig. 7 shows a systemic view of the internal circuit diagram of the complete system. It reflects the integration of Sprint IR sensor along with microcontroller and display tool. fig.8 shows a complete prototype device with its casing.

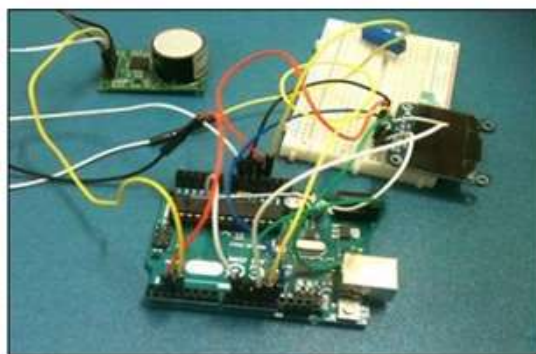


Figure 7. Signal Acquisition System with Standard Sprint IR Sensor



Figure 8. Proposed Prototype with cover

Fig. 9 shows the CO₂ concentration output of asthma and non-asthma subjects. The fig.9 (a) indicates mild asthma and found the expired value of CO₂ less than 35000 ppm whereas fig. 9 (b) elucidates non-asthma condition and expired values were more than 35000 ppm and less than 55000 ppm. In addition, the shape of the signal is different from the previous one. It looks like flat for the mild case whereas the shape of the non-asthma subject is sinusoidal. A similar pattern has been observed for all subject tested.

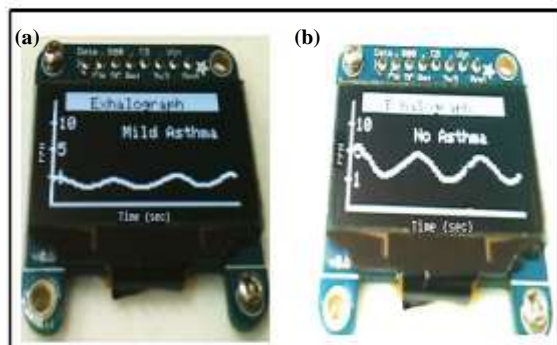


Figure 9. (a) Asthmatic Subject (b) Non-Asthmatic Subject

Statistical analysis was carried out to confirm the performance of the device. The mean and standard deviation values for demographic data, including gender, age, height, weight and measured parameters such as forced expiratory volume in 1 second (FEV1), Force vital capacity (FVC), Force expiratory volume in 1 second in percentage (FEV1%) using spirometer and the output of CO₂ monitoring device have shown in the table 1 for the asthmatic (mild) and non-asthmatic subjects along with its p-value.

Table 1 illustrates that there are no statistically significant differences in among age (p=0.778), weight (p=0.991) and height (0.267) of asthma and non-asthma groups. Furthermore, males (40%) were predominantly affected by asthma in comparing to females (20%) which indicate that males are more likely to be affected by asthma. While testing the same subject using proposed device, the asthmatic subject has lower CO₂ values (mean 22000, SD 3225.01 vs mean 32377.03, SD 3920.16) with respect to the non-asthmatic subjects and the p-values (0.000) were statistically significant.

TABLE I. VALUES ARTICULATED AS MEAN± STANDARD DEVIATION

	Asthma	Non-asthma	p-value
Gender (M/F)	2/3	3/12	
Age (years)	23.2± 1.09	22.9± 0.99	0.778
Height (meter)	1.562± 0.059	1.595± 0.0462	0.267
Weight(Kilogram)	59.84± 10.10	58.85 ± 8.18	0.991
FEV1	1.37± 0.03	1.788± 0.27	0.050
FVC	1.85± 0.18	2.06± 0.25	0.034
FEV1/FVC ratio, (%)	74.68± 8.03	90.07± 1.96	0.012
CO₂ (ppm)	22000± 3225.01	32377.03± 3920.16	0.000

On the basis of independent t-test analysis, the proposed CO₂ monitoring device has higher p-value (0.000) than spirometer p-value (0.012), which reveals that the developed device is highly statistically significantly than the traditional device. In addition, the sensitivity (80%) and specificity (90%) were appreciably higher than the existing device sensitivity (49%) and specificity (78%) with cut point <80% for FEV1/FVC ratio. Similarly, Andrew et.al reported that the sensitivity and specificity of the spirometry were lower compared to exhaled nitric oxide [29].

IV. Conclusion and Future Work

We proposed a portable CO₂ monitoring device for early screening of asthma. The proposed device can be used in hospital environments by skilled medical personnel as well as in home environment by the general public in order to perform real-time respiratory CO₂ monitoring. The device is developed using simple technology and low-cost material such as Sprint IR CO₂ sensor and Arduino. In addition, the designed device was tested on 20 subjects and the results shows that it can differentiate mild asthma and non-asthmatic group based on CO₂ concentration level. From this, it can be concluded that developed device can be useful for the early screening of asthmatic condition if it is been validated with a number of samples along with the different data collection methods. However, still, it has some drawback such as the use of face mask and display tool. The subjects tested complained that the face mask was suffocating and the graph was not clearly visible due to the size of the GLCD. Apart from this, the appearance of the shape was sinusoid which makes difficult to understand the inspiration and expiration phase over existing capnograph. Therefore, in future, these problems will be tackled and reported elsewhere. Furthermore, the device will be validated with the larger database by healthcare professionals.

Acknowledgment

The authors gratefully acknowledge Universiti Teknologi Malaysia (UTM) for supporting and offering the required facilities and laboratory equipment. This study was conducted as a part of the Research University Grant, supported by Universiti Teknologi Malaysia, Government of Malaysia, under Grant no. R.J130000.7945.4S107.

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