A New Method for the Quantification of Breathing

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Abstract - **Quantification of the breath flow and nostril dominance reveals internal physiological cycles. There are very few existing methods for unobtrusive monitoring of the breath flow. In this paper we present a new method for the quantification of breath flow and evaluation of the symmetry of breathing through both nostrils. The system utilizes thermal film to visualize the flow of breath and implements image processing techniques to quantify the flow. We present system design and preliminary results from an experiment with 11 subjects. Preliminary results indicate a good correlation between subjective measure of the nostril dominance and two analyzed parameters – ratio of left/right area and average intensity. The proposed method can be used as a diagnostic tool, for stress monitoring, biofeedback techniques, and circadian rhythm analysis.**

Keywords - **Breathing, Sensors, Non-invasive, Diurnal cycles, Quantification.**

I. INTRODUCTION

IT is agreed by physicians that balancing internal bodily cycles is essential to maintaining a healthy life. The most important cycles in our body include circadian (24 hours), tidal (12 hours), and diurnal (2 hours). Unfortunately, many people are simply too busy to observe and detect possible disruptions within their own bodies. Furthermore, few devices are available that can adequately and unobtrusively monitor internal cycles.

Many difficulties lie in devising methods for the measurement of internal bodily cycles. This is mainly because most cycles are internal to our tissues, organs, and organ systems and it is quite challenging to extract significant data without causing much discomfort to the patient.

Fortunately, many breathing cycles are easily observable and measurable due to their extrinsic nature. For example, diurnal cycles represent the activity of hormonal glands which are hard to monitor unobtrusively; however, the same cycle is reflected in breathing that can be monitored unobtrusively. These breathing patterns provide a window into our bodies in which many internal cycles may be observed as they are reflected. One cycle of interest is the dominance switch from left to right nostril while breathing through the nasal passage. This occurs approximately every 90 minutes, but can be affected by external stimuli such as sharp temperature change. Another important cycle, the circadian rhythm, is a type of breathing rhythm that repeats every 24 hours. Both of these cycles provide useful insight into the internal workings of our bodies. It is the authors' belief that close examination and quantification of these patterns will aid in the identification of any disruptions in normal cyclic activity as well as the detection of the onset of illness. By alerting an individual of such findings, counter-measurements may be taken to uphold and ensure good health.

Despite the increased ease of measuring internal cycles through the quantification of breathing, special care must still be taken to ensure the process is as non-invasive as possible. One example of an effective, but obtrusive device [1] employed the use of thermistors placed in each individual nostril. Temperature data was captured by a microcontroller affixed to a PCB worn by the patient. Data was then wirelessly transmitted to a base station for further processing. Although this approach allows for long-term data collection (excellent for circadian rhythm measurement), the requirement of placing thermistors within the patient's nostrils greatly reduces the comfort level of the device. Another approach [2], which directly addressed the patient contact issue, proposed a touchless monitoring system of breathing function using an analysis of infrared-based video cycles. Although this approach eliminated all contact with the patient, the system could only process a profile of the patient's face. Because of this, it is impossible to distinguish between the intensity of airflow for each individual nostril. Furthermore, the image processing techniques involved required training on a particular region of interest before data could be gathered. These setup issues should be avoided for practical use of such a device. Many breathing quantification studies are aimed towards the identification of sleep-related disorders. One such study [3] employed the use of both nasal thermistors and a CCD camera to measure breathing patterns as they related to posture changes in patients. An image processing board was constructed to observe the patient's entire bodily position as they slept. It is clear the use of image-processing techniques in breathing analysis greatly reduces patient discomfort and improves on the practicality of using such as device in normal day-to-day activities.

Based on this need, we propose a new device to measure the state of breathing, estimate rhythms, and detect irregularities in breathing cycles of individuals in a unique, effective, and non-invasive manner. We use a specialized sensor composed of a special heat-responsive film and a CCD camera. Digital videos capture the patient breathing on the heat-responsive film and various image-processing techniques are employed to quantify breathing based on attributes of the individual frames. In this paper, we present

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the design of the sensor prototype, preliminary measurements taken on a group of subjects, and results of preliminary analysis.

II. METHODS

A block diagram of the implemented system is represented in Fig. 1. The subject places his/her nose into an enclosed container that houses the thermal film, CCD camera, and associated lighting devices. The thermal film is affixed in such a manner that as air passes over it from the patient's breath, the film changes color in response to the heat. A mirror is then strategically placed to reflect the activity of the thermal film into the camera. It is then possible to capture digital videos on a host PC for further processing.

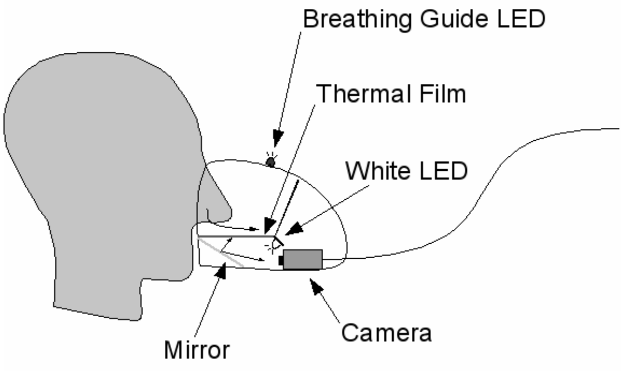

Fig. 1. Block diagram of the system.

A. Sensor

To adequately accomplish this functionality, several parameters had to be considered during the sensor prototype design such as lighting control, stabilization of thermal film and mirror, and the separation distance between the thermal film and patient's nose. To allow for plenty of room to work and make adjustments, a large box was used to house all required elements for the sensor. Control over lighting was accomplished by affixing two white LEDs to adjustable stands and anchoring them to the bottom of the enclosure. To aid in light absorption, the walls and lid of the box were spray-painted black with a matte finish. It was determined the LEDs were best oriented by placing them on either side of the camera and shining them upwards directly on the thermal film. This maximized the illumination of the film and minimized the reflection of direct light into the camera. Due to the flexibility of the thermal film, it was affixed to a small sheet of plexi-glass to provide it with rigidity as the patient breathed. The film and glass were placed perpendicular to a nasal slit carved into the side of the enclosure. A mirror was placed at an angle of approximately 45° underneath the film. The film and mirror were held in place using two blocks with slits cut appropriately to achieve a clear reflected image of the underside of the film. Any variability in this distance would result in skewed results for successive measurements. Fig. 2 shows the box with nasal hole connecting to a host computer.

Fig. 2. Breathing Sensor

B. Thermal Film

The thermal film reacts to a temperature range of 25-35°C, with the higher temperatures being represented by blue and the lower temperatures being represented by red. This behavior is shown in Fig. 3 where warmer sections are visible in the center of the two nostril regions followed by cooler regions of green and red pixel values.

Fig. 3. Thermal film response to subject's breath.

During the exhalation, the film's temperature will increase causing the response area to increase. Inversely, during inhalation, the thermal film's temperature will decrease which will decrease the response area. Since the response area changes dynamically in regards to a person's inhalation/exhalation, this area can be used to depict and quantify an individual's breath.

Fig. 4 shows a typical breathing cycle taken from a subject's processed data. The peaks represent changes in the response of the thermal film. Multiple peaks for the same sequence of frames show varying nostril area values. The gradual increase in values for subsequent breaths arises from a slight increase in the overall heat surrounding the thermal film as the subject continues to breath.

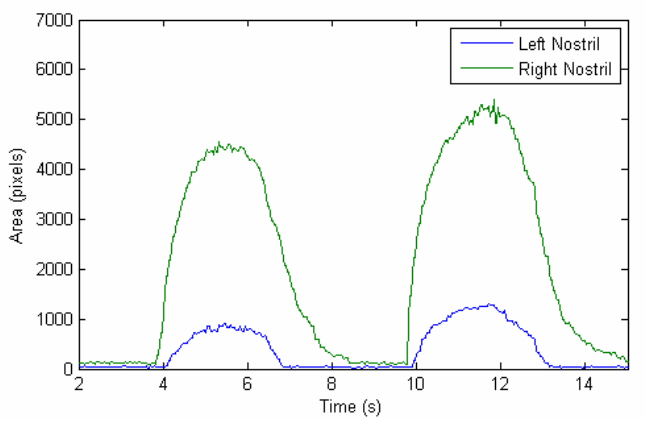

Fig. 4. Plot of area vs. time for two breaths.

C. Image Processing

Images of the thermal film captured during one's breath are processed to quantify the person's breath. When processed, the images reveal grayscale regions of the thermal film's response area for each nostril (Fig. 3 shown in color). The sequence of image processing techniques applied to the images include: image cropping, background subtraction, and custom-grayscale conversion. From these techniques, we generate two metrics (area and intensity) to describe each nostril for every frame of the video. The collected parameters for each frame include: left area (in pixels), left region's average intensity, right area (in pixels), and right region's average intensity. A mean and standard deviation is computed for each of these parameters for every video. We compare the two different types of parameters (area and average intensity) to determine which produces a more accurate description.

III. RESULTS

An experiment was conducted in which participants were asked to subjectively quantify their current nostril dominance on a scale from 1-9; where 1 constitutes complete left nostril dominance, 5 constitutes complete nostril symmetry, and 9 constitutes complete right nostril dominance. After each individual completed his/her subjective evaluation, each subject's breath was captured for approximately 20 seconds with the breathing sensor. Processing was conducted on the images captured to determine if the image processing techniques used replicate similar results to the subjective evaluations of each participant.

A total of 11 subjects were used in the experiment consisting of 3 females and 8 males. Ages of subjects ranged from 19 to 27 with a mean of 22.27 and a standard deviation of 2.0.

Preliminary results are represented in Table 1 and Fig. 5. The columns of Table 1 show case number for each patient (Case), the subjective measurement made by each patient (Subj), the left over right intensity ratio (L/R_Int), the left over right relative intensity ratio (Rel_Int_L/R), the left over right area ratio, and the left over right relative area ratio (Rel_Area_L/R). Relative intensity ratio (Rel_ratio) of two parameters L and R is calculated as:

TABLE I
EXPERIMENTAL ANALYSIS RESULTS

Case	Subj	L/R_Int	Rel_Int_ L/R	L/R_Area	Rel_Area _L/R
1	6	0.49	0.86	0.21	-0.65
2	6	0.65	0.81	0.37	-0.47
3	7	0.76	0.74	0.42	-0.41
5	7	0.98	0.85	0.96	-0.02
6	2	1.12	0.81	1.79	0.28
13	1	1.36	0.86	1.88	0.31
12	6	1.12	0.65	0.65	-0.22
9	2	1.41	0.72	1.69	0.26
11	7	1.18	0.70	0.42	-0.41
8	8	0.66	0.56	0.59	-0.26
7	8	0.75	0.92	0.39	-0.44
Mean	5.40	0.93	0.75	0.94	-0.17
STdev	2.26	0.29	0.11	0.81	-0.38

$$\text{Rel\_ratio} = (L - R) / (L + R) \tag{1}$$

It should be noted that the relative ratio does not represent linear change of the ratio. For example, if the value of L = 2R Rel_ratio will be 0.33, while L = 4R generates value of 0.6.

Correlation of calculated parameters and subjective evaluation is presented in Fig. 5. The x-axis represents the subjective measurement of nostril dominance as selected by each participant before measurements were taken. The y-axis represents ratio of left and right average intensity values (red circles) and the relative difference ratio of left and right area values (blue triangles).

It is observable through the results that subjects with pronounced nostril dominance also have significantly different values for area and intensity ratio. Since we calculate left/right ratio, left nostril dominance exhibited values larger than 1 (upper left quadrant) while right nostril dominance exhibited values smaller than 1 (lower right quadrant) in Fig. 5. Experimental measurements were approximated with the linear functions. Relative intensity and area can be represented as:

$$\text{Rel\_Int\_L/R} = 1.4131 - 0.0844 \cdot \text{Subj} \tag{2}$$

$$\text{Rel\_Area\_L/R} = 2.069 - 0.223 \cdot \text{Subj} \tag{3}$$

It can be seen that the relative area (Rel_Area_L/R) much better correlates with the subjective estimate of nostril symmetry. This can be also seen from the standard deviation in Table 1. However, it should be noted that the subjective estimate poorly represents the actual airflow as subjects with permanent nostril deviation perceive relative symmetry differently than subjects with balanced airflow and normal rhythmic change in nostril dominance.

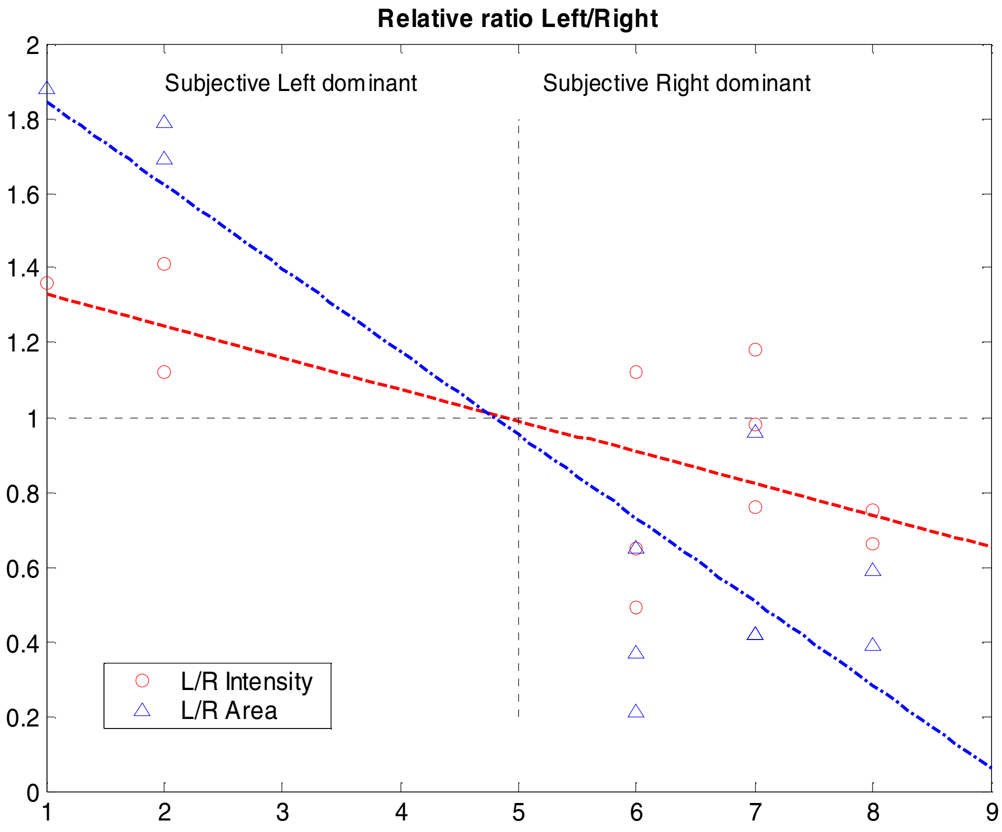

Fig. 5. Relative difference ratio vs. subjective self-measurement.

IV. Discussion and Conclusions

We present a new method of optical analysis of breathing based on temperature response of nostril breath on thermal film. Our results have shown that subjective estimates given by the subjects are in good correlation with parameters generated by image processing provided the subject does not have permanent nostril deviation. Preliminary results indicate that this is a viable method for breathing quantification. Based on the results of the preliminary analysis, the area seems to be a better indicator of the nostril flow than the average intensity. One of the issues influencing absolute value of parameters is ambient temperature. Relative temperature difference will influence both size and color of the image, as represented in Fig. 3. However, relative ratio between nostrils cancels the effect of the ambient temperature. Future work will include further analysis using the relative difference ratio and alternative image processing techniques. We believe that this method could be used for the quantification and analysis of diurnal, tidal, and circadian physiological cycles.

References

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