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Non-contact Respiration Measurement Using Structured Light 3-D Sensor

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Abstract: We have examined a non-contact respiration measurement using Kinect, that is 3D sensor based on structured light, in order to decrease the burden of the pulmonary function test. In our proposed method, the respiratory waveform is produced from the volume change of thoracoabdominal part of examinee measured by the three-dimensional measurement function of Kinect. In this paper, we examine the validity of our proposed method by simultaneous measurement with the expiration gas analyzer and the flow meter. The experimental results implies that quantitative respiration measurement without contact-type sensor is realized by Kinect.

Keywords: Respiration measurement, non-contact physiological measurement, 3-D measurement, structured light.

1. INTRODUCTION

In the pulmonary function test, the function of respiratory gas exchange and air infiltration is examined. The pulmonary function test by the spirometer is generally conducted. In this test, the respiratory compromise is diagnosed by the forced expiratory volume 1.0% and % vital capacity for screening the chronic obstructive pulmonary disease (COPD). The examinees, especially children, women and older people, sense the restraint sensation, because the mouthpiece and the nasal plug must be attached to the face of the test subject under the test. Measurement failures by leaking air-flow happen occasionally. And, it is necessary to change a mouthpiece at every measurement. Therefore, the operation of the pulmonary function test is difficult in a general medical examination to intend for many subjects.

We have studied the respiration measurement using the dot-matrix pattern projection in order to decrease the burden of the pulmonary function test to the examinee [1]-[3]. In our proposed system, the pattern light projector irradiates the thorax with the dot-matrix pattern light. And the CCD camera takes a time-series images of the dot-matrix pattern light. The 3-D shape of the thorax surface can be calculated by the distribution of the dot-matrix pattern. The respiratory waveform is calculated by the time-series volume change of the body surface [4].

The change of the 3-D shape calculated by our system should be the alternate index of the vital capacity for the realization of the non-restraint pulmonary function test. We had examined the relationship between the respiratory flow volume and the volume change of the thorax surface. In the comparative experiments with the spirometer, we compared the volume change of the thorax surface with the flow volume. As a result of comparing the volume change of the thorax surface with the respiratory flow volume, the volume change is linearly related to the respiratory flow volume [5].

In our proposed method, the light projector of the dot-matrix pattern is consist of the Fiber diffraction Grating (FG), which is proposed by Machida et al. [6].

The 3-D sensor with the FG are not mass-produced, and the sensor must be assembled by our hand. The development of sensor by hand is unfavorable with development speed and cost. Difficulty of the development is obstruction of the collaborations with medical researchers.

Meanwhile, Microsoft corporation released Kinect which was the 3-D sensor by using the structured light as like our proposed sensor with FG in December, 2010. Kinect is a low-priced interface for home-use game console. The Software Development Kit for Kinect is prepared from Microsoft corporation and we can use Kinect by a PC connected by the USB connector. Kinect attracts attention in various research fields, since procurement and use are easy.

We except that the COPD screening at the general medical examination and at the home are realized if a non-contact respiration measurement with Kinect in substitution for our proposed sensor with FG is possible. In this paper, we propose a new non-contact respiration measurement by using Kinect and examine the validity of our proposed method by simultaneous measurement with the expiration gas analyzer and the flow meter.

2. METHOD

2.1 System configuration

In this research, the non-contact respiration measurement is executed with the measurement system shown in Fig. 1. During the measurement, the examinee sit back so as not to appear the body movement except the respiratory movement. Kinect is arranged in the front of sitting examinee. The distance between the bearing surface end and Kinect is set at 1,200mm. The installation height of Kinect is set at 1,100mm. The height of the bearing surface is 500mm.

Kinect is mainly consist of a color camera, an infrared camera, and a pattern light projector. Kinect simultaneously acquires depth image of QVGA with color image of VGA. The depth information acquired by Kinect is 13bits information and the depth value at each pixel is calculated with millimeter order. The specifications of Kinect is shown to Table I [7].

In this system, Kinect is connected to the PC by USB cable. We developed the measurement software with Kinect for Windows SDK Beta distributed by Microsoft Research.

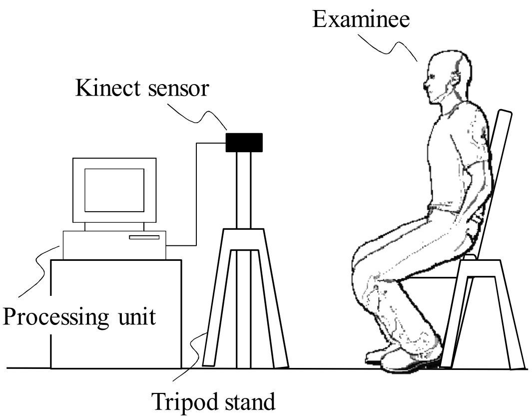


Fig.1 System configuration.

TABLE I
SPECIFICATION OF KINECT

Item	Specification
Range of color and depth stream	1.2 to 3.5 meters -
Range of skeletal tracking	1.2 to 3.5 meters -
Viewing angle	43 degrees vertical/ 57 degrees horizontal
Mechanical tilt range	27 degrees (vettical)
frame rate	30 frames per second
Resolution, depth stream	QVGA(320 x 240)
Resolution, color stream	VGA(640 x 480)

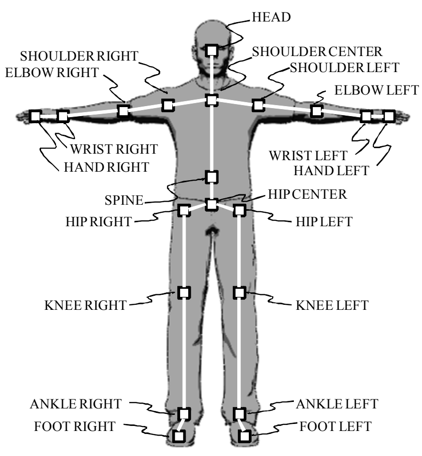


Fig.2 Joints of skeleton.

2.2 Non-contact respiration measurement by Kinect

The procedure for measuring respiration without contact by using Kinect is shown below.

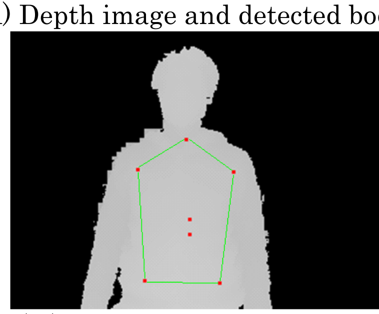
First, the examinee sits down in front of Kinect. Then, the system acquires the depth image, and the body area of examinee is detected till the examinee sits down. the skeleton is simultaneously extracted from the detected body area. Kinect possesses the function for detecting the body area and extracting the skeleton.

The skeleton consists of 20 joints such as "HEAD", "SHOULDER CENTER", "SHOULDER RIGHT", "SHOULDER LEFT", "ELBOW RIGHT", "ELBOW LEFT", "WRIST RIGHT", "WRIST LEFT", "HAND RIGHT", "HAND LEFT", "SPINE", "HIP CENTER", "HIP RIGHT", HIP LEFT", "KNEE RIGHT", "KNEE LEFT", "ANKLE RIGHT", "ANKLE LEFT", "FOOT RIGHT", "FOOT LEFT" as shown in Fig. 2.

In our proposed method, the domain contained by "SHOULDER CENTER", "SHOULDER RIGHT", "SHOULDER LEFT", "HIP RIGHT" and "HIP LEFT" is defined as abdominal thoracoabdominal domain corresponding to the

(i) Color image.

(ii) Depth image and detected body.



(iii) Thoracoabdominal domain

Fig.3 Determination of thoracoabdominal domain.

thorax part and the abdomen part of the examinee, as shown in Fig. 3. And, respiratory waveform is calculated by finding a volume change with the breathing of the thoracoabdominal domain.

Fig. 4 shows the 3-D shape of thorax surface. The relationship between each pixel in the depth image and 3-D coordinate (X, Y, Z) in the real space is shown as the next equation based on the triangulation.

$$X = \frac{(x_p - p_h/2)\tan(\theta_h/2)}{p_h/2} z_p$$
$$Y = \frac{(p_v/2 - y_p)\tan(\theta_v/2)}{p_v/2} z_p \quad (1)$$
$$Z = z_p$$

where x_p is horizontal coordinate of the pixel, y_p is vertical coordinate of the pixel, z_p is depth value of the pixel, p_h is number of horizontal pixels, p_v is number of vertical pixels, θ_h is horizontal viewing angle of the depth sensor, and θ_v is vertical viewing angle of the depth sensor.

The volume of the thoracoabdominal domain is found by calculating the numerical integral of 3-D coordinate corresponding each pixel in the thoracoabdominal domain. And, the respiratory waveform is produced by calculating the time-series change of the volume of thoracoabdomial domain. Here, 3-D coordinates in the thoracoabdominal domain distribute discretely in the 3-D space. Therefore, the 3-D shape is calculated by applying the Delaunay triangulation with linear interpolation [8].

3. EXPERIMENT AND RESULT

We examined the validity of our proposed method by the simultaneous measurement with the expiration gas analyzer (AEROMONITOR AE-280S manufactured by Minato Medical Science Co., Ltd.). The expiration gas

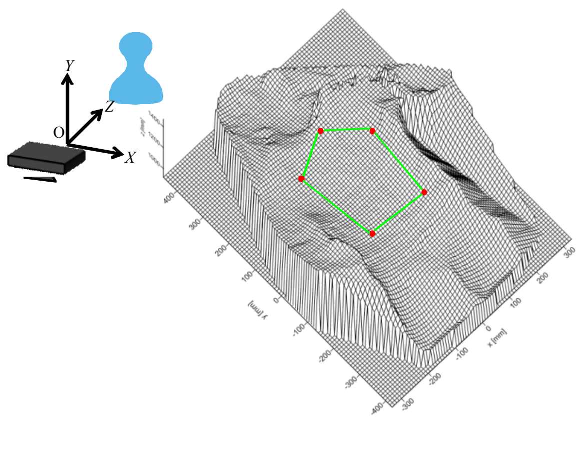
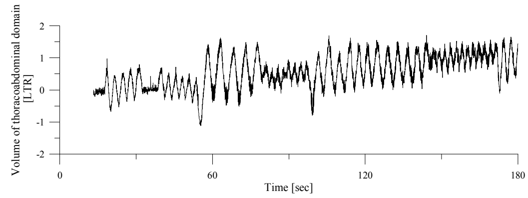
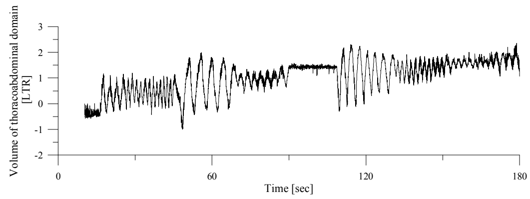


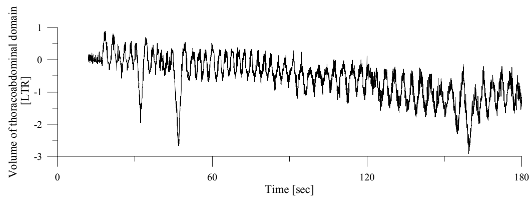
Fig.4 3-D shape of body surface.



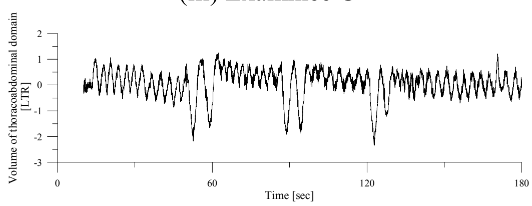
(i) Examinee A



(ii) Examinee B

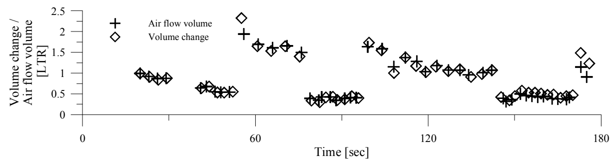


(iii) Examinee C

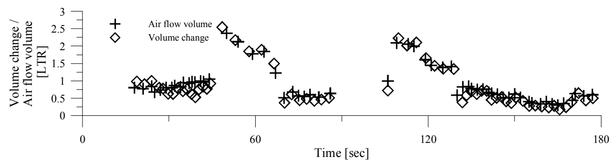


(iv) Examinee D

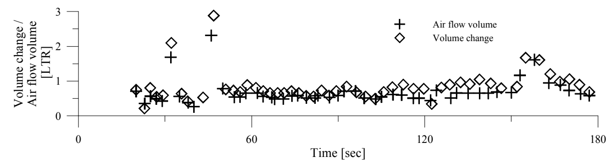
Fig.5 Respiratory waveform obtained by Kinect.



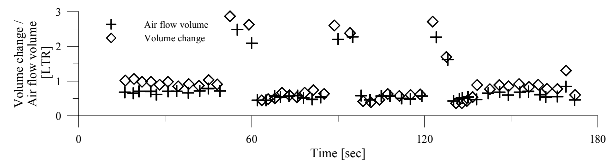
(i) Examinee A



(ii) Examinee B



(iii) Examinee C



(iv) Examinee D

Fig.6 Results of simultaneous measurement.

analyzer is generally used for the measurement of the respiratory flow volume, and it is widely utilized in the medical institution. The respiratory flow volume is measured by the expiration gas analyzer, with the mask-type sensor attached on the face of examinee.

Examinees are 4 healthy males (age: 34+/-4 years old, body weight: 72.4+/-6.1 kg). Prior to the measurement, we obtained the consent document on the measurement execution from the examinees. In the measurement, the examinees wear T shirt. The measurement time is set at 180 seconds. Examinees change the respiratory flow volume variously.

Fig. 5 shows respiratory waveforms obtained by Kinect. The peak-to-peak value of waveform corresponds to the tidal volume change with expiration / the tidal volume change with inspiration in the thoracoabdominal domain.

Fig.6 shows the change of the volume change obtained by Kinect and the expiratory flow volume measured by the expiratory gas analyzer. Both are almost similar in change trend.

Fig. 7 shows the correlation between the volume change by Kinect and the expiratory flow volume by the expiratory gas analyzer. We calculated the regression line and the correlation coefficient. Fitted line is a straight line through origin. All graphs show the volume change is highly correlated with the air flow volume. There was the high correlation over 098 between the volume change and the air flow volume in all examinees.

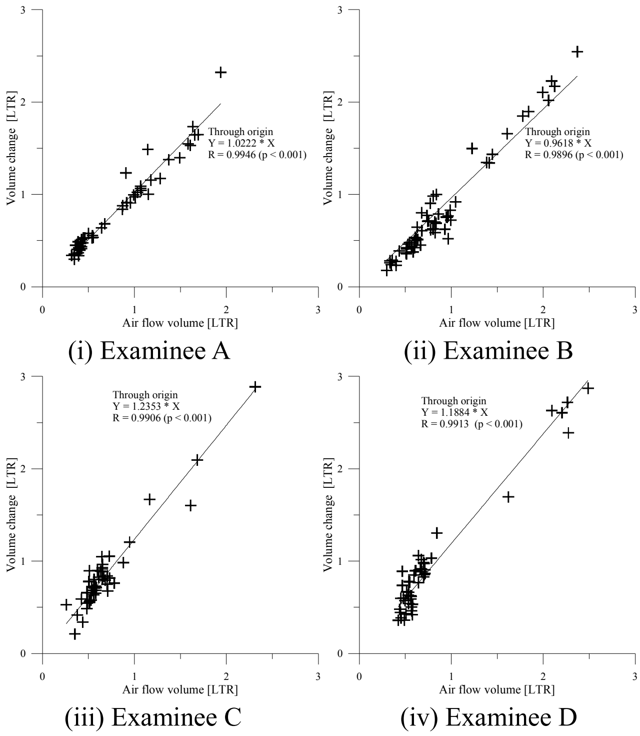
Fig. 8 shows Bland Altman plots about the volume change and the expiratory flow volume. In each subject, a slight addition error was recognized, but the proportion error did not appear. We think that the cause of the addition error is the automatic determination of the thoracoabdominal domain by Kinect for Windows SDK. It will be necessary to examine the influence of the body-build difference of the subjects in the setting of thoracoabdominal domain by the SDK in near future.

Moreover, we make comparison between measurement waveforms of our proposed method and the flow meter.

The flow meter like the expiratory gas analyzer is used for measuring respiration with attaching a mask type flow sensor on the nose and mouth. The flow meter can measure the respiratory flow waveform, unlike the expiratory gas analyzer. Here, we used FM-200 manufactured by Arco-system ltd. as the flow meter.

The experimental result for examinee A is shown in Fig. 9. The dimension of waveform obtained by our proposed method is litter. Therefore, the dimension of obtained waveform is translated to letter per second that is the measurement dimension of the flow meter. As the result of the dimension translation, the waveform include noisy component, and the respiratory periodicity is lost on the surface, as shown in Fig.9 (i).

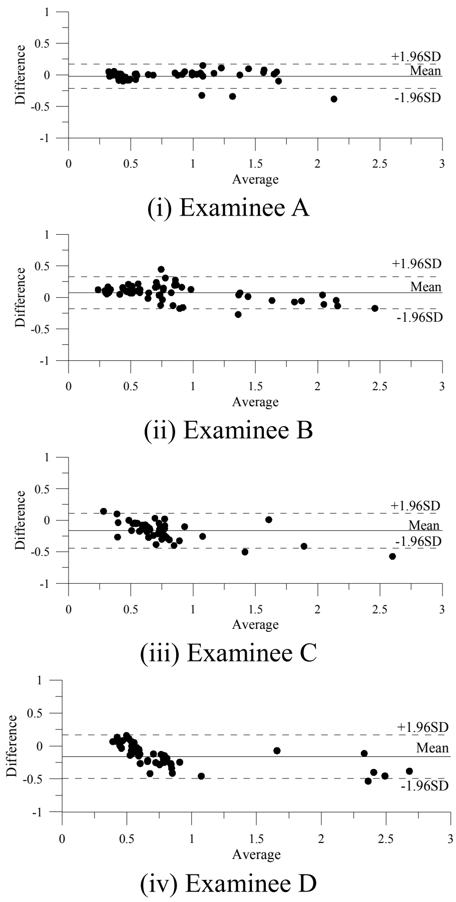
Accordingly, the moving-average method is applied to the waveform. The moving-average value of target datum point is calculated as the un-weighted mean of



(i) Examinee A (ii) Examinee B

(iii) Examinee C (iv) Examinee D

Fig. 7. Correlation between air flow volume and volume change.



(i) Examinee A

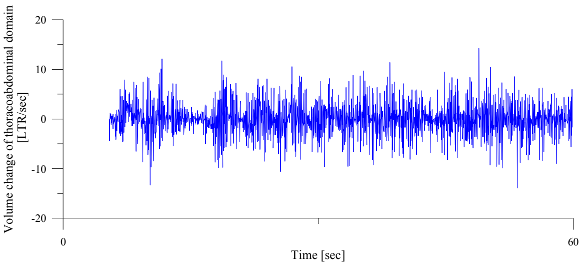
(ii) Examinee B

(iii) Examinee C

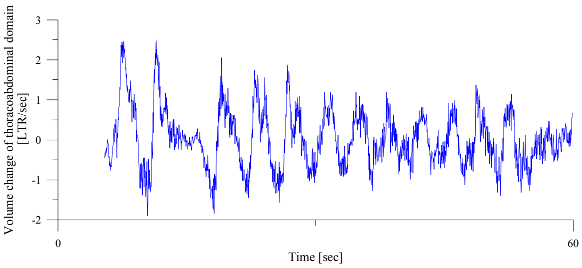
(iv) Examinee D

Fig. 8. Bland-Altman plot about air flow volume and volume change.

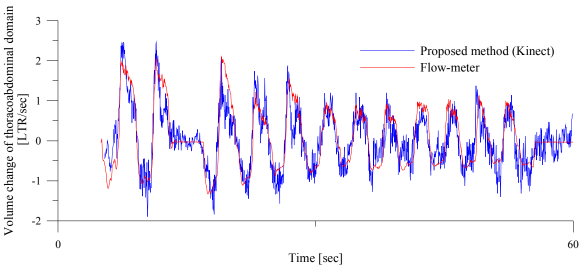
15 datum points, that are the target datum point and the previous 7 and the following 7 datum points. The respiratory periodicity is actualized by applying the moving- average method, as shown in Fig. 9(ii). Fig. 9(iii) shows the result of simultaneous measurement with our proposed method and the flow meter. There is high similarity between both waveforms. However, the waveform of our proposed method include high-frequency noise, and there is partially difference between two waveforms.



(i) Dimension translated waveform.



(ii) Moving-averaged waveform.



(iii) Comparison between proposed method and flow meter.

Fig.9 Result of comparative experiment with flow meter.

4. CONCLUSION

We proposed the non-contact respiration measurement by using Kinect. And, we examined the validity of our proposed method by simultaneous measurement with the expiration gas analyzer. As the results, the volume change of thoracoabdominal surface of examinee obtained by our proposed method is highly correlated with the expiratory air flow volume measured by the expiration gas analyzer. This result implies that our proposed method realizes quantitative respiration measurement without contact-type sensor. And, as the result of simultaneous measurement with the flow meter, high similarity between waveforms obtained by our proposed method and the flow meter is indicated clearly.

Therefore, we expect the realization of low restrictive pulmonary function test, as a substitute of the spirometer, by using Kinect.

The motion-capture function of Kinect become the focus of public attention, but the result of this paper indicate that Kinect provides 3-D measurement of high precision.

ACKNOWLEDGEMENT

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