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Heart rate measurement based on a time-lapse image

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Abstract

Using a time-lapse image acquired from a CCD camera, we developed a non-contact and non-invasive device, which could measure both the respiratory and pulse rate simultaneously. The time-lapse image of a part of the subject's skin was consecutively captured, and the changes in the average image brightness of the region of interest (ROI) were measured for 30 s. The brightness data were processed by a series of operations of interpolation as follows a first-order derivative, a low pass filter of 2 Hz, and a sixth-order auto-regressive (AR) spectral analysis. Fourteen sound and healthy female subjects (22–27 years of age) participated in the experiments. Each subject was told to keep a relaxed seating posture with no physical restriction. At the same time, heart rate was measured by a pulse oximeter and respiratory rate was measured by a thermistor placed at the external naris. Using AR spectral analysis, two clear peaks could be detected at approximately 0.3 and 1.2 Hz. The peaks were thought to correspond to the respiratory rate and the heart rate. Correlation coefficients of 0.90 and 0.93 were obtained for the measurement of heart rate and respiratory rate, respectively.

Keywords: Respiratory rate; Heart rate; Time-lapse image; Non-contact measurement

1. Introduction

Various technologies using non-contact, non-invasiveness, and ambulatory methods have been studied and developed for biomedical measurement. X-ray computed tomography and magnetic resonance imaging are typical examples of the non-contact method for collecting anatomical information. Research studies using non-contact measurement have continued for some years, such as measurement of brain activity by near-infrared radiation [1] and detection and evaluation of a wound and ischemic tissue by non-contact electric impedance measurement [2]. Chen et al. also measured the breathing and heartbeat signals of human subjects buried under earthquake rubble by using a microwave beam [3]. Optical methods are also widely used for non-contact measurement. For example, Sinko et al. evaluated the spine shape by using Moiré topography [4]. Matsui et al. monitored heart rate and respiration rate using laser irradiation by fast Fourier transform [5,6], and Augousti et al. measured respiratory and cardiac function by using optical fibers [7].

Because measurement of circulatory or musculoskeletal parameters can be principally invasive, attempts have been made to develop bloodless, painless, and less invasive methods by using ultrasound techniques such as diagnosis of fetal anemia [8] or arterial occlusive disease [9] by the Doppler ultrasound method, measurement of large sudden pressure drops seen in hypovolemia based on pulse wave transit time [10], measurement of bone deformation by echo tracking [11], and tendon force measurement by analyzing the transmission of ultrasonic waves [12]. In addition to these studies using ultrasound techniques, electrocardiography and photoplethysmography can be used for the non-invasive evaluation of blood pressure [13] and the detection of vascular disease [14], respectively.

For measurement of normal activities, various ambulatory methods have been developed by minimizing the monitoring devices. Typical examples are the Holter monitor and the pedometer [15]. de Lusignan et al. developed a wireless data collection system by using small sensors placed on the chest and recorded heart and breath rate, blood pressure, the electrocardiogram, and body temperature [16]. Gramse et al. mounted dry ECG electrodes as well as capacity-based elastic strain gauges on infant pajamas and monitored cardiopul-

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monary parameters [17]. Chen et al. also installed an air-free water-filled tube sensor under the pillow and monitored heart and breath rate during sleep by measuring the pressure under the near- and far-neck occiput [18]. Regarding the measurement of gait parameters, Veltink et al. proposed the use of two six-degrees-of-freedom force and moment sensors mounted in the shoe sole [19]. Since worldwide ageing of societies has been rapidly going on for some years, the ambulatory methods above could be useful for the health care of the elderly.

In recent years, there has been a trend in the development of non-contact instrumentation by combining a handy imager, or the CCD, and highly advanced PC technologies. A typical example is kinematics measurement by using the VICON system [20]. In addition, motion analysis of neonates in incubators by motion tracking [21], analysis of visual-gestural language using video cameras [22], and automatic recognition of facial expression [23] have been conducted. Furthermore, trials have been carried out to extract physiological parameters from the obtained kinematics data. Nakajima et al. [24] recorded the real-time image sequence of a subject in bed and measured the respiratory rate based on postural change. Cala et al. estimated lung volume using chest wall motion data acquired by reflective markers places on the body surface [25]. We also applied these image technologies and developed a new non-contact measuring method, which could collect heart and respiratory rate simultaneously.

2. Methods

2.1. System configuration

Analogue images from a CCD camera (Network Handycam IP, Sony Corp., Japan) were acquired through a picture board (PX500, Image Nation, USA) and stored in a PC (GP7-500, Gateway Corp., Windows NT). Using the timer function of Visual Basic (VB), the time-lapse image of a part of the subject's skin was consecutively captured, and the changes in the average image brightness of the region of interest (ROI) were measured using image-processing software (X Caliper, Optimas Corp., USA), which is executable through VB. Since sampling of the time-lapse image by VB was not conducted with a constant time interval (the time interval actually varied around 200 ms), the measured illumination data were corrected and regulated by spline interpolation.

2.2. Experimental procedure

Fig. 1 shows an example of the acquired picture by the system. The image size is 480 pixels × 640 pixels, and the ROI was set as a rectangular area (30 pixels × 40 pixels) in the cheek image as shown. The actual dimension of the ROI on the skin surface was approximately 3 cm × 4 cm. The average brightness of the ROI was consecutively measured at intervals of around 200 ms by an X Caliper device. The brightness data were interpolated and regulated into those with an interval of 100 ms by up-sampling software (Auto Signal, Aeasolve Software Inc., USA). The data were then processed by a series of operations involving first-order derivative, a low pass filter of 2 Hz, and Auto-Regressive (AR, 6th-dimension, 40th-order) spectral analysis.

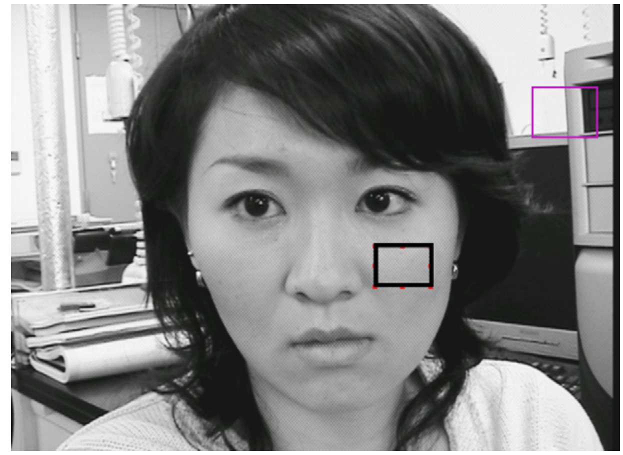

Fig. 1. An example of the acquired picture by the system. The image size is 480 pixels × 640 pixels. The ROI was set as a rectangular area (30 pixels × 40 pixels) on the cheek shown in the picture, and the average brightness of the ROI was consecutively measured with an interval of around 200 ms by an X Caliper device.

Fourteen sound and healthy Japanese subjects (female, 22–27 years old, 23.1 ± 1.7 years, Asian skin color) participated in the experiments. No specific instruction regarding skin cosmetics was given to any of the subjects because the system was intended as a home-based monitor in daily life. Each subject was told to keep a relaxed seating posture with no physical restriction, and the time-lapse image of the body surface was acquired for 30 s. At the same time, heart rate was measured by a pulse oximeter (OLV-2100, Nihon Kohden Co., Ltd., Japan) and respiratory rate was measured by a thermistor placed at the external naris. The illuminance of the subjects during image sampling was set at 860 lx. The experimental procedures were explained and informed consent was obtained from each subject.

3. Results

Fig. 2 shows a typical example of the heart rate measurement by time-lapse imaging. Fig. 2(a) shows the changes in the average image brightness in the ROI regulated with spline interpolation. Two kinds of waves, which are considered to be caused by respiration and heart beat, were observed. Fig. 2(b)–(d) shows the results of the process of the first-order differentiation, low pass filter, and AR spectral analysis, respectively. As shown in Fig. 2(d), two peaks could be clearly detected at approximately 0.3 and 1.2 Hz. The 0.3 Hz peak was thought to correspond to respiratory rate, and the 1.2 Hz peak to heart rate. The correlation coefficients for

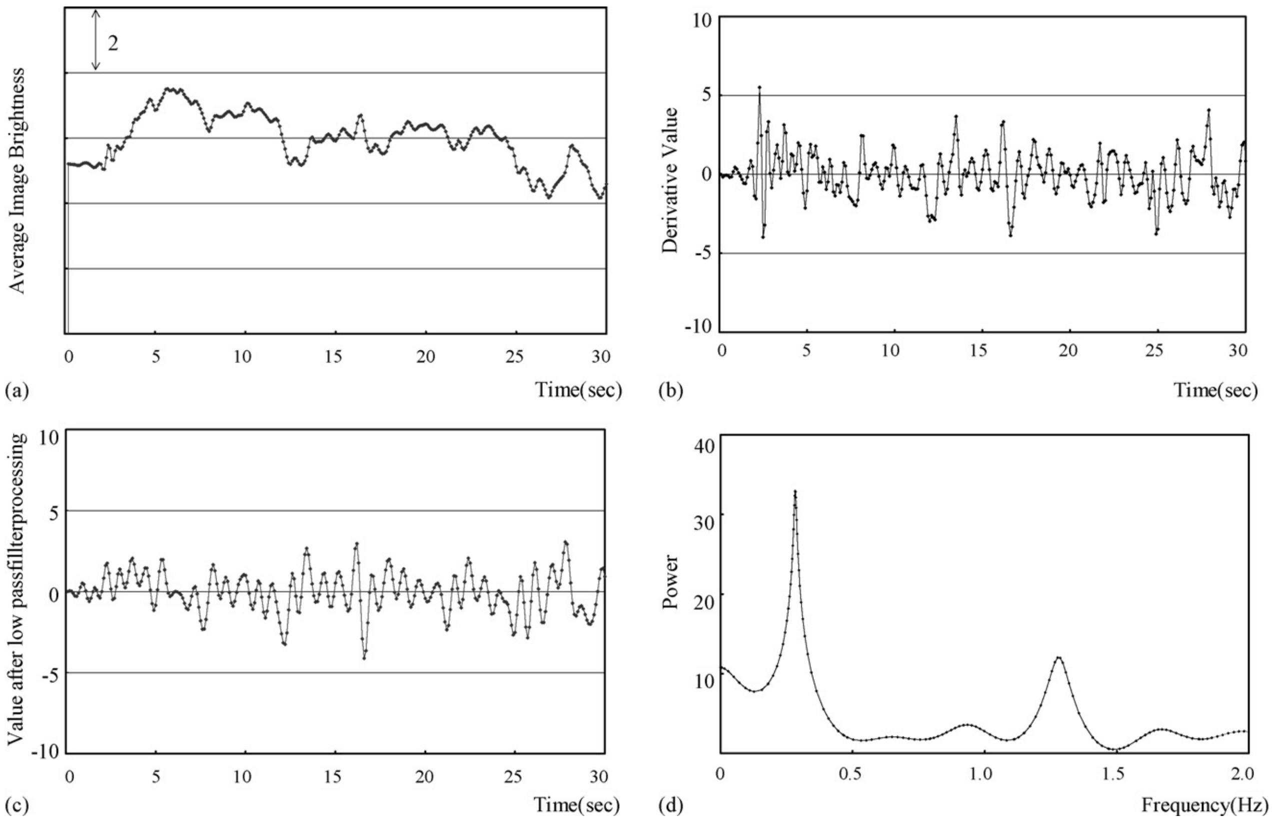

Fig. 2. A typical example of the measurement. (a) The changes in the average image brightness in the ROI regulated with spline interpolation. Two kinds of waves, which are considered to be caused by respiration and heartbeat, are observed. (b)–(d) The results of the process of first-order differentiation, low pass filter, and AR spectral analysis, respectively. As shown in (d), two peaks could be clearly detected at approximately 0.3 and 1.2 Hz. The 0.3 Hz peak is thought to correspond to the respiratory rate, and the 1.2 Hz peak to heart rate.

both rate measurements were examined through experiments with fourteen subjects, which are shown in Figs. 3 and 4. Fig. 3 shows the correlation coefficient between heart rate measured by our method and the one by the pulse oximeter, and the correlation coefficient was found to be 0.90 (p-value: 1.16×10^{-5}). Fig. 4 also shows the correlation coefficient between respiratory rate measured by our method and the thermistor. The correlation coefficient was found to be 0.93 (p-value: 1.23×10^{-6}). High correlation coefficient values were obtained for both measurements.

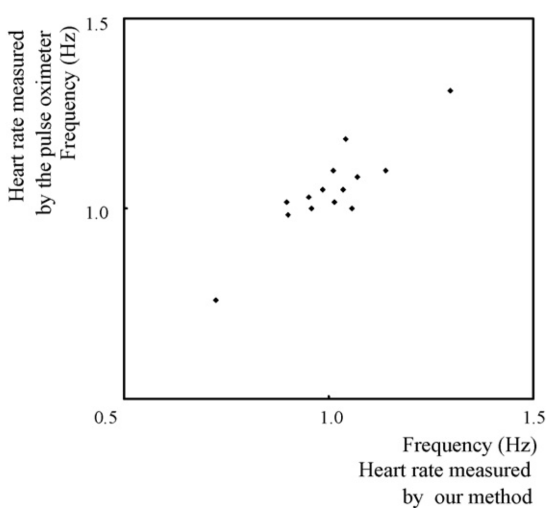

Fig. 3. Correlation coefficient between heart rate measured by our method and the one by the pulse oximeter. In experiments with fourteen subjects, the correlation coefficient was found to be 0.90 (p-value: 1.16×10^{-5}).

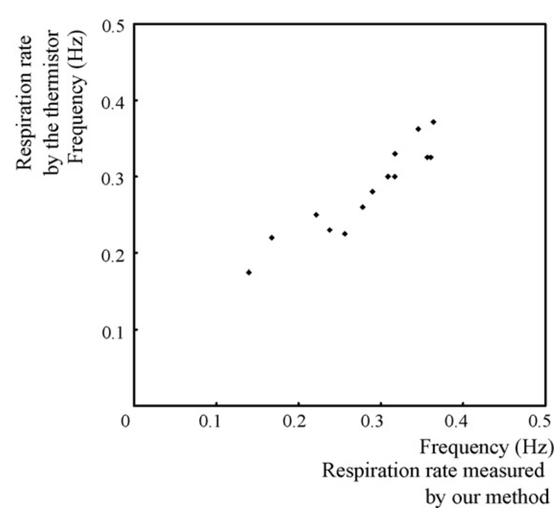

Fig. 4. Correlation coefficient between respiratory rate measured by our method and the thermistor. In experiments with fourteen subjects, the correlation coefficient was found to be 0.93 (p-value: 1.23×10^{-6}).

4. Discussion

In this study, we developed a new device by combining a time-lapse image from a handy video camera and image processing on a PC, and found that it could measure the 30-s average heart and respiratory rates based on the changes in the brightness of the ROI set around the cheek of the unrestricted subject. Regarding the mechanism of the respiratory measurement, the cheek skin moved due to the respiratory motion of the upper thorax, which varied the brightness of the ROI. The same mechanism might apply to the measurement of heart rate, considering that the measurements were successfully conducted for subjects with or without facial cosmetics and that the system tended to detect the pulse rate more clearly around typical palpation points such as the common carotid artery and ulnar artery. With regard to the measurement of pulse rate, there might be some correlation with oxygen saturation, which needs to be investigated in future experiments.

For the numerical processing method of the brightness data, various methods were evaluated through trial-and-error testing, and a combination of interpolation, first-order derivatives, a low pass filter, and AR spectral analysis were employed in this study. When determining the interpolation method, the cubic spline, the B-spline, and the non-uniform rational B-spline (NURB) were evaluated for comparison. As a result, the cubic spline and the B-spline tended to be suitable for this measurement, while the NURB was not. In order to determine the spectral analysis method, the fast Fourier transform, the wavelet transform, and AR modeling were tested, and the peaks of respiration and heartbeat could be clearly detected by the wavelet transform as well as AR modeling. In future studies, other processing methods or other combinations should be investigated to increase the measurement accuracy.

Generally, setting the conditions for illuminating the object to be measured could be critical in image analysis, and once decided, the conditions have to be controlled strictly. The developed device showed that even in the case of sudden changes in scene illumination between 270 and 1500 lx, the measurement could be conducted due to the auto iris function mounted on the CCD camera (the brightness level of the image could be properly controlled within a few seconds). Our daily activities are carried out under this illuminance range. Therefore, away from limited environments such as a laboratory, the developed device could be useful for the measurement of normal activities. Moreover, with this device, there is no need to transmit the acquired images to another site via a network for analysis, which means that there are no problems with privacy involved in human image handling.

With the ongoing worldwide ageing of societies, in order to maintain and improve the quality of life of the elderly, care must be taken at home or in community dwellings for both disease prevention and health management. For this purpose, a number of health monitors have been proposed. Examples of health monitor are studies on the data collection method for a home health care service [26,27], portable equipment for daily physiological measurements [28], an automatic health monitoring system at home [29,30], a health care service based on video telephony [31], a residence with intelligent sensors for longevity effectiveness [32], and inquiry into the user-friendliness of medical technology influences [33]. Parallel with hardware development, analysis techniques have to be developed in order to accurately evaluate the health conditions of a subject and to detect a tiny symptom of disease from huge amounts of physiological data, which the monitors accumulate daily. To support the elderly living without a partner, Chan et al. [34,35] studied a diagnostic method to detect unusual condition changes based on voluntary calorie consumption data associated with daily activities such as going to the toilet, which were collected by a multisensor home monitoring system. Considering that the home care devices would be used by a user unfamiliar with new technology, the devices installed around him/her have to be handy and easy-to-use without specific knowledge. The method developed in this study is promising for these purposes, especially considering projections of progress in PC technology, miniaturization of the CCD sensor, and installation of the imager on home equipment such as a mobile phone. However, the various practical aspects involved in the installation of the device have to be investigated with elderly subjects, such as the ability of an elderly patient to sit still and quietly for the required period of time outside of a laboratory environment.

5. Conclusion

In this study, we found that the simultaneous measurement of both respiratory and pulse rate was possible by acquiring the time-lapse image of a subject's face for 30 s and examining the image brightness in the ROI by AR spectral analysis. Through calibration experiments with a thermistor and a pulse oximeter, correlation coefficients of 0.93 and 0.90 were obtained for respiratory and pulse rate measurements, respectively. With the attractive features of ambulatory and non-contact monitoring, flexibility of the site of the body surface for imaging, and the robustness of the image processing for normal activities, the device shows potential for application to health care for the elderly at this stage of development.

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