# Noncontact Estimation of Qualitative Flow Velocity in Nasal Breathing by using Far Infrared Imaging

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***Abstract*-- In this research, we propose a method for non-contact estimation of qualitative flow velocity in nasal breathing by using far infrared (FIR) imaging. Our proposed method consist of two kind of function: estimation of the strength of flow velocity and extraction of the region including nasal cavity on FIR images. According to the result of experiments, the accuracy of our proposed estimation was ranged from 67% to 100 %. Moreover, the accuracy of our proposed extraction was ranged from 73% to 82%.**

## I. INTRODUCTION

The technics for vital information sensing have been one of the hot issues in the area of information and communication technology. Especially, measurement of human breathing is an important technique when we construct future home healthcare systems.

In this research, we study a method for non-contact measurement of human breathing by using far infrared (FIR) imaging. There have been several researches on measurement of human breathing by noncontact manner (for example [1]). A few researches have shown that FIR imaging was useful for monitoring of breathing [2]-[4]. However, measurement of flow velocity by using FIR imaging, has not been studied. First, we propose a method to estimate the qualitative strength of flow velocity in nasal breathing based on the change in temperature of nasal region extracted from FIR images. Next, we propose a method to extract the region including nasal cavity on FIR images by using the variance of temperature in each pixel over the latest several frames of FIR images. Finally, we evaluate the accuracy of these methods based on the results of evaluation experiments.

## II. ESTIMATION OF THE STRENGTH OF FLOW VELOCITY IN NASAL BREATHING

### *A. Proposed method*

We assumed that the strength of flow velocity in a user's nasal breathing can be classified as one of the five states: (a) No breathing, (b) Normal exhalation, (c) Strong exhalation, (d) Normal inhalation and (e) Strong inhalation. Estimation process for estimating the above strength is the following.

**Step 1:** FIR images including a user's face are captured by an FIR camera.

**Step 2:** The regions including nasal cavity are extracted as Region of Interest (ROI) from each FIR image.

**Step 3:** Average temperature at time $t$ for ROI is calculated. The average temperature per pixel of ROI at time $t_i$ $(i=1, 2, ...)$ is presumed as $A(t_i)$.

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**Step 4:** A moving average of $A(t_i)$ is calculated for smoothing of data:

$$A'(t_i) = (A(t_{i-m})+\ldots+A(t_i)+\ldots+A(t_{i+m})) / (2m+1). \quad (1)$$

**Step 5:** The velocity of temperature's change in nasal cavity at time $t_i$ is calculated by backward difference of $A'(t_i)$:

$$V(t_i) = (A'(t_i) - A'(t_{i-1})) / (t_i - t_{i-1}). \quad (2)$$

Next, we find exhalation/inhalation start time $t_s$ and its end time $t_e$ by using $V(t_i)$.

**Step 6:** If both $t_s$ and $t_e$ are found, average of $V(t)$ between $t_s$ and $t_e$ is calculated by:

$$E_v(t_s, t_e) = (A'(t_e) - A'(t_s)) / (t_e - t_s). \quad (3)$$

**Step 7:** Nasal breathing from $t_s$ to $t_e$ is classified as follows.

**if** $A'(t) \fallingdotseq 0$ over a fixed period then "(a) No breathing"
**else if** $th_1 >= E_v(t_s, t_e)$ then "(b) Strong inhalation"
**else if** $th_1 < E_v(t_s, t_e) < 0$ then "(c) Normal inhalation"
**else if** $0 < E_v(t_s, t_e) < th_2$ then "(d) Normal exhalation"
**else if** $E_v(t_s, t_e) < th_2$ then "(e) Strong exhalation"

### *B. Experiments*

An examinee sat in front of the FIR camera (NEC/Avio, TH7102MX, 320x240 pixel, 30fps) in a room (Fig. 1). We asked for each examinee to breathe under four kind of scenarios via the nose while being recorded: (i) Normal inhalation and normal exhalation, (ii) Strong inhalation and normal exhalation, (iii) Normal inhalation and strong exhalation, and, (iv) No breathing. Based on the preliminary experiments, we empirically determined the parameters described in previous subsection as follows: $m=7$, $th_1=-1.8$ ˚C /s, and $th_2=1.5$ ˚C /s. In these experiments, we manually extracted ROIs on each frame.

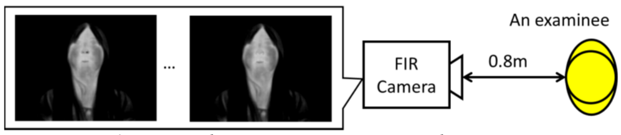



*Fig. 1. Position between an FIR camera and an examinee*

Table I shows the results of accuracy (confusion matrix) in our proposed method for four examinees with ages from 21 to 22 years. We calculate accuracy of proposed by using confusion matrix. In Table I, the cells colored in yellow mean correct classification. According to the result of experiments, proposed method scored mostly good results.

TABLE I EXPERIMENTAL RESULTS

| | | Result of estimation by proposed method | | | | |
|---|---|---|---|---|---|---|
| | | (a) No breathing | (b) Strong inhalation | (c) Normal inhalation | (d) Normal exhalation | (e) Strong exhalation |
| Actual State | (a) | 87.5% | 0.0% | 0.0% | 0.0% | 0.0% |
| | (b) | 0.0% | 66.7% | 33.3% | 0.0% | 0.0% |
| | (c) | 0.0% | 16.7% | 83.3% | 0.0% | 0.0% |
| | (d) | 0.0% | 0.0% | 0.0% | 85.7% | 14.3% |
| | (e) | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |

## III. Extraction of Nasal Cavity

### *A. Proposed method*

In usual case, temperature on inside wall of nasal cavity undergoes change continuously over time by breathing via nose. We use this characteristic for detection of nasal cavities. We supposed that a position of a user's face on FIR images is stable while measurement. This extraction process for estimating the above strength is the following.

**Step 1:** Variance of temperature from $t_{i-n+1}$ to $t_i$ in each pixel over the latest $n$ frames of FIR images are calculated by following equations:

$$v_n(x,y,t_i) = \frac{1}{n}\sum_{k=i-n+1}^{i}\left(f(x,y,t_k) - e_n(x,y,t_i)\right)^2, \quad (4)$$

$$e_n(x,y,t_i) = \frac{1}{n}\sum_{k=i-n+1}^{i} f(x,y,t_k). \quad (5)$$

Here, $f(x, y, t)$ is a FIR image captured at time $t$.

**Step 2:** Binarize process using a threshold.

$$g_n(x,y,t_i) = \begin{cases} 1 & (v_n(x,y,t_i) \geq th_t) \\ 0 & (v_n(x,y,t_i) < th_t) \end{cases} \quad (6)$$

Here, $th_t$ is a threshold to discriminate between pixels that seem to be on nasal cavity and the others.

**Step 3:** Candidate regions are segmented by labeling process to the above binarized image $g_n(x, y, t_i)$.

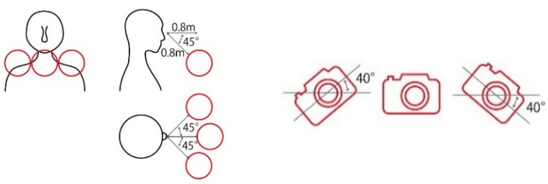
**Step 4:** For each region segmented by Step 3, area size, roundness and the average temperature per pixel are calculated.

**Step 5:** Threshold processing using these values is applied to exclude regions which are judged as not suitable for nasal cavity from the candidate regions.

### *B. Experiments*

Experiments were conducted to evaluate the accuracy of proposed extraction method. FIR images were captured by an FIR camera with the following conditions. Each subject was asked to breathe in the following three scenarios via the nose while being recorded. (a) Normal exhalation and normal inhalation, (b) Strong exhalation and normal inhalation, and (c) Normal exhalation and strong inhalation. Fig. 2 shows experimental conditions on camera setting. We employed three kind of camera positions and three kind of rolling angles for recorded breathing of an examinee. FIR images from five subjects (five females with ages from 21 to 22 years) were acquired in totally 27 conditions. Based on the preliminary experiments, we calculate threshold $th_t$ for binarize process as follows:

$$th_n(t_i) = \frac{1}{30}\max_{0\leq x\leq 320, 0\leq y\leq 240} v_n(x,y,t_i). \quad (7)$$




(a) distance and position (b) rolling angle

Fig. 2. Experimental conditions on camera setting

Based on the human body properties database [5], we set the conditions to select candidate regions as follows:

- Area size: 12 $pixel^2$ ~ 104 $pixel^2$,
- Roundness: 1/1.9 ~ 1,
- Average temperature per pixel: more than 32.9 ℃.

Fig. 3 shows the results of accuracy in our proposed method. Fig. 4 shows an example of the result of ROI extraction. According to the result of experiments, proposed method scored mostly good results. Moreover, proposed method has a fixed robustness for camera position, rolling angle and a way of breathing.

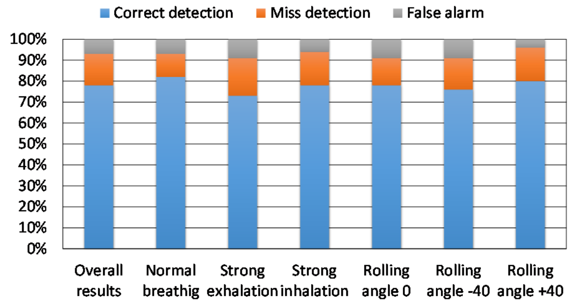



Fig. 3. Experimental results


(a) FIR images (b) Result of labeling (c) Result of extraction

Fig. 4. Extraction of ROI from FIR images

## IV. Conclusion

In this research, we propose methods for noncontact estimation of qualitative flow velocity in nasal breathing by using far infrared imaging. This work is a basic study to achieve an automatic remote monitoring for human breathing. We showed that our proposed estimation for the flow velocity is rather accurate. We also showed that our proposed extraction is mostly feasible under the condition that a position of a user's face on FIR images is stable.

In future work, we will study how to improve the accuracy and the robustness for body movement. We plan to combine the proposed method with other object detection method based on machine learning.

## Reference

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