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NOTE

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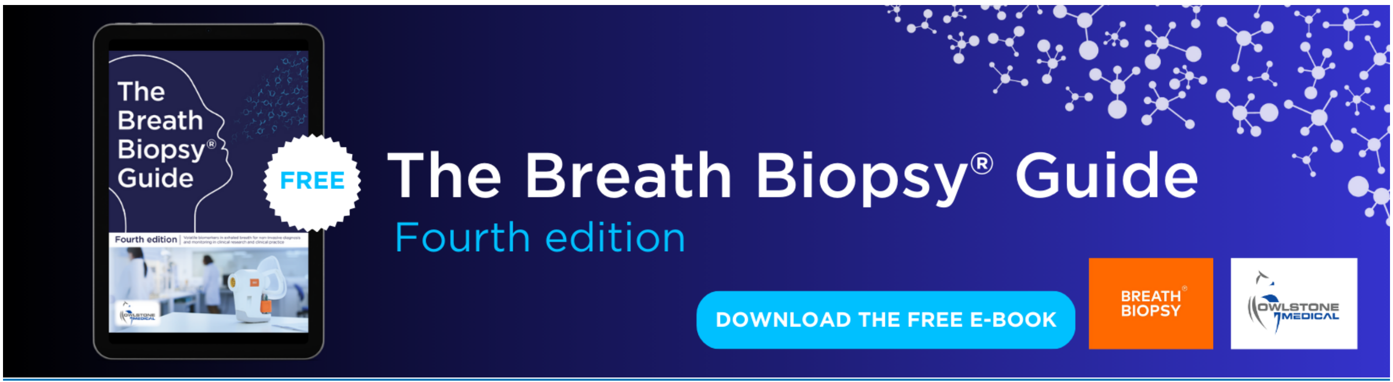

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NOTE

Development of real-time image sequence analysis for evaluating posture change and respiratory rate of a subject in bed

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Abstract
An image sequence analysis technique was developed to evaluate posture change and respiratory rate of a subject in bed without any physical contact. Although the image sequence analysis requires many calculations, the system can perform them in real time. The system consisted of a CCD video camera and a PC equipped with a high-speed image processor. To evaluate the system, we tested it on five subjects at a nursing home. The system evaluated 99.4% of the movements of subjects during the total monitoring time (about 61 hours). The waveform was flat when the subject was out of view of the video camera. The system has the possibility of evaluating not only posture changes and respiratory rate, but also sleeping patterns.

Keywords: posture change, respiratory rate, sleeping pattern, image sequence analysis, optical flow

1. Introduction

The bed is a good place for evaluating vital signs. Some monitors, such as electrocardiography (ECG) and respiration and body movement monitors (Ishijima 1997, Carlson *et al* 1999, Tamura *et al* 1999), have already been developed. These monitors evaluate the vital signs without constraining the subject; however, they use sensors that contact the subject. We have developed an image sequence analysis technique for evaluating vital signs in bed without an attached sensor (Nakajima *et al* 1997a, b). This system uses a video camera as a sensor, and the system does not physically constrain the patient. The system detects both posture change and respiration of the subject in bed by observing chest or blanket movement, and uses an

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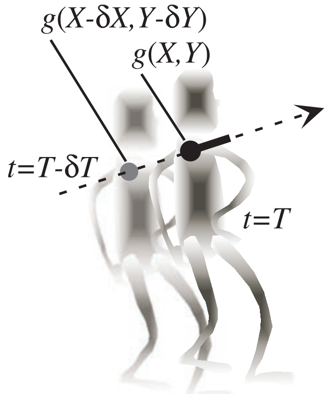

Figure 1. A schematic illustration for the concept of optical flow.

image processing method to evaluate the frequency of posture change and respiration rate. In the previous studies, analyses were performed offline because many calculations were required to detect the movement of a subject (Nakajima *et al* 1997a, b). The aim of this study was to develop a real-time system for evaluating both the frequency of posture change and respiratory rate of a subject in bed using image sequence analysis.

2. Optical flow detection

Posture changes and the respiration rate of subjects in bed are confirmed by observing blanket or chest movement. An optical flow method was developed to detect blanket or chest movement of a subject in bed. Optical flow is an apparent velocity arising from the relative motion between the object and the observer (e.g. the video camera). It has been used in the field of robot vision (Horn and Schunck 1981, Jähne 1997). Figure 1 shows a schematic illustration for one concept of optical flow. The body is assumed to move from left to right in time δT. The dotted arrow indicates the direction of the motion. The displacement vector in time δT, the apparent velocity (i.e. optical flow), is indicated by a dot and bar on the shoulder. A number of different approaches to determine optical flow have been proposed; for instance, gradient-based, correlation-based, energy-based and phase-based methods. A survey was carried out by Barron *et al* (1994), where the different approaches were compared on a series of synthetic and real images. In the actual scene analysis, however, the performance of conventional methods is not satisfactory. We have proposed an extended gradient-based method to obtain a reliable measure of optical flow in the actual scene. Details of this method have been described previously (Nakajima *et al* 1997a, b). In this study, the essence of the extended gradient-based method is described as follows.

Optical flow is assumed to be constant in the local vicinity, including the spatial and temporal local area (Chaudhury and Mehrotra 1995, Zhang *et al* 1996). Consider the motion of a brightness pattern that is displaced by a distance $(\delta x, \delta y)$ in time δt. The brightness pattern on the shoulder is assumed to remain constant so that

$$g(x, y, t) = g(x + \delta x, y + \delta y, t + \delta t). \tag{1}$$

Expanding the right-hand side of equation (1) around the point (x, y, t), and neglecting second-and higher-order terms and setting δt to zero, the following expression is obtained:

$$\frac{\partial g}{\partial t} = -\frac{\partial g}{\partial x}\frac{\mathrm{d}x}{\mathrm{d}t} - \frac{\partial g}{\partial y}\frac{\mathrm{d}y}{\mathrm{d}t} \tag{2}$$

where $(\mathrm{d}x/\mathrm{d}t, \mathrm{d}y/\mathrm{d}t) = \boldsymbol{v}$ is the apparent velocity to be determined.

3. Real-time system for image sequence analysis

Detection of optical flow requires many calculations. In earlier work, optical flow was detected by offline analysis (Nakajima *et al* 1997a, b). In this study, we developed a real-time system to analyse chest or blanket movement. The system comprised a CCD video camera and a PC that was equipped with an image processing board (RVS-DX-10G, Mitani Corp., Japan). The video monitor was only used for checking the image. The image processing board consisted of 256 eight-bit linear processor arrays and 256 kB inner and 16 MB outer memories. The image processing board was a single-slot PCI-bus board designed for PC-based real-time vision application, with 10 giga operations per second (GOPS) peak performance. The program for detecting the optical flow ran on the image processing board and did not use the resources of the host PC. The system calculated the optical flow of 256×240 pixels within 150 ms. Optical flows were superimposed on the view from the video camera.

In a test installation of the system, a CCD video camera (KP-M2RN, Hitachi Denshi, Japan) that had sensitivity in the near-infrared spectrum was suspended from the ceiling at a distance of two metres from the feet of the subject, and image size was adjusted to include the head and upper body. A small bedside lamp was used if the subject usually slept with a light on. If the subject was used to darkness during sleep, an array of light-emitting diodes (DNP324U: 880 nm, Stanley, Japan) was used as a near-infrared lamp for image acquisition.

4. Subject and experimental procedure

To evaluate performance of the system, a volunteer (male, 23 years old) participated in a laboratory test including posture change and brief cessation of breath. A test installation of the system was also trialled in a nursing home. Before the test installation, formal ethics committee approval was obtained for this study. All subjects gave written informed consent. Two females and three males (93–96 years old) participated in the test. The monitoring period was seven hours from when the subject went to bed, and the video image was recorded simultaneously. Monitoring was carried out on two or three successive nights for each subject.

In this study, we classified the motions of the subject into five groups: respiration, cessation of breath, full posture change, limb movement and out of the view of video camera. Periods of the five motions were analysed by referencing the videotapes.

5. Results

5.1. Laboratory test

5.1.1. Detected optical flows. Figure 2 shows a typical result of detected optical flows. The subject was in a supine position on a bed. Ordinary bedding with a mosaic pattern was used. Although the directions of optical flows were analysed precisely, the arrows are only shown in eight directions because the video display performance of the image processing board was low. The main arrows on the subject's chest changed their directions alternately from upward to downward for every respiration; the arrows pointed up in the period of inspiration, and down in the period of expiration, and thus reflected chest movement due to respiration.

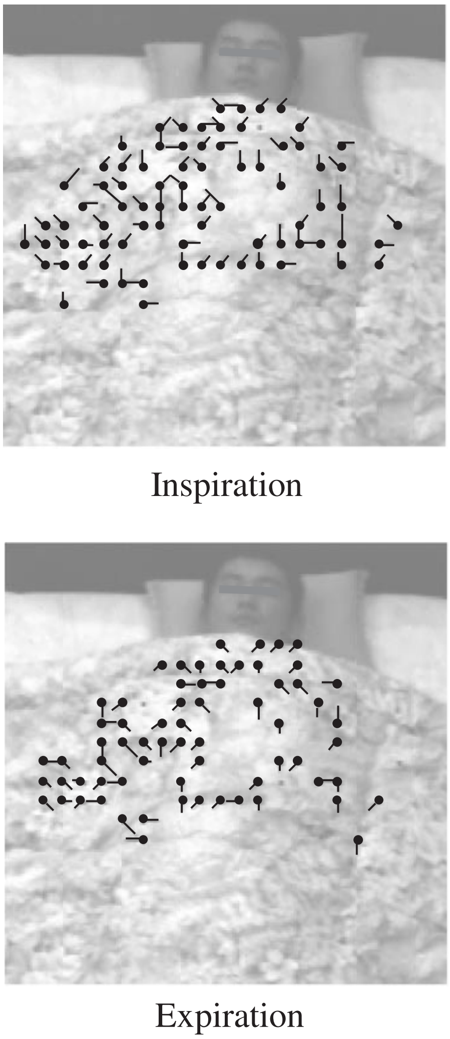

Figure 2. Typical results of the detection of optical flows for a subject in a supine position.

5.1.2. Comparison of respiration waveform. The averaged velocity was compared with the respiration waveform from a thermistor in a nasal cavity, as shown in figure 3. The upper waveform is the averaged velocity from the optical flow and the lower waveform is from the thermistor. In the averaged velocity, clear peaks corresponding to respiration were observed, as shown in the previous report which used offline analysis (Nakajima *et al* 1997a). When we asked the subject to stop breathing for about 30 seconds, both these waveforms became flat. When the subject breathed again, the respiration waveforms appeared, and clear peaks corresponding to respiration were observed. We also asked the subject to change posture from a supine to a lateral position. After 10 seconds, the subject was asked to return to a supine position. Although large peaks appeared in the averaged velocity, the waveform from the thermistor had no particular peak. After the full posture changes, clear peaks corresponding to respiration were again observed from both monitoring devices.

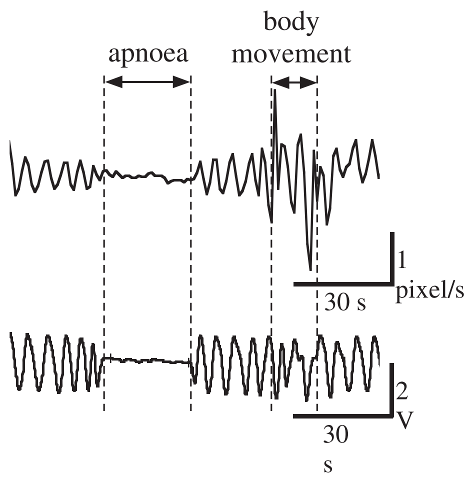

Figure 3. Comparison of the waveforms of respiration: the upper waveform is from the optical flows; the lower waveform is from the thermistor.

Table 1. Results of the motion classification.

	R	CB	FPC	LM	OV	ND	Total
Accumulated time	51:14:57	1:24:16	3:44:45	0:56:07	3:10:46	0:23:33	60:54:24
Percentage	84.2	2.3	6.2	1.5	5.2	0.6	100.0

R, respiration; CB, cessation of breath; FPC, full posture change; LM, limb movement; OV, out of view; ND, optical flow not detected.

5.2. Test installation of the system

Figure 4 shows a typical result for a 94-year-old male subject. In figure 4(a), the waveform looks noisy because the figure is displaying data from over seven hours. If the waveform is expanded in the time course, the clear waveform of respiration can be confirmed (see figures 4(b) and (c)). Four small circles (OV) indicate when the subject left the bed to go to the toilet. Figure 4(b) shows a typical waveform at OV1. The waveform became flat because the subject was out of view of the video camera. Large and frequent peaks were obtained when the subject moved into and out of the view of the video camera. The centre oval (CB) in figure 4(a) indicates when the subject might have stopped breathing. Amplified and expanded behaviour of the waveform at CB is shown in figure 4(c). Similar phenomena were found in two other subjects (female 93 years old, and male 96 years old).

Table 1 shows the results of the motion classification. Although a subject was in the bed, the system could not detect 0.6% of the optical flow in the whole monitoring time (60 hours, 54 minutes and 24 seconds), but evaluated 99.4% of the movements of subjects during this period.

6. Discussion

We developed a system to analyse image sequences in real time for evaluating posture change and respiratory rate of the subject in bed. As the system uses a video camera as a sensor, it evaluates posture change and respiratory rate of the subject without any physical constraints on the subject. Stereovision analysis, which uses two cameras or more, can provide

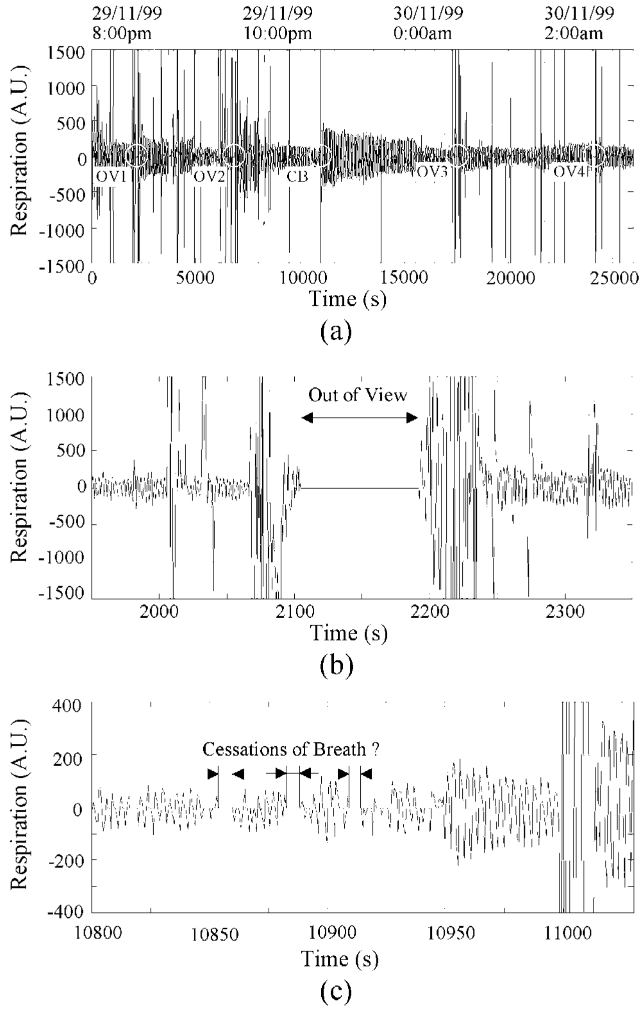

Figure 4. A typical result of monitoring a subject (male, 94 year old) for one night. The vertical axis is arbitrary unit (A.U.). (a) Waveform obtained from the proposed system; OV: out of view of the video camera; CB: cessation of breath. (b) Expanded waveform at OV1. (c) Amplified and expanded waveform at CB.

three-dimensional information, while monocular vision analysis can provide two-dimensional information. Our system uses monocular vision analysis. Therefore, it enables both the number of posture changes and the respiratory rate to be counted, but quantitative evaluation of body motion or tidal volume is difficult.

When the subject left the bed to go to the toilet, the waveform was flat. Moreover, large and frequent peaks appeared when the subject moved into and out of the view of the video camera. This waveform pattern was different from the waveform of both the posture change and the respiration. In the next stage, the system may automatically differentiate the subject being out of bed from other behaviours. Abnormal breathing events during sleep in adults and their associated syndromes were defined by the American Academy of Sleep Medicine Task Force (1999). The waveforms of three of five subjects showed phenomena that might be cessation of breath, as shown in figure 4(c). Unfortunately, no data from polysomnography, which has been used in sleep studies (Coleman *et al* 1981, Phillips *et al* 1998), were available for this study. Therefore, we were unable to diagnose whether the three subjects suffered from abnormal breathing events during sleep. The system has the possibility of evaluating not only the total number of posture changes and respiratory rate, but also the overall sleeping pattern (whether a subject normally sleeps through the night or whether their sleep is regularly interrupted by visits to the toilet).

Although the system evaluated most motions of the subjects, it was unable to detect 0.6% of the optical flow in the whole monitoring time. As optical flow is the apparent velocity of motion, the lighting conditions are important. In general, optical flow detection has a problem with non-uniform lighting, as was shown by this system. We used a small lamp or a near-infrared lamp in this study, but the dawn temporarily caused non-uniform lighting. Nomura *et al* (1995) have proposed a method to solve the non-uniform lighting problem, and we intend to adapt our system to incorporate their method of optical flow detection under non-uniform lighting.

In this study, the whole image sequence was analysed in real time by using a high-speed image processor. If the system analysed a small area, or region of interest (ROI) of the image, optical flow could be detected in real time without the high-speed image processor, although the ROI would have to track the movement of the subject.

7. Conclusions

A system that evaluates posture change and respiratory rate in bed without any physical contact was developed. As the system detects the optical flow of a subject in real time, it has the possibility of evaluating not only the total number of posture changes and respiratory rate, but also the overall sleeping pattern.

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