Non-Contact Thermal Medium-Based Breathing Analysis

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ABSTRACT

Respiratory monitoring is used in medical applications to detect abnormal breathing conditions. In sleep studies, respiration monitoring detects disorders such as obstructed breathing and sleep apnea. Respiration monitoring methods either place sensors on the patient's body, causing discomfort and altering natural breathing, or they measure respiration remotely at the cost of accuracy. We present a method of non-contact analysis that monitors respiration directly and remotely. We place a thin medium perpendicular to the individual's face, and record the heat signature from their breath on the material using a thermal camera. We then use image processing to extract respiratory behaviors.

INTRODUCTION

Respiration monitoring techniques are often a tradeoff between accuracy and patient comfort. Contact methods provide accurate results, but require direct contact with the patient's body, which results in discomfort and unnatural breathing behaviors. Popular contact methods include:

- ECG electrodes on the patient's body [5]
- Thermistors in the patient's nose [7]
- Abdominal strain-gauge transducer[5]
- Polysomnography [2]

Non-contact methods have the opposite problem: they provide a comfortable experience, but are less accurate. These methods often utilize remote sensors such as:

- Cameras [8][10]
- Volumetric sensors [9]
- Microphones [6]
- Radar [3]

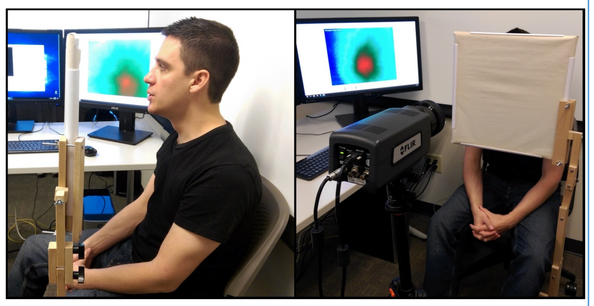

Figure 1: Medium-based respiration monitoring setup.

We propose a method of respiratory analysis that is non-contact, but gives more accurate results than other contact methods by measuring respiration directly. We have the patient breathe onto a thin medium, and record the thermal signature on the medium with a thermal camera. We then use image processing to extract information about breathing behavior. Figure 2 illustrates this process.

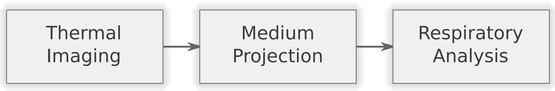

Figure 2: Method overview of medium projection-based thermal respiration analysis.

Using this technique, we can extract breathing activity information such as:

- Breathing rate and pattern
- Nose to mouth distribution
- Exhale strength and flow

This method has several advantages over other non-contact methods, including:

- Direct measurement and comprehensive analysis of breathing activity
- Ability to monitor individuals of various ages and sizes, including young children
- Algorithm works independently of hardware
- Ability to be deployed as a small, inexpensive standalone device

METHOD

To visualize respiration, we have the patient breathe onto a medium and record the exhale pattern on the medium. We see a stark contrast between the medium and the exhale thermal signature because the human exhale is generally warmer than the surrounding environment. Figure 3 shows a series of thermal images taken during the course of a normal exhale.

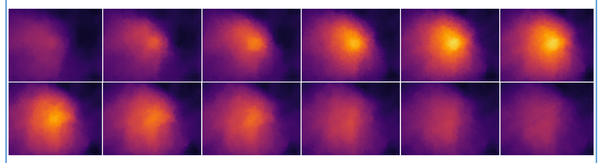

Figure 3: Thermal images taken during the course of one exhale.

The performance of this method relies on the choice of medium material. The ideal material should be:

- Thermally conductive to allow for rapid thermal dissipation
- Insulative enough to retain heat signatures long enough to capture
- Large to encompass the thermal signature from the nostrils and the mouth
- Thin to promote dissipation through the material
- Thermally opaque to block out the face of the subject
- Highly emissive so that the heat signatures can be accurately recorded
- Evenly and finely textured
- Common, inexpensive, and widely available.

We compared cotton, linen, and standard copy paper as medium materials. These materials have similar thermal properties, but we chose copy paper because it is the most thermally opaque and had the finest texture and smoothest surface. Figure 4 shows a comparison of the thermal signatures from these materials.

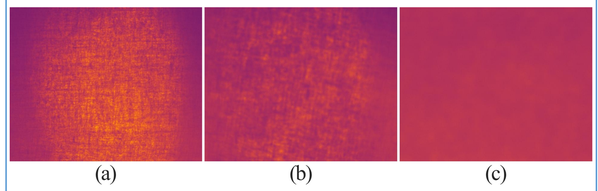

Figure 4: Medium materials (a) cotton, (b) linen, and (c) copy paper.

Another factor that contributes to the accuracy of this method is the distance between the medium and the patient. Further distances require a larger medium, introduce more delay, and heat may dissipate more before reaching the medium. Closer distances result in less dissipation, and smaller delay, but may make the patient uncomfortable. Through experimentation, we chose a distance of 3-6 inches for our experiments.

To calculate breaths per minute, we sum the increasing temperatures for each frame over the course of several seconds, multiply these values by a Hamming window, and then perform an FFT of this data. The frequency with the highest amplitude indicates the breathing rate in hertz, which is converted to breaths per minute by multiplying this value by 60. Figure 5 shows an example of finding the breathing rate from this data.

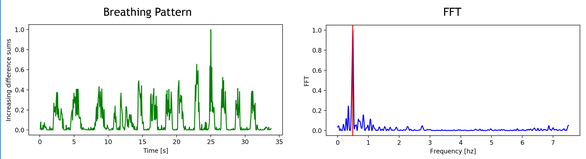

Figure 5: Breath rate can be determined by calculating the increasing temperature sums of the breathing data (left) and performing an FFT of this data (right).

The proposed technique has been used to study the nasal cycle by comparing the thermal signature of each nostril [1]. In this method, patients exhale through their nose onto a thermochromatic liquid crystal film, and images are taken of the opposite side. Our method improves upon this technique by using a thermal camera and image processing techniques, neither of which were available at the time the initial experiment was conducted. Our technique also extracts more metrics than the previous experiment.

EXPERIMENTAL DESIGN

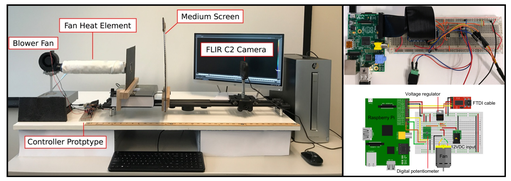

Figure 6: Fan experimental setup (left) and Raspberry Pi electronics design (right).

The first experimental setup uses a Raspberry Pi controlled fan and a FLIR C2 thermal camera. The fan blows air through a heated tube to simulate breathing activity. This setup allows us to control fan timing, duration, and strength so that we can assess the accuracy of our method. Figure 6 shows the fan experiment setup.

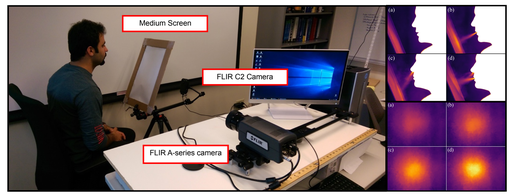

Figure 7: Human experimental setup (left), images from FLIR A-series camera (top right), and images from FLIR C2 camera (bottom right).

In our second experimental setup, human subjects are studied to see how our method works under real-world conditions. Two thermal cameras are used for the human study: a FLIR A-series camera that can visualize CO2 gas that views the exhale from the side, and a FLIR C2 camera that records the medium. Figure 7 shows the human experiment setup.

We have developed a graphical user interface (GUI) that displays the thermal data and breathing rate in real time. Figure 7 shows the breathing rate monitor GUI.

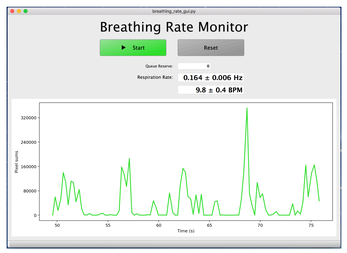

Figure 8: The breathing rate monitor plots exhale activity in real time, and calculates respiration rate.

RESULTS

We conduct three 60 second trials for each experimental setup and record the BPM statistics for each trial. In the fan experiment, the fan is set to a constant 10 BPM. For the human experiment, we process both the side thermal view and the medium thermal view in the same way to see how both the data sets correlate. Figure 9 shows the results from the fan experiment and the human experiment.

Fan Experiment Results		
Sample	Mean	Std. Dev.
1	10.000	0.203
2	9.996	0.159
3	10.008	0.160

Human Experiment Results from Medium and Reference				
Sample	Medium Mean	Side Mean	Medium Std. Dev.	Side Std. Dev.
1	17.455	17.581	1.346	1.205
2	10.509	10.801	0.471	0.270
3	10.577	10.299	0.398	0.294

Figure 9: Breaths per minute statistics from fan experiment (left) and the human experiment (right).

The fan results show that under ideal conditions, the method has an accuracy of +/- 4%. The human data also shows a strong correlation between the medium thermal view and the side thermal view. Figure 10 shows two plots of this correlation.

RESULTS (cont.)

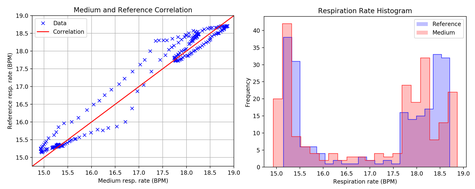

Figure 10: Two views of the correlation between the medium thermal view and the side thermal view.

This method can also be used to provide other information about respiration besides breathing rate. Nose to mouth distribution measurements can be obtained by filtering the images and using clustering algorithms to segment the image into the heat signatures from the mouth and each nostril. The breathing strength of the individual can be determined by using optical flow to determine the heat spread across the medium. If stacked over time, these images can also be used to create a 3D reconstruction of the exhales, which could aid in determining exhale volume. Figure 11 shows images of these different processing methods.

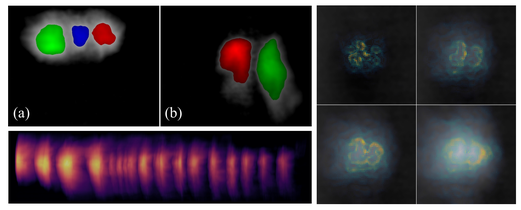

Figure 11: This method can be used to determine nose to mouth distribution (top left), exhale strength (right), or to create a 3D reconstruction of the exhales (bottom left).

CONCLUSION

This method of non-contact respiration rate monitoring measures respiration directly, yet comfortably. It can accurately measure breathing rate, and provide other information such as nose to mouth distribution and breathing strength. This method is widely applicable to many clinical applications. The proposed technique represents a novel approach to respiration monitoring, providing a comprehensive and accurate analysis of breathing behavior while keeping the patient comfortable and preserving natural breathing.

ACKNOWLEDGMENTS

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