CAMERA BASED ESTIMATION OF RESPIRATION RATE BY ANALYZING SHAPE AND SIZE VARIATION OF STRUCTURED LIGHT

Vishnu Vardhan Makkapati

Myntra Designs Pvt. Ltd.
Bangalore - 560068, India
Email: vishnu.makkapati@myntra.com

Sai Saketh Rambhatla

Department of Electrical Engineering
Indian Institute of Technology, Kharagpur-721302
Email: rssaketh@iitkgp.ac.in

ABSTRACT

Respiration rate is a key parameter that is monitored in intensive care units. The current solutions for respiration rate require that a sensor is placed in contact with the subject to derive it. However, this will cause discomfort to the subject and may damage the fragile skin if the subject were a neonate. There are several other applications where the respiration signal is used in clinical settings. The respiration signal is used to correct for organ motion during diagnosis scans, e.g., computed tomography. It is expected that the respiration signal results in clear peaks and troughs during the breathing cycle of the subject so that these corrections can be made. We propose a contactless system and method by using a camera to derive a faithful respiration signal. We project a circular dot of light onto the chest and abdomen region of the subject and monitor the shape and size changes of it using a camera. In an oblique projection of the structured light, both the shape and size of the dot will vary with breathing. We segment the dot and derive the respiration signal from it. Numerical results presented show that we are able to obtain the respiration rate accurately.

***Index Terms*—** Respiration rate, camera, structured light, segmentation, size and shape change

1. INTRODUCTION

Respiration rate (RR) monitoring of subjects is routinely performed in clinical settings, particularly in intensive care units (ICU). Patient monitor is the preferred device for RR monitoring and it requires that ECG electrodes be put on the subject. However, this may cause discomfort to the subject and may peel off the fragile skin of the neonates. Hence touchless ways of monitoring RR are desired.

The respiration signal is used in several other clinical procedures e.g., diagnosis scans using computed tomography (CT) and radiation therapy [1]. Four-dimensional CT imaging technology has been developed for radiation therapy to provide tumor and organ images at the different breathing phases. However, the motion of organs/tumors with breathing is a concern. Motion poses a number of serious problems, including inaccurate target definition (moving targets may appear with distorted shapes and in wrong locations on CT). Increased irradiation of normal tissues is also common since larger fields are often used to ensure that the tumor is not missed [2]. Respiratory gating is commonly performed to correct for the motion of the organs during the diagnosis and therapy procedures.

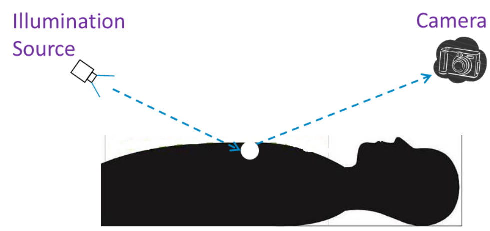


Fig. 1. Schematic showing structured light and camera.

Two devices are commonly used for sensing respiratory movements for the purpose of CT gating. One is the air bellows belt [3] and the other is a six-dot marker block used in conjunction with an infrared tracking camera [4]. These respiratory sensors are placed on the patient's chest or abdomen prior to the CT procedure. However, both of them require preparatory time to place them on the subject and the results vary depending on their placement. Hence methods that offer robust respiration signal with minimum preparation time are required.

Camera lends itself nicely to monitor the respiration rate of the subject [5] and several camera based solutions have been proposed recently. In this paper, we propose a structured light based approach to monitor RR. Hence we restrict our literature review to these methods only. The methods that use structured light including a Microsoft Kinect device can be broadly classified into two classes:

1. The first set of methods reconstruct the 3D depth [6, 7, 8] to get the 3D volume of the subject. The respira-

Patent pending. This work was performed when V. Makkapati was with Philips Research India and S.S. Rambhatla was an intern there.

(a) Exhalation (b) Inhalation

Fig. 2. Example frames showing shape and size changes of structured light dot during breathing.

tory rate is estimated by the determining the variation in the volume of chest/abdomen. However, they require expensive hardware to process the 3D volume in real-time.

2. The second set of methods process the motion of structured light dots with breathing [9, 10]. However, estimating the motion of dots and deriving RR from them is also computationally expensive.

We propose a simple structured light based solution to estimate respiratory rate using a camera. We project a structured light spot of circular shape on the subject (Fig. 1) and track the change in the geometry and size of the spot as the person breathes to derive RR. The system has the advantage of being computationally light with minimal hardware requirement.

2. PROPOSED SOLUTION

We exploit the fact that when structured light is projected onto the chest/abdomen region of a person, the size and geometry of the light changes during breathing (Fig. 2). When we monitor this change over the breathing cycle, it will faithfully represent the respiration signal of the subject.

We project a circular spot onto the chest/abdomen region of the subject lying on a bed. The original spot is circular but when it is projected onto the chest/abdomen at an angle, it becomes slightly elliptical (Fig. 1). When the subject breathes, the shape and size of the spot varies in a periodic fashion that is in sync with the breathing pattern. We use parameters that describe the change in shape and size of the spot to obtain the respiration signal at a given frame.

Since we are interested in monitoring a spot of light, a monochromatic camera is used. We segment the spot of light projected onto the chest/abdomen region. It has been extensively studied and reviewed [11, 12] that the morphological operation of opening applied on a grayscale image with a suitable structuring element highlights the spots in the neighborhood. A spot in a grayscale image is defined as a bright area surrounded by a darker one. In order to isolate such spots, we use a White Top-Hat morphology operator [12] (Fig. 3).

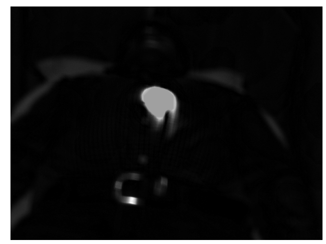


Fig. 3. Response to a morphological top-hat operator using a disc structuring element of size 36×36.

After applying the operator, we obtain a threshold using Otsu's method [13] and threshold the grayscale image to obtain a binary image. Since the operator highlights any bright area in the neighborhood, we noticed that a good number of false positives were also detected (Fig. 4).

We filter the false positives, by removing those blobs whose basic geometric, size and position properties do not match that of the projected light spot. For a certain mounting of the illumination source and camera, we know the minimum and maximum area of the spot in an image. Hence we first remove all the blobs that fall beyond this range. We also observe that the elongation of the spot, defined as ratio of width to height, rarely exceeds a certain threshold. Hence we remove all the blobs whose elongation is beyond this value. Since the position of the spot is more or less at the center of the frame, the region around the center of the frame can be searched to detect the projected spot (Fig. 4).

It can be clearly seen from the Fig. 2 that both the size and shape of the spot varies as the person breathes. We can compute several shape (major axis, minor axis, form factor) and size (area, perimeter) metrics for the segmented spot. The form factor m is defined as

$$m = \frac{4\pi A}{P^2} \tag{1}$$

where A and P are the area and perimeter of the spot respec-

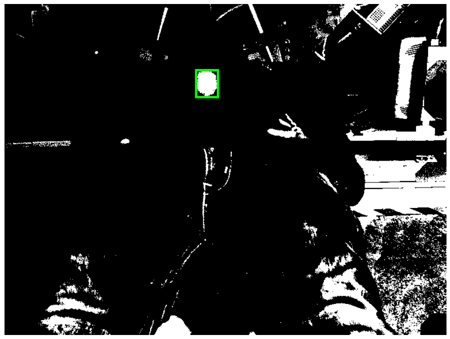


Fig. 4. Detection of the spot in ambient illumination.

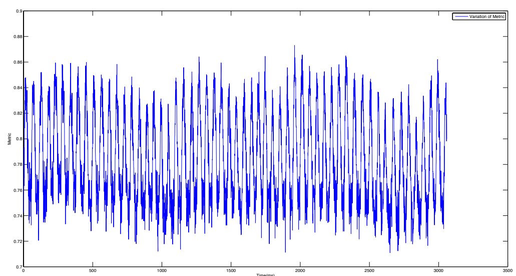


Fig. 5. Plot of form factor vs. time.

tively. The form factor will be 1 for a circle and close to 0 when the shape largely deviates from a circle. Hence as the subject breathes, the value of m will vary between a value from 0 and 1 (Fig. 5). Though this signal has characteristics of a respiration signal, it suffers from noise. Hence we compute the other shape (major and minor axes length) and size (area and perimeter) parameters of the segmented spot (Fig. 7). From these plots, we observe that the major axes length (Fig. 7(a)) (length of the spot along the line of sight of the camera) gives a faithful estimate of the respiration signal that does not suffer from noise.

We compute the Fourier transform of the respiration signal to calculate the respiratory rate (Fig. 6). The signal had a high DC offset which had to be removed while calculating the rate. The Fourier transform of the signal will have a peak at 0 frequency (DC) and also some peaks at the fundamental frequency of the respiratory signal and its harmonics, till half of the sampling frequency. The DC value of the transform is removed and the next largest peak in the profile is taken as the respiratory rate since the magnitude of the harmonics is very small in the signal.

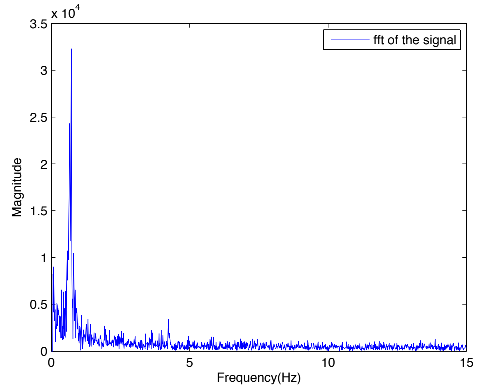


Fig. 6. Fourier transform of the signal in Fig. 5 after DC removal.

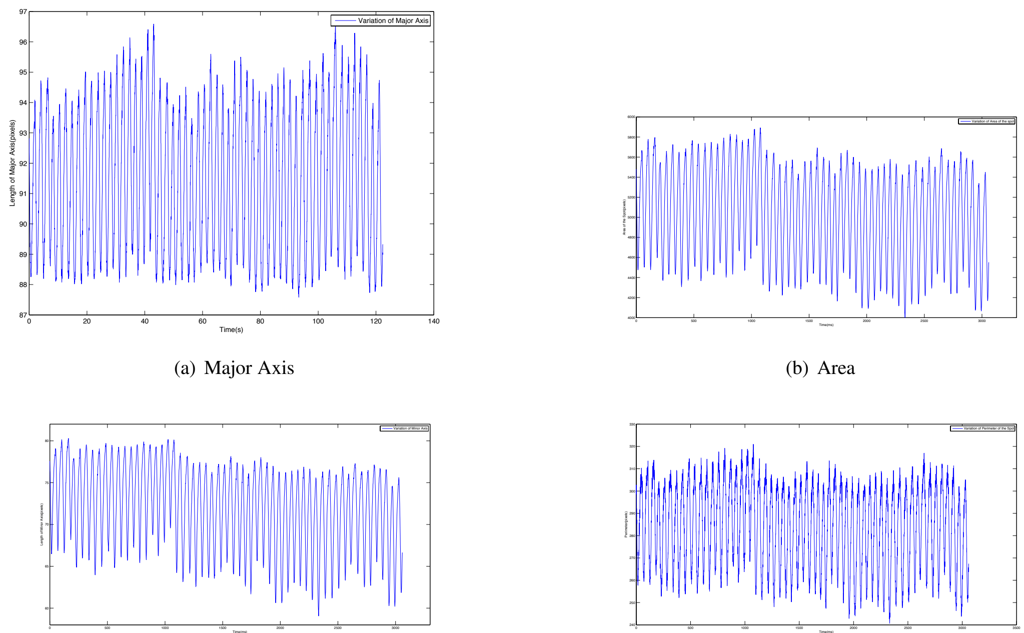
Table 1. Comparison of RR results

Video No.	Calculated Rate (breaths per minute)	Observed Rate (breaths per minute)
1	14	14
2	14	15
3	13	14
4	19	19
5	20	19
6	20	20
7	21	20

3. PERFORMANCE EVALUATION

We evaluated the performance of our scheme using several videos taken from subjects in different illumination conditions. The camera used in our experiment was UI-2220SE from IDS Imaging. The camera is monochromatic, with a CCD sensor with an ADC resolution of 12bits. It requires a voltage input of 5V and captures frames at a constant rate.

The camera was used with a frame rate of 20. The spot was projected from a retractable super bright zooming flashlight. The experiment was conducted on various subjects in two different settings with variation in ambient illumination. To begin with, we used a dark room to test the hypothesis that the shape and size of the project light spot varies with breathing (Fig. 2 and Fig. 3). Then we experimented on the table of a CT device in our in house lab. The video feed analyzed was of a duration of 2-3 minutes. The normal respiratory rate of a healthy adult is in the range $12-20$ breaths per minute. We compare the results from our method with those observed manually from the video feed (ground truth). The results in Table 1 show that the RR from our method matches the ground truth well.



(a) Major Axis

(b) Area

(c) Minor Axis

(d) Perimeter

Fig. 7. Variation of other size and shape parameters of the projected spot.

4. CONCLUSION

We proposed a non-contact camera based respiratory rate estimation method using structured light. The shape and size variations of the projected spot with breathing were utilized to derive the respiration signal. This method is particularly useful in a CT scan setup. Instead of the white light used in our experiments, infrared light can also be used to achieve the same results. The method provides an accurate respiration signal that has potential to be used in various clinical applications.

5. REFERENCES

[1] P. J. Keall, G. S. Mageras, J. M. Balter, R. S. Emery, K. M. Forster, S. B. Jiang, J. M. Kapatoes, D. A. Low, M. J. Murphy, B. R. Murray, C. R. Ramsey, M. B. Van Herk, S. S. Vedam, J. W. Wong, and E. Yorke, "The management of respiratory motion in radiation oncology report of aapm task group 76a)," *Medical Physics*, vol. 33, no. 10, pp. 3874–3900, 2006.

[2] "4d computed tomography / respiratory gating," http://cancer.ucsd.edu/care-centers/radiation-oncology/procedures/Pages/respiratory-gating.aspx.

[3] P. S. P. Klahr and J. Yanof, "Respiration-correlated multiscale ct for radiation therapy planning: imaging and visualization methods," http://www.healthcare.philips.com/pwc_hc/main/about/assets/Docs/medicamundi/mm_vol49_no3/mm_49-3_Klahr.pdf.

[4] V. M. Systems, "Real-time position management system," https://www.varian.com/sites/default/files/resource_attachments/RPMSystemProductBrief_RAD5614B_August2007.pdf.

[5] A. Venkitaraman and V. Makkapati, "Motion-based segmentation of chest and abdomen region of neonates from videos," in *International Conference on Advances in Pattern Recognition*, Jan 2015, pp. 1–5.

[6] H. Aoki, M. Miyazaki, H. Nakamura, R. Furukawa, R. Sagawa, and H. Kawasaki, "Non-contact respiration measurement using structured light 3-d sensor," in *SICE Annual Conference (SICE), 2012 Proceedings of*, Aug 2012, pp. 614–618.

[7] F. Benetazzo, A. Freddi, A. Monteri, and S. Longhi, "Respiratory rate detection algorithm based on RGB-D camera: theoretical background and experimental results," *Healthcare Technology Letters*, vol. 1, pp. 81–86(5), September 2014.

[8] L. K. MESTHA, E. A. BERNAL, and B. XU, "Process-

ing a video for respiration rate estimation," U.S. Patent 20 130 324 875, June 21, 2012.

[9] M. Martinez and R. Stiefelhagen, "Breath rate monitoring during sleep using near-ir imagery and pca," in *Pattern Recognition (ICPR), 2012 21st International Conference on*, Nov 2012, pp. 3472–3475.

[10] F. J. D. Bruijn, A. Heinrich, and R. Vlutters, "Respiratory motion detection apparatus," U.S. Patent 20 130 035 599, April 13, 2011.

[11] J. Serra, *Image Analysis and Mathematical Morphology*. Orlando, FL, USA: Academic Press, Inc., 1983.

[12] F. Meyer, "Contrast features extraction," *SPIE MILESTONE SERIES MS*, vol. 127, pp. 139–145, 1996.

[13] N. OTSU, "A threshold selection method from gray-level histograms," *Systems, Man and Cybernetics, IEEE Transactions on*, vol. 9, no. 1, pp. 62–66, Jan 1979.