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Analysis of Breathing Patterns from Thermal Images Using an Automated Segmentation Method

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Abstract. Breathing is one of the important vital signs in diagnosing and monitoring for patients' treatment and disease. Few modalities have been used to evaluate breathing activity such as respiratory belt, thermistor and capacitive sensor. However, these requires external attachments such as electrode or sensor which might be inconvenience over long period of time. Hence, we proposed the use of thermography as a contactless monitoring device. In this study, inspiration time and expiration time of three different breathing patterns such as normal, prolonged and rapid breathing patterns were measured by using the thermography. Thermal images obtained from the subjects were processed and analysed by using an automated segmentation method which integrate the knowledge of edge-based and region-based segmentation methods into the algorithm developed. The algorithm developed in this study has shown that the tracker was able to segment the region of interest of the thermal images automatically and it provides a more accurate and stable results than manual calculation method. Thus, three different types of breathing patterns could be identified based on the inspiration time to expiration time ratio. Results shows that there was less than 5% of relative error which suggest the benefit of this algorithm.

1. Introduction

Breathing is a significant human physiological phenomenon and a vital sign to indicate overall body health and to diagnose a number of diseases such as apnoea or heart attack. Generally, human exhaled carbon dioxide and inhaled oxygen during breathing in maintaining vital body function. Breathing pattern contributes to clinical monitoring, sleep hierarchy and feedback adjustments of our cardiovascular system and other diseases (1). Thus, activity of breathing such as cycle phase, breathing rate, volume, patterns and gas content should be obtained continuously in order to identify the underlying disease. This can help doctors to monitor and diagnose certain disorders by using the information obtained from breathing patterns.

Currently, there are various methods used to analyse breathing activities such as respiratory belt, thermistor, capnography, and capacitive sensor mounted to shirt (9,10). However, the use of these modalities requires attachment of external device such as electrode, mouthpiece, sensor, cables and belts which can cause discomfort if used continuously over a long period of time especially in monitoring. Recent advancement of technology shows an increase in demand for comfortable and unobtrusive monitoring devices. Hence, in this study, we proposed the use of thermography for assessment of breathing particularly in assessing the timing of inspiration (TI) and expiration (TE) and its ratio since research in this area is still very limited. Understanding the dynamic of breathing through changes in TI, TE and its ratio could reflect several respiratory problem such as chronic obstructive pulmonary disease (COPD) and asthma as shown in several studies (2–4).

The assessment of breathing dynamics using thermography is based on the fact that during inhalation, air is being inhale through nostril causing drop in temperature at nostril area (5). Conversely during expiration, air is being release into atmosphere and has higher temperature than the typical indoor temperature since air particles emitted has higher energy (5). These variation in temperature can be assessed by capturing series of thermal images. Thermography provide several advantages since it does not require any contact with the subject and it does not require sources of illumination to operate.

Previously, there was a study conducted on the timing of inspiration and expiration using thermography, however those study didn't implement automatic segmentation and tracking hence required significant amount of time to analyse the data. The development and implementation of automatic segmentation and tracking system of the thermal images is expected to reduce the data extraction time significantly while maintaining its performance.

Therefore, in this study, we proposed the use of thermography to assess timing of inspiration and expiration in different type of breathing patterns with the implementation of automatic segmentation and tracking of the thermal images.

2. Methods

A total of 11 participants who were selected among undergraduate students from School of Biomedical Engineering and Health Science were involved in this study based on the calculated sample size. Subjects selected must fulfil the inclusion criteria which includes the age range from 20-25, having a normal BMI, and healthy. Participants with medical illness or having a blocked nose during the experimental day were excluded. In this study, participants were instructed to simulate the designated three different type of breathing patterns. The three breathing patterns that were chosen are normal breathing, prolonged expiration breathing and rapid breathing with the ratio of inspiration time to expiration time of 1:2, 1:3 and 1:1 respectively. As for the correct way in performing different types of breathing patterns, the experiment methods were then conducted based on the confirmation made by a medical doctor.

Experiments were conducted in a dimly lit and temperature-controlled environment. Participants were placed inside the room 10 minutes prior to the start of experiment to allow acclimatization with the room temperature. Prior to simulation of the breathing, a short period of demonstration and practice were conducted to familiarize them with the breathing patterns hence allowing precise simulation during experiment. Each breathing pattern were recorded for 1 minutes at 5 frames per second using Epidermal Thermal Imaging Professional (ETIP) camera system model 7640 P series. The camera was positioned at 1-meter distance to the nostril area to provide better focus and visualisation of the region on interest (ROI). Figure 1 shows the overview of our experimental setup.

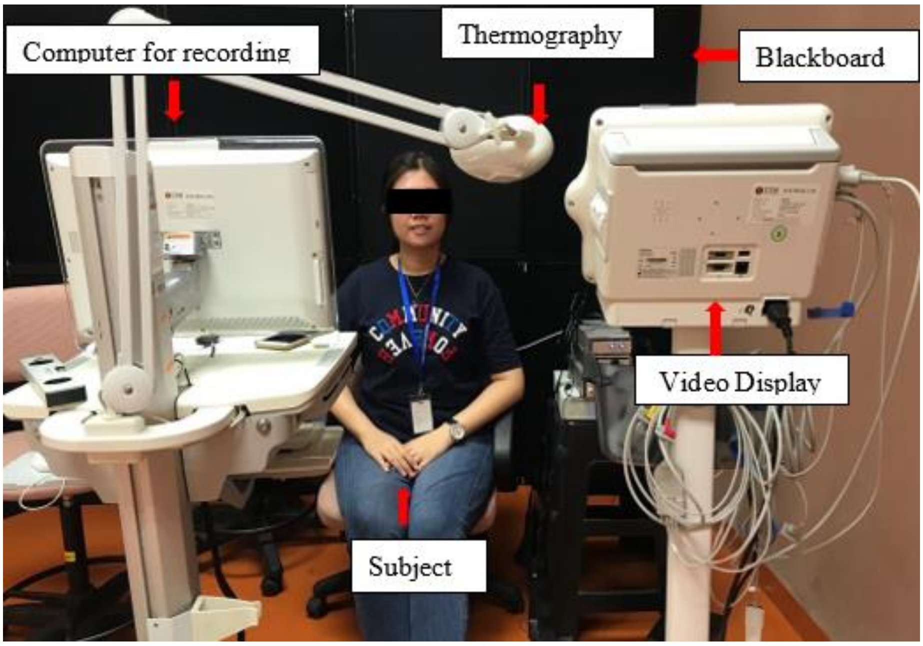

Figure 1. Experimental setup.

After series of infrared thermal images were obtained through thermography, we developed the first algorithm to extract the data. Firstly, a rectangle box is drawn at the thermal images to resize the thermal images in order to refine the thermal images and remove unwanted information. It consists of nose, mouth and eyes area. Then, a second rectangle box is drawn to extract the ROI and is known as ROI tracker. The same size of the ROI tracker was applied across all the thermal images captured. The tracker tracked region consists of only mouth and nose area as the distance between mouth and nose area are too small to be divided as compare to the distance to eyes area. By only focusing on the ROI instead of the entire human face, the computational time can be shortened and results would be more accurate and stable. After the segmentation process, the features of the ROI which is the pixel intensity is extracted through Harris Corner Detection. This technique is very useful to extract corners and infer features of the images, as well as it provides better repeatability under changing illumination and rotation. The tolerance for x-axis and y-axis is set at 10 and 12 in the ROI tracker respectively. The tolerance was set in order to indicate any points that were out of the tolerance would be eliminated and thus, to remove unwanted and false readings in the results. Based on the data obtained from the measurements, the average TI and TE and the average ratio between TI and TE were calculated. To further confirmed the performance of the developed algorithm, relative error for different breathing patterns were also calculated using the formula (1).

$$\textit{Relative Error (\%)} = \frac{|\text{Experimental value} - \text{Theoretical value}|}{\text{Theoretical value}} \times 100\% \qquad (1)$$

3. Main results

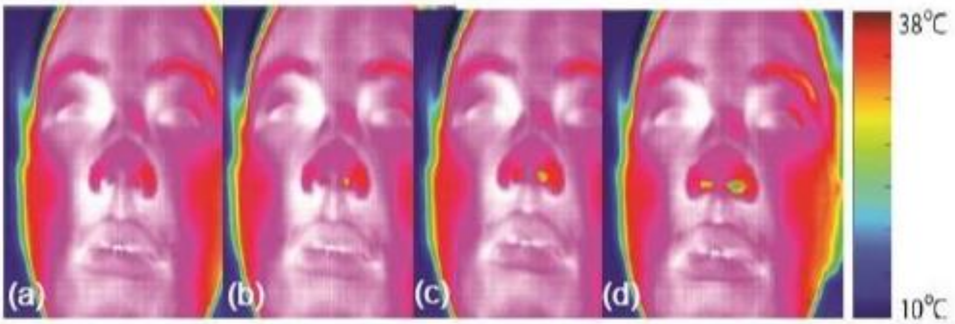

Figure 2. Series of multi-coloured images (a) expiration, (b) early inspiration, (c) mid inspiration and (d) late inspiration.

Figure 2 shows a series of multi-coloured images captured by an Infrared Thermal Imaging (ITI) camera. Based on the data extracted from the thermal images, several graphs of each breathing type were plotted to visualize the pattern of the breathing, which is figure 3a, figure 3b and figure 3c. In order to construct the graph, the data of pixels of region of interest (ROI) are needed, in which each different breathing patterns have their own pixel values. Based on the 300 images taken for each breathing pattern, we were able to compute these graphs. The P graph is the original graph plotted directly from the extracted values. The Q graph is the inverted graph of the original which provides better visualisation for identification of transition point while the R graph is the gradient graph which assist in the acquisition of transition point which were discussed in the next part. For pattern analysis, we can observe in Q graph that the pixel intensity moved in a cyclical pattern which represent the temperature changes at the ROI.

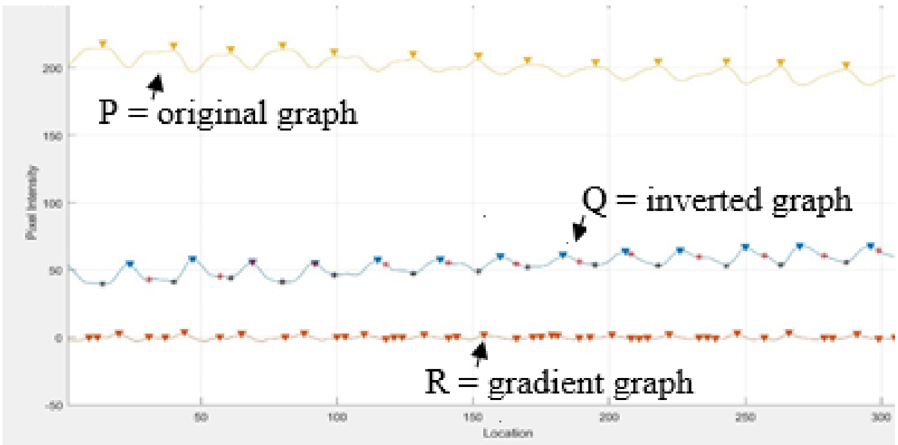

Figure 3a. Normal breathing pattern.

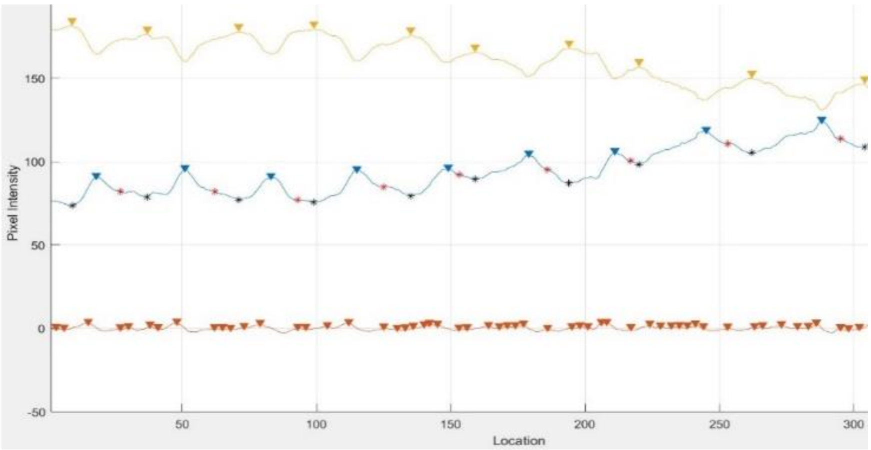

Figure 3b. Prolonged expiration breathing pattern.

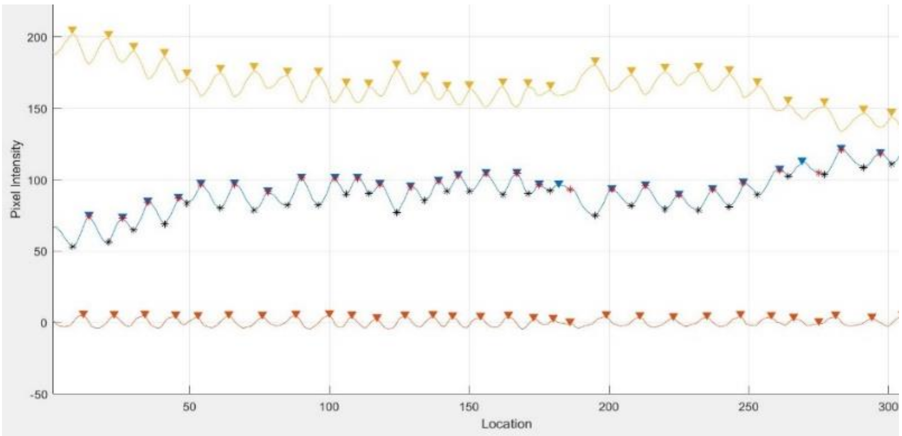

Figure 3c. Rapid breathing pattern.

Next, in order to measure the TI and TE, transition point that determine the start of inspiration and expiration were identified. This transition point is defined as a rapid and consistent deflection in the breathing patterns between two phases of inspiration and expiration. Figure 4 illustrated the transition point (6).

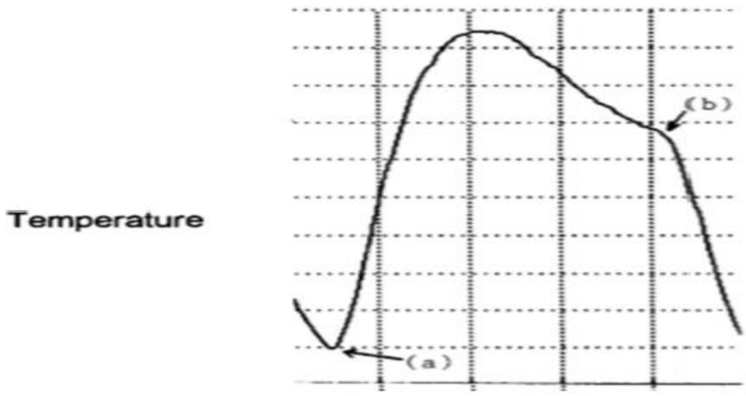

Figure 4. Transition point of breathing cycle.

Based on figure 4, point (a) shows the start of expiration and point (b) shows the start of inspiration. This shows that the start of inspiration does not happen at the peak of the graph due to the presence of short period of relaxation known as post expiratory period, which allow a drop in the temperature at the nostril before inspiration take place which eventually led to further drop in temperature (7). It is common to identify post expiratory phase in normal and prolonged breathing on healthy individuals. However, in rapid breathing pattern, the post expiratory period is very minimal hence the inspiration point is often seen at the peak of the graph (8). These transition points were tracked by using our developed algorithm from the inverted graph as it provides better visualization than the original graph. A gradient graph (gradient set at 1) was used to indicate there was a deflection which reflect the starting point of inspiration. The red and black asterisk form the inverted graph in figure 5 shows the starting point of inspiration and expiration. There were two assumptions made at which the red asterisk must be in between the maximum peaks in the inverted graph and the black asterisk while the black asterisk must be in between maximum peaks in the inverted graph. This is to make sure the starting point for inspiration and expiration are located correctly.

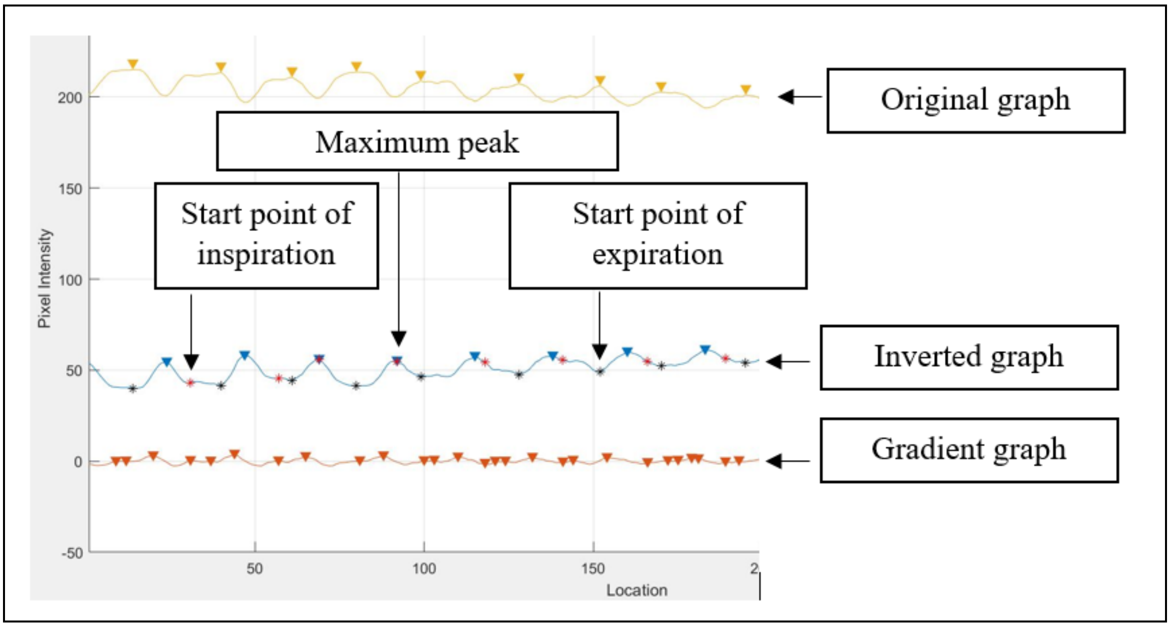

Figure 5. Starting point of inspiration and expiration.

Once the transition points of inspiration and expiration were identified, the length of TI and TE were calculated based on the time difference between two transition points. The ratio of TI to TE were also calculated from these values. The average values for TI, TE and ratio of TI to TE from all subjects were summarized in table 1.

Table 1. Average value of TI, TE and ratio of TI to TE for different breathing pattern

Breathing pattern	Inspiration Time (TI), s	Expiration time (TE), s	Ratio of TI:TE
Normal	1.61	3.20	1.98
Prolonged	1.65	4.86	2.94
Rapid	1.17	1.22	1.04

The average ratio obtained from all subjects were then compared with the actual ratio for the designed breathing patterns by using percentage of relative error. Table 2 shows the results of the relative error. Results show that the percentage of relative error for the three breathing patterns were less than 5% which suggest the excellent performance of thermography for breathing assessment. This relative error exists possibly due to vigorous movement of subjects during measurement which potentially affect our tracking ability.

Table 2. Relative error of TI:TE ratio

Breathing pattern	Average TI:TE	Actual Ratio	Relative Error (%)
Normal	1: 1.98	1: 2	0.83
Prolonged	1. 2.94	1: 3	1.97
Rapid	1. 1.04	1. 1	4.29

4. Conclusion

As a conclusion, results shown from this study suggests that thermography has good reliability to measure timing of inspiration and expiration in various breathing pattern which can be useful for health practitioner to diagnose and monitor patient with respiratory problems. Furthermore, the development and implementation of image segmentation and tracking has enhanced the performance of thermography in monitoring breathing dynamics while significantly improve the data extraction time from previous study.

Acknowledgment

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