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Development of an Electronic Kit for detecting asthma in Human Respiratory System

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Abstract. In this paper, a prototype of a carbon dioxide (CO2) measurement device is designed to detect and used to monitor asthma patients. Nowadays, capnogram device is widely used in monitoring asthma and asthma related medical services. However, capnogram is very costly and unaffordable for patient especially those who are in low income household. Thus, the proposed device is cost effective, affordable, and produced to detect and monitor the severity of asthma. Meanwhile, flow meter will cause patient to have chest pain as they needed maximum effort to blow in the device. To overcome these limitations, this prototype electronic kit is easy to use and suitable for all range patients. This prototype electronic kit consists of MH-Z14A carbon dioxide (CO2) sensor to detect the concentration of carbon dioxide from the user exhaled air. Arduino microcontroller is used to process the data while TFT Display shield is applied for data presentation. In addition, HC-06 Bluetooth module is used to communicate with PC for further analysis of the captured graph. This device was tested with 3 asthmatics and 3 normal users. The results showed that asthmatic user has a different graph pattern compared with normal user and these graphs are clearly differentiated on the device TFT screen. Asthmatic user produces “shark fin”-like pattern whereas normal user produces “square wave”-like pattern. This device has successfully produced distinguished-patterns difference between asthmatic and normal user; therefore, it is suitable for asthma monitoring.

1. Introduction

Asthma is a chronic disease involved the airways in the lungs and it causes difficulty in breathing due to respiratory condition marked by the spasms in the bronchi of the lungs. Mc Phee et al. [1] reviewed that asthma exacerbation is a reduction in expiratory flow which is caused by many asthma triggers and the main triggers which will lead to the symptoms of respiratory diseases included viral infection, air pollutions, exercise, cockroach allergen and dust mists.

Furthermore, spirometer and peak flow meter is well known in monitoring asthma. Unfortunately, these two devices have their own limitations in which spirometer has complex procedures as the patient face difficulties on performing multiple criteria when using it and only suitable for age range above 6 years old.

At present, peak flow meter and spirometer are commonly used for monitoring asthma. However, they have their limitations. Based on Zuileka et al. [2], patients whose are tested using peak flow meter will experience chest pain as they need maximum effort to blow into the device. Meanwhile, spirometer is only suitable for patient age 6 and above and not suitable for early-detection of asthma. It also required multiple criteria to fulfill the requirement set by the device. To overcome these problems, capnography is introduced to monitor the severity of asthma without harming patient and suitable for all age patient. Non-invasive continuous analysis of the concentration of carbon dioxide in respiratory cycle is called capnograhy. Infrared technology is used to determine the concentration of carbon dioxide (CO2). Therefore, it can easily use to differentiate normal and asthmatic patient. Figure 1 below shows the difference concentration carbon dioxide between normal and asthmatic patient.

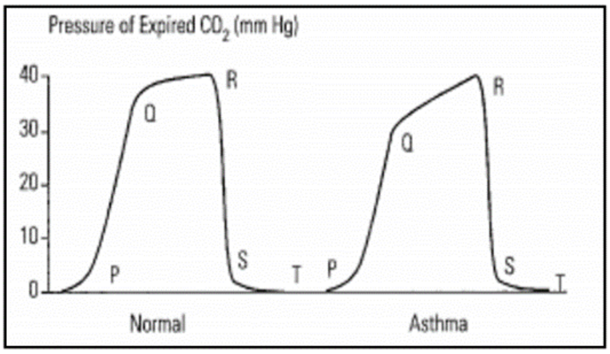

Figure 1. Capnogram between Normal and Asthmatic Patient

There are few sensors considerations in producing this electronic kit. Sensor comparisons were done to select the best sensor. Based on Marani et al. [3], pressure sensor is used for lung sound analysis. It can prevent damages caused by mechanical ventilation which can induce serious damage due to the natural pulmonary elastance. Yu et al. [4] used soft stethoscope for detecting asthma wheeze in young children. Soft stethoscope has been modified and it can be easily used on young children. This sensor can easily use on young children. Normally, soft stethoscope is easily effected by loud sound but this modification of soft stethoscope improves the limitation of this phenomenon whereas high sound amplitude will not affect the soft stethoscope.

On the other hand, Zuleika et al. [2] designed a respiratory carbon dioxide measurement for home monitoring asthma using carbon dioxide (CO2) sensor. This sensor is suitable for all range patient including children below 6 years old. It can also avoid all type of complicated test which leads to the chest pain. However, the reading between normal and asthmatic patient is not much different and hardly differentiated. Kaushal et. al [5] use a pellet sensor based asthma detection system for exhaled breath analysis. This pellet sensor consists of metal oxide semiconductor (MOS) and it is sensitive to exhaled breath. It eliminates the disadvantages of other technique by its low cost and easy operation features. On the other hand, Liu et al. [6] use ultrasonic transducer for asthma pattern identification via continuous diaphragm motion monitoring. It can overcome the limitations of implementing the ultrasound images of diaphragm movement to identify the asthma pattern. In addition, Gathy et al. [7] used amperometric nitric oxide for asthma detection. It has a detecting limit and sensitivity to changes in relative humidity, response time, flow sensitivity and stability.

Signal transmitter is an electronic device which is capable of generating electromagnetic wave carrying information and signal which lastly received by an electronic receiver. Buechley [8] through multi-purpose user awareness kit for consumer electronic devices used infrared sensor (IR) to receive and process the received signal through electronic devices such as personal computer (PC) and smart phone. Meanwhile, Bjelice et al. [9] used UART communication device in construction of kit for electronic textiles. This kit interface binary intra-processor protocol and data are present by Sky TV application GUI. Next, Ramli et al. [10] developed heartbeat detection kit for biometric authentication system whereas Bluetooth Module is used as signal transmitter. It received and processed by Android platform developed. Captured data will be presented on Android application GUI.

Data processing refers to transformation of collected data into information which is useful in a certain manner for user understanding. There are many types of data processing such as GUI, LCD and oscilloscope. Based on Yu et al. [4], android is used as a platform to collect and present the data. Android operating system is so convenience as this system can be open in any electronic device such as smartphone, PC or even pads everywhere. Rasmli et al. [10] reported that android platform is used as a function of login into the system. Graphical User Interface (GUI) is used to present the result and data to the user [8]. Matlab software is used by Zuileka et al. [2] as a real time data plotter. A real time data logger was developed by sorting the data into the array using the basics of Serial Communication in Matlab by updating the output or data pot according to real-time application.

After comparisons and reviews, carbon dioxide (CO2) sensor has been decided to be used as it can measure the concentration of carbon dioxide (CO2) in a relaxing way and it does not depend on user age unlike some of the sensors used by previous researchers. Arduino microcontroller is used to collect and process the data from the sensor. Meanwhile, Bluetooth Module is used as a signal transmitter to communicate with personal computer. TFT LCD shield is used as a data presentation element. The data will be generated into a graph. Meanwhile Graphical User Interface (GUI) will be build inside the computer for better view of the result. GUI is also used as a platform to analysis the result from the user.

2. Methodology

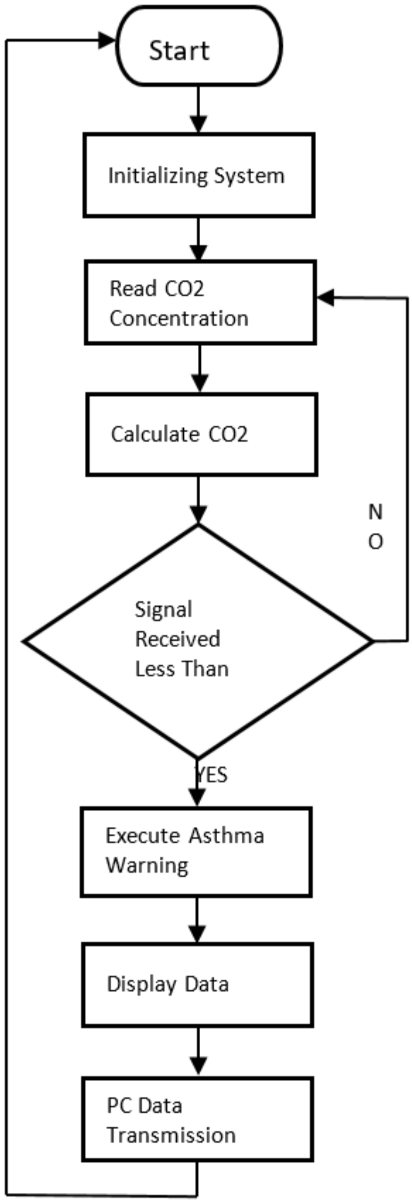

Figure 2 System Flowchart

Figure 2 shows the process flowchart of the electronic kit. Basically, this electronic kit consists of three main parts including electronic, hardware and software parts. The process flowchart will be controlled by the software part. Code is programmed in Arduino microcontroller to process the data collected from the carbon dioxide (CO2) sensor by calculating the CO2 concentration. Next, it will send the data to the TFT LCD shield to display the result in graph form. When a possible asthmatic user is detected, threshold will be activated then warning through LED will be given to the user. Meanwhile, Bluetooth module is used to communicate with personal computer (PC) for a better view of the result.

Figure 3 shows the MH- Z14A carbon dioxide (CO2) sensor which is used in this project. This sensor has three types of output including analogue, PWM and UART communication. In the proposed technique, UART communication is used which consists of host and subsidiary detector. On the other hand, concentration of carbon dioxide (CO2) is calculated based on the Eq. 1 below:

$$Concentration\,of\ CO2 = HC * 255 + LC \qquad (1)$$

where CO2 = Carbon Dioxide; HC = High channel; LC = Low channel

Figure 4 shows the schematic diagram of the electric circuit. This circuit included MH-Z14A carbon dioxide (CO2) sensor as shown in Figure 3, Arduino microcontroller, level logic converter, TFT LCD shield, HC-06 Bluetooth module and LED. The purpose of the level logic converter is to collect the low voltage signal from the sensor and convert to a high voltage signal. TFT LCD shield is used as a tool for data presentation whereas Bluetooth module is used for the communication with PC. In this proposed prototype, LED is used as an indicator to differentiate between asthmatic and normal user. Figure 5 shows the mechanical design for the proposed prototype drawn using CATIA software. In this design, the electronic kit (prototype) included electric junction box, TFT LCD shield, ON/OFF switch, LED, buttons, hose and breather.

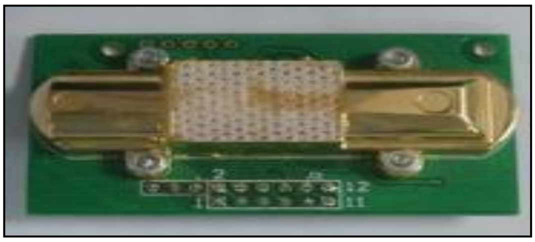

Figure 3. MH-Z14A Carbon Dioxide Sensor

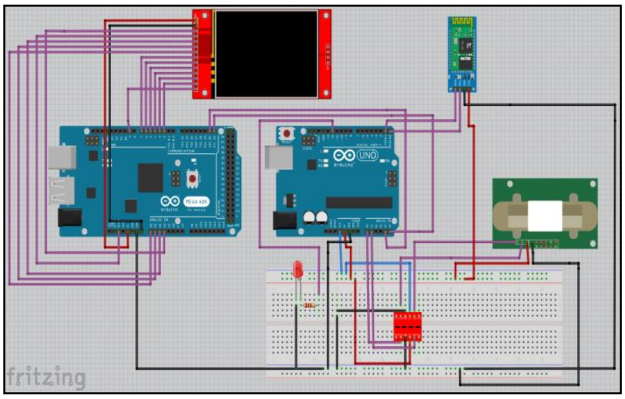

Figure 4. Schematic Diagram for Electric Circuit

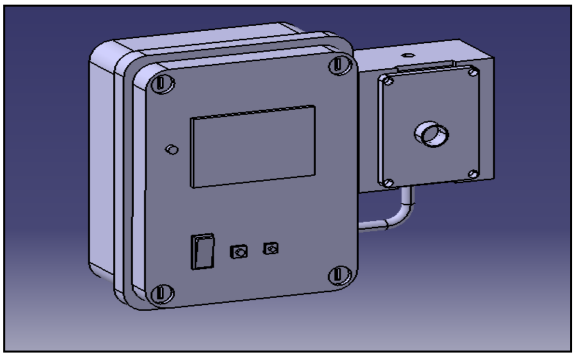

Figure 5. Mechanical Design for Electronic Kit

The sizes of the individual parts are stated in the following table.

Table 1: dimension of the proposed prototype

Part/Model	**Size (mm)**
Cover-front	28.59 x 121 x 161
Cover	3 x 108.5 x 140
Breather	25 x 50 x 76
Breather cover	13 x 50 x 70
Body	50 x 122 x 155

3. Result and Discussion

Figure 6 indicates the sample of output graph of CO2 concentration agains time. As shown in the figure, the concentration graph is divided into 4 phases in which, it is used as main parameter to differentiate between normal and asthmatic patient. Table 2 shows the sample of raw data collected from the normal user. From the table below, there will be at least two same peak value for each test within the range of 40 to 60 seconds. After maintaining the value, CO2 concentration starts to decrease. This shows that, the graph of CO2 concentration for normal user will have flat characteristic which refers to phase 3 in Figure 6. On the other hand, Table 3 shows the CO2 concentration raw data from asthmatic user. From the table, there will be only a peak value before the concentration of carbon dioxide dropped. The peak value happened at 60 seconds then it dropped at least 100ppm. This value could be referred as the peak characteristic of phase 3 in Figure 6. Therefore, from the both table and based on these characteristics, normal and asthmatic user can be differentiated.

Figure 7 refers to the generated graph of carbon dioxide (CO2) concentration obtained from a normal user. From the graph, the concentration of carbon dioxide (CO2) started to rocket up to reach 2880 parts per million (ppm) then it became stable before it decreases to 2264 ppm then back to its original value. Meanwhile, the graph has a “square wave” pattern from time 30s to time 80s. However, the data after that time shows some inconsistent value. This might due to the concentration of carbon dioxide from the surrounding environment.

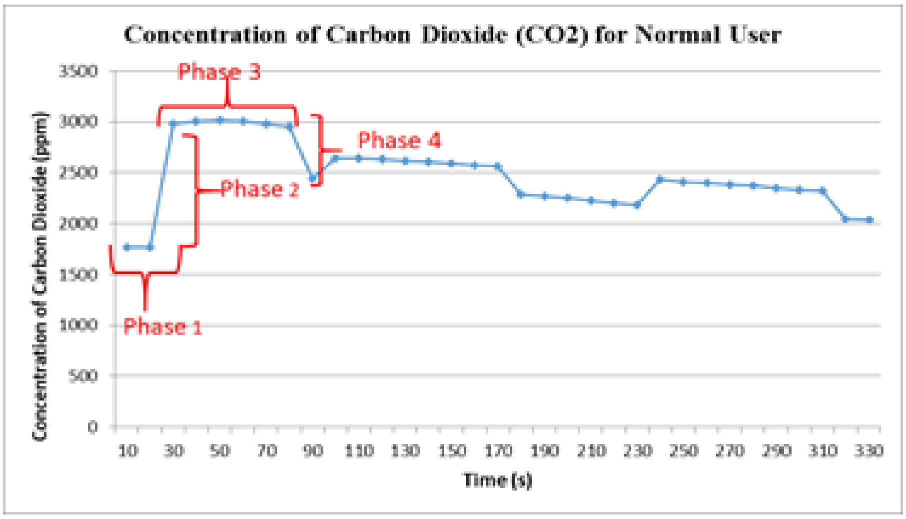

Figure 6. Phase division of CO2 concentration

Based on D’Mello et al. [11], capnogram consists of 4 phase as shown in Figure 6. Phase 1 is also known as Baseline. Baseline is the beginning of exhalation where there is no carbon dioxide presented. As shown in Figure 7, baseline started around 1800ppm due to this sensor measured the concentration of carbon dioxide of the surrounding instead of the human exhalation. When the user exhalation was sensed thus it caused phase 2 to begin. Phase 2 also known as ascending phase, caused by the carbon dioxide from the alveoli begins to reach the upper airway and caused the amount of carbon dioxide to rise rapidly. From Figure 7, the concentration rises from baseline to the peak refers to the phase 2.

Table 2. Raw Data from Normal User

Time (s)	Concentration of CO2 (ppm)		
	Test 1	Test 2	Test 3
10	1764	1724	1754
20	1765	1934	1744
30	2984	2754	3064
40	3004	2774	3400
50	3004	2784	3400
60	3004	2784	3380
70	2984	2774	3150
80	2954	2754	2544
90	2444	2734	2534
100	2640	2714	2524
110	2640	2264	2514

Table 3. Raw Data from Asthmatic User

Time (s)	Concentration of CO2 (ppm)		
	Test 1	Test 2	Test 3
10	1484	1580	1560
20	1484	1580	1570
30	3890	2814	1764
40	4410	4094	4744
50	4400	4360	4744
60	4140	4094	4594
70	3690	3850	4314
80	3670	3620	4284
90	3314	3400	3484
100	2734	2784	3474
110	2724	2714	3710

Next will be phase 3, also known as alveolar plateau. The concentration of carbon dioxide in this phase is stable as shown from the graph above. This is because the carbon dioxide rich alveolar gas constitutes the majority exhaled air. Meanwhile the concentration of carbon dioxide is uniform from alveoli to mouth or nose. Lastly, phase 4 (descending phase) where the carbon dioxide level drops quickly to its lower value. This phase can be seen from the graph above when the concentration starts to drop after the peak level. Figure 8 shows the graph generated from the asthmatic user. The raw data started to rocket up when the sensor senses the concentration of Carbon Dioxide (CO2) from the asthmatic user. Then, the concentration of the Carbon Dioxide (CO2) starts to decrease until it reached the lower (initial) value.

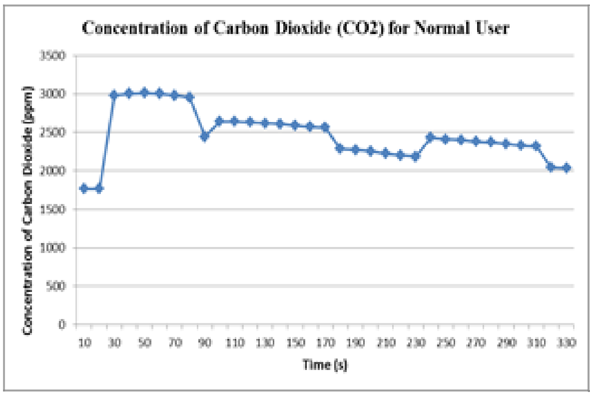

Figure 7. Graph of Concentration Carbon Dioxide for Normal User

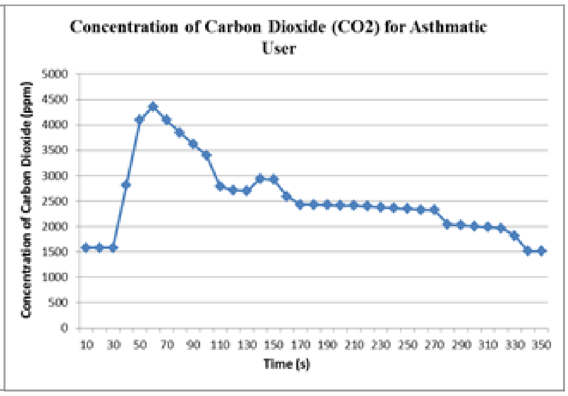

Figure 8. Graph of Concentration Carbon Dioxide for Asthmatic User

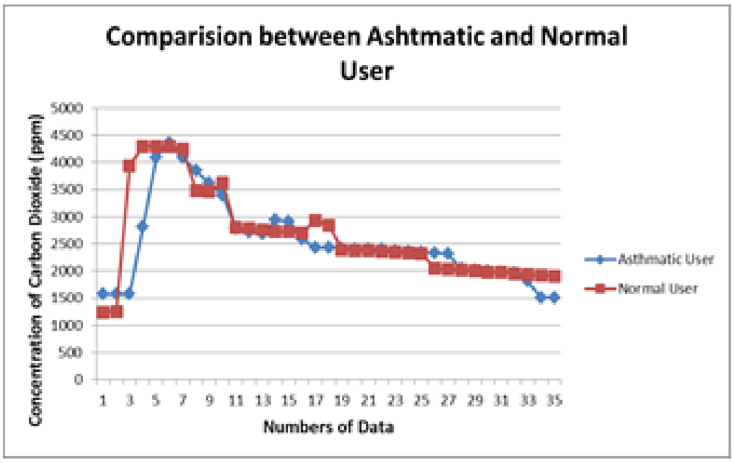

Figure 9. Comparision between Normal and Asthmatic User

For asthmatic user, smaller airway is narrow by the half mark of asthma and caused obstruction to flow within the airways especially during expiration. In asthmatic patient, airway obstruction causes regional decreases in airflow and thus leads to "alveolar ventilation". Therefore, it causes the deformation of the curve as shown in Figure 8. From the graph, it can be observed that the deformation causes the opening angle between the phases 2 and 3.

Figure 9 shows the comparison between the asthmatic and normal user. As shown in the graph, the pattern between the two graphs are slightly difference. At first, the starting point and the peak concentration of carbon dioxide is almost the same. However, when they reach the peak level, the concentration of the normal user stabilizes and maintain for quite some time and formed a "square wave" before it started to decline. Meanwhile, for the concentration of the asthmatic user, it started to decline just after reaching the peak. Then, both of the CO2 concentration stated to fall until they reached a level below 2000ppm.

From Figure 9 above, it is observed that the angle in phases 2 and 3 are slightly different. For asthmatic user, the graph in phases 2 and 3 is wider than the normal user graph due to "alveoli ventilation". Therefore, from the comparison above, the category of the user can be easily categorized either normal or asthmatic.

Figure 10 shows the prototype of electronic kit. The body of the lit was built using electric junction box. Whereas Perspex was used to build the body of the inhaler and the cover was made by 3D printing model. Based on the figure, TFT LCD Shield, ON/OFF button, switches and hose have been included in this prototype.

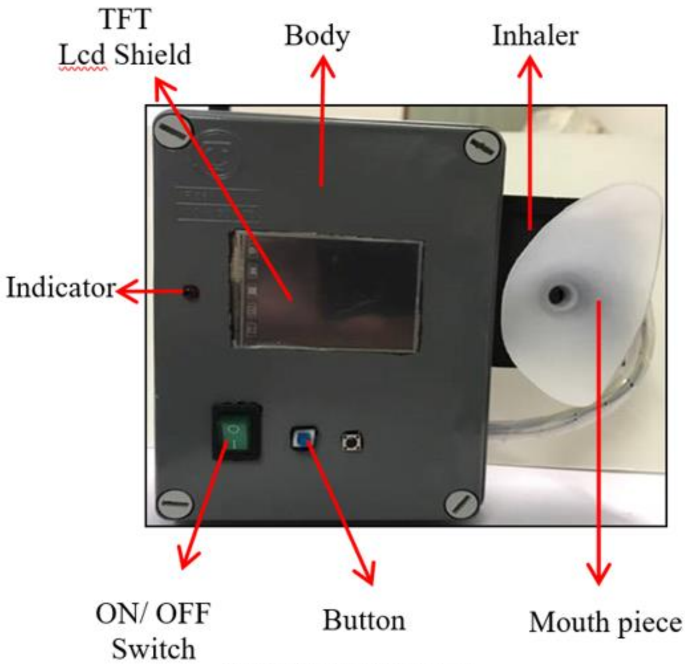

Figure 10 Actual Protoype

4. Conclusion

Use of capnography in monitoring asthma and medical services is increasing; however, capnography is still expensive and unaffordable for patient especially those from low income family for the purpose of asthma self-monitoring application. Therefore, in this research a low cost and portable asthma monitoring devices is proposed. For this device, the main component is carbon dioxide sensor, TFT LCD display and also Bluetooth module. The result from the user can be displayed using TFT LCD display and also PC; meanwhile the result display in a type of graph which can categorize the user either asthmatic or normal. In this research, three asthmatic and normal users are gather to test this device and the result for each of them are gather for analysis. The pattern of the graph for asthmatic user show a significant different compared with normal user. In future, prototype of this device can be tested and validate for the use as a home monitoring device instead of others device such as peak flow meter and spirometer as this prototype device cancelled out the complex procedure for both of the available asthma monitoring devices.

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