Asthma Monitoring Systems Based on Electro-Infrared Sensors: A Review

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ABSTRACT: Asthma is one of the chronic diseases that affected on the respiratory system. Studies had showed that more than 350 million people who suffering from asthma around the world which is equivalent to 1 in each 12 adults. Many intelligent monitoring systems had proposed in order to help the patient to know the situation before the frenzy happens. This approach has additionally been applied by individuals wanting to boost the standard of life by utilizing this technology. This paper tends to perform a comprehensive coverage and review that aim to show and analyze the advances of the most recent studies supported medical aid in the field of respiratory system especially monitoring and detection of the asthma disorder based on infrared sensors. The present analysis covers revealed manuscripts in scientific journals and recognized conferences since the year 2016. Also, it tends to show a reference model supported the analysis of the resources used from the chosen studies. Finally, the objective of the present proposal is to assist future enthusiasts to get and enumerate the specified factors related with asthma monitoring systems based on infrared sensors.

KEYWORDS: Respiratory system, Asthma monitoring systems, Chronic disease, Infrared sensors.

1. Introduction

The most important parameter in the human lungs is the Carbon Dioxide (CO2) concentration, this measurement called capnogram. Which was first measured in the early 1900s [1, 2]. The concentration of the CO2 can be measured accurately by using capnogram, Also its features use to provide overall information about Chronic Pulmonary Disease in addition to cardiorespiratory disorders, Congestive Heart Failure, and asthma [3-5]. Nowadays, asthma consider as one of the most threatened diseases of respiratory disorders. In the world, Asthma considered as the fourteenth rank of the most common respiratory disorders. About 334 million people affected by asthma around the world, 9% from them are adult while children represent 14% of them [4, 6, 7]. In Malaysia, 10-13% of population affected by Asthma, While in Malays 67% of population affected by this disease, In Chinese and Indians the percentage goes from 7.3% to 12.9% respectively [8, 9]. The devices that used to diagnosis asthma are patient dependent device, which they require co-operation from patients, so it’s difficult to use by children. Therefore, an independent device used to diagnosis asthma must be exist, for example, capnography in order to assess the respiratory the function of asthmatics [10-12]. Many devices were developed to make the diagnosis and monitoring of asthma easier such as Spirometer and peak flow meter. Hence, many studies were carried out in Google Scholar between 2010 to 2023 by utilizing standard English language, By using different keywords such as (capnogram, infrared sensor, asthma monitoring system, CO2 sensor, respiratory CO2, capnograph, and monitoring system) to define CO2 sensors technology, and capnogram features [13-15].

The concentration of exhaled carbon dioxide was measured by using end-tidal CO2 (ETCO2) detectors. The end-tidal CO2 represent the partial pressure or maximal concentration of CO2 at the end of exhalation. Which is correlates to the arterial concentration of CO2 in patient [16]. Different design of the detectors are introduce along the time, But overall quantitative and qualitative Detectors can be considered as the main type of capnograph [17]. If the detector use to detect the presence or absent of the CO2, it’s a qualitative detector such as colorimetric detector which indicate the absent or present of the CO2 in exhaled
gas by using color. More detailed information given by using the quantitative detector because it read the level of CO₂ in the exhaled gas [18-20]. Another classification of the detector depend on their location in the airway system divide into mainstream and sidestream devices, IR sensor (Infrared sensor) are a mainstream detectors where gas flow goes directly into the device to produced real-time wave of the CO₂ waveform. Which is used mainly with intubated patients. While Sidestream detectors are located away from the path of air flow in the respiratory system. Such as Nasal monitoring of end-tidal CO₂ [21, 22].

Capnography used in patients through anesthesia, ventilator cases, and head trauma. But its main benefit used in intubated patients. Also it can be used in patients that are awake in children and adult [23, 24]. By using a sidestream capnograph attached to a nasal catheter produced ETCO₂ values that correlated well with PaCO₂ readings capnography could be used attached to a facemask [25-28].

The main different between mainstream and sidestream are shown in table 1 and figure 1. witch represent the different in definition of the names, the effect of the environment on the reading to show that mainstream capnogram has an issue by mixing the sample gas which will effect on the reading, While the sidestream capnogram has delay time results from remote location. Also the table and figure show the different in the main parts of each devices and give the end result of each device.

Table 1: Comparison Between Mainstream and sidestream capnography [21, 27, 29, 30]

<table>
<thead>
<tr>
<th>Mainstream</th>
<th>Sidestream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name as Non-Diverting capnometer measuring CO₂ concentration away from the patient airway.</td>
<td>Name as Diverting capnometer measuring CO₂ concentration at the patient airway.</td>
</tr>
<tr>
<td>Issue of the mainstream capnometer include different in temperature and humidity between sampling site and monitor site, removal of water through the distance, the sample gas may mix through the cell which will affect on the reading, pressure drop across the tubing, and dynamic distortions to the waveform</td>
<td>Issue of the sidestream capnography include delay time results from using a remote location, this delay may last for up to several seconds with 200ms distortion the total response time (delay) can be useful to provide time for the clinician to prepare for the patient’s case</td>
</tr>
<tr>
<td>It consists from the sample cell and infrared bench</td>
<td>It consists of 6- to 8-foot-long small-bore tube with water trap and drying tubing and sample cell</td>
</tr>
</tbody>
</table>

Give a real-time reading of the partial pressure of CO₂ (carbon dioxide) within the respiratory system

To aspirate a sample of gas from the breathing circuit in the respiratory through a 6- to 8-foot-long small-bore tube at a flow rate that may vary as much as ±20%

2. Related Work

In 2013, the authors made a comparison between mainstream and sidestream measurement of end tidal carbon dioxide (PETCO₂) was made by taking 114 subjects which was patients require arterial blood gas analysis. By using Bland-Altman method (it’s a method used to calculates the mean difference between two methods of measurement (the ‘bias’)) to evaluate between the PETCO₂ measurements and PaCO₂ measurement which represent the measures of an arterial blood gases (ABG) to evaluates carbon dioxide (CO₂) levels in the blood. It results in the mainstream, 13mm Hg value different between PETCO₂ and PaCO₂ (0.6 to 25.5 agreement limits to 95%) with moderate correlation (P < .001, r 0.55). While in the sidestream 9.7 mm Hg value difference between PETCO₂ and PaCO₂ (5.4 to 24.7 agreement limits to 95%) with poor correlation (P < .001, r 0.41). that improve PETCO₂ has lower value than the PaCO₂ [26].

In 2016, the authors had proposed a continuous monitoring system that helps asthmatics to monitor the activity of their lungs as well as the related environmental parameters. Asthma symptoms can be detected by using this monitoring system. The designed system consists of a device module to monitor the temperature, humidity,
activity, air pressure and the flown gases that surround asthmatics patient. The data then sent from the device to the patient’s doctor by using a Global System for Mobile Communication (GSM). The doctor could examine the sensed values and he could take the desired decision for giving the asthmatics the right treatment and medications. This proposed system is low cost, credible, and friendly to use in order to find out the asthma symptoms in asthmatics [31]. In 2017, the authors had developed a smart model of asthma prediction system using Internet since there are 334 million people around the world are suffering from asthma. Asthmatics are sensitive to things that may not bother the normal people, they feel uncomfortable when the level of smoke increased, either fog or pollution in the surrounding air. The number of asthmatics has been increasing so fast over the years. The developed model helps to prevent asthma from happen by detecting the causes of asthma [32]. In 2018, the authors made a review study investigate, and compare between different infrared carbon dioxide sensors specifications, this study also gives the capnogram features that use to develop an asthma-monitoring device. The keywords used was (infrared sensor, CO₂ sensor, capnograph, CO₂ measurement, capnogram, and asthma detection) by using PubMed, Google Scholar, scoups and another search engine. The COMET (COMET is the name of the company made the sensor) carbon dioxide sensor distinguish as the most suitable and reliable sensor proper for asthma diagnosis and monitoring according to this study, this device was chosen from other based on its weight (7 g), warm-up time (2-15s), output range (0-99 mmHg), and response time (0.028 s). Furthermore, to screen asthma severity level, slope and time-frequency components must be measured from alveolar phase and complete breath cycle respectively [33]. In 2018, the authors made a Narrative Review on the Applications of End-Tidal Carbon Dioxide (ETCO₂) Monitoring in Emergency room was made by using PubMed, Scopus, Cochrane Databases, and other search engine by using keywords like emergency department monitoring, ETCO₂, and critical monitoring. In this study capnography was use to measure many clinical cases. It's use to measure ETCO₂ as an precise method that use to help in emergency cases. But this device is not used in all emergency cases and not used regularly. it's usually used in patients under sedation (Anesthesia) or connected to mechanical ventilation, patient suffering from shock, heat dropping due to pulmonary disease, patient who suffering from metabolic disorder, or has trauma. Which is means that capnography considered as an essential tool in emergency department [34].

3. Methodology

Depending on the introduction, we propose a review for home-based and handheld monitoring system capnograph device [3, 35, 36]. The main objective of this study is to show the best device that has the ability to monitor asthma in the home environment and assists in the progression and handling of asthma which is the COMET CO₂ sensor [5, 37, 38]. Till now, too many studies have made huge steps towards the monitoring and detection of cardio-respiratory conditions and disorders, specifically, asthma, this is done by using a capnography [32, 39]. The schematic block diagram in figure 2 shows the proposed system in the present study for monitoring asthma and also it determines the lung disease in asthmatics.

This system measures several parameters because the device is dealing with air so the Humidity, pressure, Airflow, voltage, temperature, and CO₂ concentration sensors represent the main feature of the air breathed that need to be monitor for example if the humidity of the air was too high it will cause suffocation of the patient and increase the illness, each active sensor then connected to a microcontroller (Raspberry Pi was use because the code of the program was written by python language to made the program more freely to edited from other language) which is supplied by line power or battery then the processed signal display on mobile communication which has GPS locater, Bluetooth module and GSM (Global System for Mobile Communications). The data that sent to mobile communication module interfaced to the specialist to make the correct examination in medications and treatment for the patient. This monitoring system is friendly to use by patient, economic. The CO₂ sensor module in which the signal conditioning (the electronic circuit that use to enhance and manipulate the signal to the desire output needed from the next process) down is shown in figure 3 [40-42].

The microcontroller also sends the data to CO₂ gas concentration to determine the concentration of the exhaled CO₂ and then display it on LCD monitor.

4. Results

As the aim of this study is to make a full review and comparison among the infrared CO₂ sensors multiple specifications and others to develop an efficient asthma monitoring device. As shown in Table 2 and 3 the specification of COMET CO₂ sensor which indicate that this sensor is the most reliable sensor used to assess the asthma. Moreover, time-frequency components and the slope which measured from the overall respiratory cycle and alveolar phase; which is found the most important
features to show the seriousness level of asthma. The feedback was done at a constant temperature (25°C) discovers that the carbon dioxide values are totally changed as (17,835.19-86,321.29) parts per million (ppm) whenever the pressure changed as (16.53-81.53) kPa. These measurements have. The sensors measurements are illustrated in figures (3), (4), and (5).

Figure 2: The Proposed Schematic Block Diagram of Asthma Monitoring System in the Present Study.

Figure 3: CO2 Sensor Module [40, 43]

Table 2: CO2 Infrared Sensor Specifications [44, 45]

<table>
<thead>
<tr>
<th>Sensor Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in gram</td>
<td>7 g</td>
</tr>
<tr>
<td>(Tr) Response Time</td>
<td>0.028 s</td>
</tr>
<tr>
<td>Pressure Output Range</td>
<td>0-99 mmHg</td>
</tr>
<tr>
<td>(Tw) Warm-up Time</td>
<td>2-15 s</td>
</tr>
</tbody>
</table>

The line graph responses of three different CO2 sensors show that the COMET I and II types are the best types of the CO2 sensors. In figure 4 these lines graph is color coded. the blue line represents the temperature which was fixed at 25°C, the orange line represents the relative humidity which is approximately between 14-24% of the air, the green line represents the Dew point between -7 to 0.8, The red line represents the CO2 level while the pink line represents the maximum limit can the result reach. In figure 5 represent the most turbulence area zoomed from figure 4 and show all the label with reading on the graph.

Figure 4. The Line Graph Response of COMET-I, II CO2 Sensors [46,47].

Figure 5. The zoomed Line Graph Response of COMET-I, II CO2 Sensors which show the pointer give the read of CO2 level, the relative Humidity and Dew point [46, 47].

In figure 6 and 7 show the different between the line graph of real and digital CO2 sensors it shows that the real CO2 sensor react as a U shape curve while the digital CO2 sensor act as downward slope to infinity because in digital CO2 many parameters were neglected like the temperature and humidity.

Figure 6: The Line Graph Response of CO2 Sensor 27929 [48].

Figure 7: The Line Graph Response of Digital CO2 Sensor EE893 [13].
Conclusion

The proposed paper gives overall investigations and also comparison between more than one research that were based on infrared CO₂ sensors. There are many specifications should be taken in considerations like, Temperature at the operating time, weight of the device that will be held by the patient, voltage at the operating time, approximate cost of the device, time that take the device to respond to the signal, the time that the device needs to warm-up, the pressure output range, and the applications of the device. It was clear from this study that both the COMET one and two, Digital carbon dioxide (EE893) sensors and carbon dioxide (27929) are the most accurate and efficient for creating a home-made asthma monitoring system. Furthermore, these sensors measured the inspired CO₂ rate of respiration, ETCO₂ (end-tidal carbon dioxide), and TIME OF inspiration and expiration. Therefore, by using the equivalent CO₂ sensors which is a light weight, hand-held, precise, and quantitative capnography device that designed and developed for this reason, the lifetime of the pretended features when developing a canograph system or device should conform in future work.

Table 3: Different Types Infrared CO₂ Sensors and their Specification

<table>
<thead>
<tr>
<th>CO₂ Sensor</th>
<th>Application</th>
<th>Sensitive/ Range of Operating</th>
<th>e (¹)</th>
<th>Operating Voltage</th>
<th>Approx. Cost (in$)</th>
<th>Approx. Weight (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMET-I, II</td>
<td>Low CO₂</td>
<td>±0.42%</td>
<td>5-55</td>
<td>0-13.8</td>
<td>6.5-12</td>
<td>&lt;7.0</td>
</tr>
<tr>
<td></td>
<td>High CO₂</td>
<td>0-70</td>
<td></td>
<td>0.035-1</td>
<td>4.75-7.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Low CO₂</td>
<td>±(0.005% at measuring value)</td>
<td></td>
<td>0-2/0.5/1</td>
<td>4.75-7.0</td>
<td>10</td>
</tr>
</tbody>
</table>

References


[52] Auns Qusai Al-Neami et al., Asthma Monitoring Systems

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