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Portable Respiratory CO_2 Monitoring Device for Early Screening of Asthma

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***Abstract*— This paper presents a portable and patient independent respiratory CO_2 monitoring device for early screening of asthma. The device is developed incorporation of hardware (Sprint IR CO_2 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 CO_2 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 CO_2 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.

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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 CO_2 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 CO_2 from subjects, transmission and computation processing of the acquired CO_2 and finally display tool to display the CO_2 signal and the result whether asthma or non-asthma. Each sub-system is described in detail in following subsections.

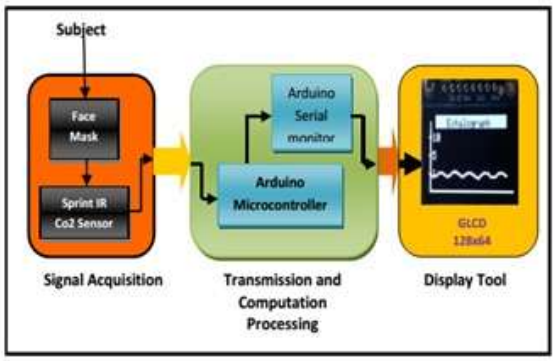

Figure 1. Block Diagram of proposed CO_2 monitoring system

B. Signal Acquisition Unit

Fig. 2 shows a pictorial view of the signal acquisition unit. The face mask is used to acquire CO_2 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 CO_2. 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 CO_2 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.

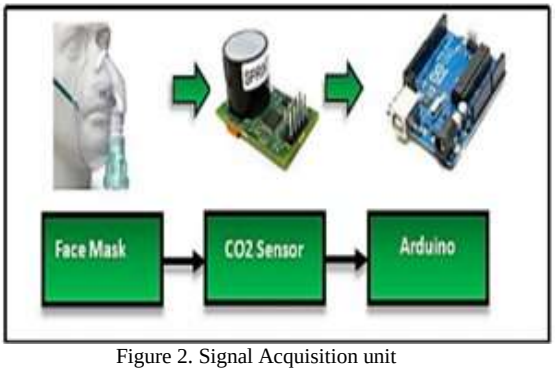

Figure 2. Signal Acquisition unit

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 CO_2 concentration on serial monitor and to interface the information on GLCD screen is shown in the flowchart below in fig. 4.

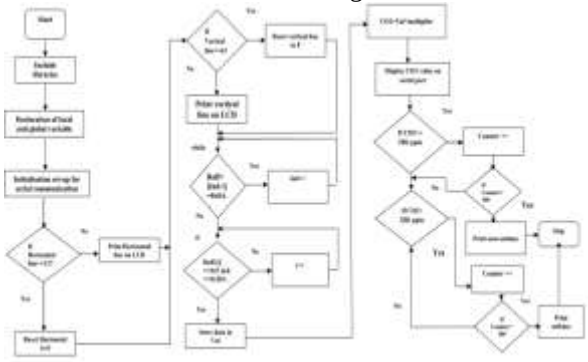

Figure 4. Flow Chart for CO_2 concentration classification and display module

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To acquire and display the CO_2 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 CO_2 values above to the size of the display, the output of the CO_2 was printed as a zero. Next, the CO_2 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 CO_2 value was limited to 28000 (2.8 % CO_2) ppm as a threshold and data were recorded for 5 seconds. Afterward, a window is selected with the width of 100 samples. Whenever the CO_2 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.

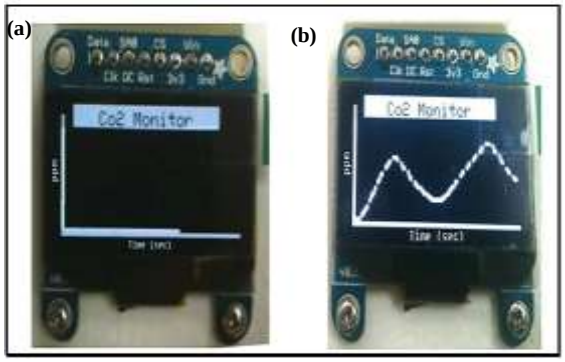

Figure 5. (a) Output during idle state (b) CO_2 waveform during Exhalation

Fig. 5 (a) represents the ideal state when there was no input line. In this, it shows continuous zero line indicating zero CO_2 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 CO_2 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 CO_2 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.

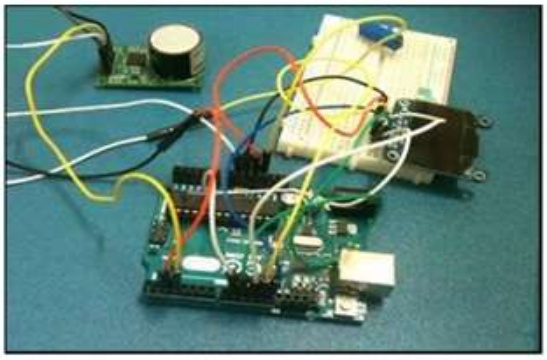

Figure 7. Signal Acquisition System with Standard Sprint IR Sensor

Figure 8. Proposed Prototype with cover

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Fig. 9 shows the CO_2 concentration output of asthma and non-asthma subjects. The fig.9 (a) indicates mild asthma and found the expired value of CO_2 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.

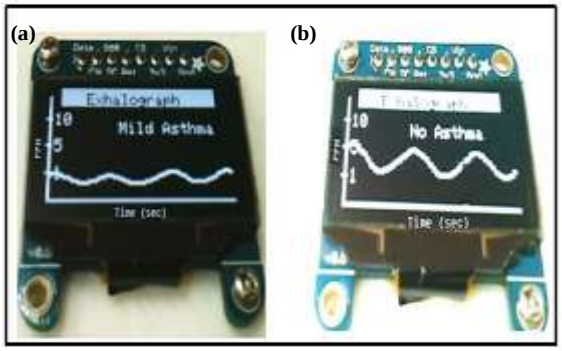

Figure 9. (a) Asthmatic Subject (b) Non-Asthmatic Subject

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 CO_2 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 CO_2 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
CO_2 (ppm)	22000± 3225.01	32377.03±3920.16	0.000

On the basis of independent t-test analysis, the proposed CO_2 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 CO_2 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 CO_2 monitoring. The device is developed using simple technology and low-cost material such as Sprint IR CO_2 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 CO_2 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

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References

[1] Arts YK. Evidence summary Asthma: Self-management education (adults). The Joanna Briggs Institute. 2013.

[2] Guy Marks et.al. The global asthma report-The global burden of Asthma [cited 2016 April 14]; 2014: [Available from: http://www.globalasthmareport.org/burden/burden.php].

[3] World Health Organization. Global surveillance, prevention and control of chronic respiratory diseases: a comprehensive approach, 2007.

[4] Kaitlin M. Hilger, Heather Krull. Controlling Asthma: Self-Management Education For Young Adults [cited 2016 August 9]. May 8, 2014. [Available from: http://www.rtmagazine.com/2014/05/controlling-asthma-self-management-education-young-adults/].

ISBN: 978-1-63248-113-9 doi: 10.15224/ 978-1-63248-113-9-61

[5] British Thoracic Society, Scottish Intercollegiate Guidelines Network. British guideline on the management of asthma. A national clinical guideline. 2008, revised 2012.

[6] Yawn BP, Enright PL, Lemanske RF Jr, Israel E, Pace W, Wollan P, et al. Spirometry can be done in family physicians' offices and alters clinical decisions in management of asthma and COPD. Chest2007;132:1162-8.

[7] Starren ES, Roberts NJ, Tahir M, O'Byrne L, Haffenden R, Patel IS, et al. A centralised respiratory diagnostic service for primary care: a 4-year audit. Prim Care Respir J2012; doi:10.4104/pcrj.2012.00013

[8] Sebastian Johnston, L. and Nikolas Papadopoulos, G. Respiratory Infections in allergy and Asthma. Marcel Dekker Inc. 2003.

[9] Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, et al. Interpretative strategies for lung function tests. Eur Respir J2005;26:948-68.

[10] Kazemi M, Malarvili MB (2011) Analysis of Capnogram Using Linear Predictive Coding (LPC) to Differentiate Asthmatic Conditions. J Tissue SciEng 2:111. doi: 10.4172/2157-7552.1000111.

[11] Steven Weinberger, E. Barbara Cockrill, A. and Jess Mandel. Principles of pulmonary medicine. 5th Edition. Elsevier Inc. 2008.

[12] Julius G. Goepp, et al., EFFORT-INDEPENDENT, PORTABLE, USER-OPERATED CAPNOGRAPH DEVICES AND RELATED METHODS. 2009, Google Patents.

[13] Zaharudin, B., et al. Designing a respiratory CO2 measurement device for home monitoring of asthma severity. in Biomedical Engineering and Sciences (IECBES), 2014 IEEE Conference on. 2014.

[14] Teo Aik Howe. Use of Capnographic Waveform indices in Monitoring Nonintubated Asthmatic Patients Within the Emergency Department. Universiti Sains Malaysia, Master Degree Thesis. 2001.

[15] Teo, A. H. Kamaruddin Jaalam. Rashidi Ahmad. Chew Keng Sheng. and Nik Hisamuddin, N. A. R. The use of end-tidal capnography to monitor nonintubated patients presenting with acute exacerbation of asthma in the emergency department. Journal of emergency Medicine. 2009, 41(6): 581-589.

[16] Corbo J, Bijur P, Lahn M, et al. Concordance between capnography and arterial blood gas measurements of carbon dioxide in acute asthma. Ann Emerg Med. 2005;46(4):323–327.

[17] Lawrence H. Brown et.al. Can Quantitative Capnometry Differentiate Between Cardiac and Obstructive Causes of Respiratory Distress?*.published in CHEST/113/2/FEBRUARY, 1998.

[18] Teo Aik Howe et.al. The use of end-tidal capnography to monitor non-intubated patients presenting with acute exacerbation of asthma in the emergency department. The Journal of Emergency Medicine, Vol. 41, No. 6, pp. 581–589, 2011.

[19] Bridgette et.al. End-tidal Carbon Dioxide Measurements in Children with Acute Asthma. the Society for Academic Emergency Medicine ISSN 1069-6563 .doi: 10.1197/j.aem.2007.08.007.

[20] M.B. Malarvili et.al. A review of capnography in asthma: A new approach on assessment of capnogram. Invited Review, Biotechnol. Bioinf. Bioeng. 2012, 2(1):555-566.

[21] M.B. Malarvili et.al. Feature Extraction Of Capnogram For Asthmatic Patient. 2010 Second International Conference on Computer Engineering and Applications. DOI 10.1109/ICCEA.2010.286.2010.

[22] Lamba, S, Gluckman, W, Nagurka, R, Rosania, A, Bechmann, S, Langley, DJ, Scott, S & Compton, S 2009 'Initial Out-of-Hospital End-Tidal Carbon Dioxide Measurements in Adult Asthmatic Patients', Annals of Emergency Medicine, vol. 54, no. 3, p. S51.

[23] Christian Dang, H. Esmat Sadeddin. Krishna Gurram. Sarvenaz Danesh. Alexandra Iaya. Stuart Chen. Tahira Saifuddin. Donald Campbell. Laura Alba. Wendell Clarkston. Qwen Smith. A Comparison of Capnography and Pulse Oximetry for the detection of Respiratory Depression in Patients Undergoing Gastrointestinal Endoscopy. Gastrointestinal Endoscopy Journal. 2006, 63(5): 125-132.

[24] Kumar, A.Y., Bhavani-Shankar K, Moseley HS, Delph Y, Inspiratory valve malfunction in a circle system: pitfalls in capnography. Canadian journal of anaesthesia, 1992. **39**(9): p. 997-999.

[25] Shin, J.H., Lee JS, Choi SH, Lee DK, Nam H, Cha GS., A planar pCO2 sensor with enhanced electrochemical properties. Analytical chemistry, 2000. **72**(18): p. 4468-4473.

[26] http://cdn.shopify.com/s/files/1/0019/5952/products/SprintIR-20Hz-20-100-CO2 Sensor_1024x1024.jpg?v=1439566356 [Accessed: 18 November, 2015].

[27] Hyekyun Rhee, Michael J Belyea,Mark Sterling, Mark F Bocko. Evaluating the V alidity of an Automated Device for Asthma Monitoring f or Adolescents: Correlational Design. 2015. Journal of medical internet research. vol. 17, iss. 10.

[28] Yaron M, Padyk P, Hutsinpiller M, et al. Ann. Emerg. Med. 1996, 38:28-34.

[29] Andrew D. Smith, Jan O. Cowan, Sue Filsell, Chris McLachlan, Gabrielle Monti-Sheehan, Pamela Jackson, and D. Robin Taylor. (2004). Diagnosing Asthma Comparisons between Exhaled Nitric Oxide Measurements and Conventional Tests. Am J Respir Crit Care Med Vol 169. pp 473–478.

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