Continuous Real-time Heart Rate Monitoring from Face Images

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Keywords: Heart Rate, Pulse Wave, Face Image, Real-time Remote Monitoring.

Abstract: A real-time monitoring method of heart rate (HR) from face images using Real-time Pulse Extraction Method (RPEM) is described and corroborated for the theoretical efficacy by investigating fundamental mechanisms through three kinds of experiments; (i) measurement of light reflection from face covered by copper film, (ii) spectroscopy measurement and (iii) simultaneous measurement of face images and laser speckle images. The investigation indicated the main causes of brightness change are both the green light absorption variation by the blood volume changes and the face surface reflection variation by pulsatory face movements. RPEM removes the motion noise from the green light absorption variation and the effectiveness is ensured by comparing with the pulse wave of the ear photoplethysmography. We also applied RPEM to continuous real-time HR monitoring of seven participants during office work under non-controlled condition, and achieved HR measured rate of 44 % to the number of referential ECG beats while face is detected, with RMSE = 6.7 bpm as an average result of five days.

1 INTRODUCTION

Recently there has been a growing attention on ICT-enabled personal health services which utilize information on personal health record (PHR) via ubiquitous devices, wireless network and cloud. By continuously monitoring vital signs and activities related to person's health condition, personalized services such as health promotion and disease prevention are expected to be provided. Therefore, the continuous data acquisition in daily life has become an active area of research (Pantelopoulos and Bourbakis, 2010; Inomata and Yaginuma, 2014; Uchida et al., 2015). Especially, heart rate (HR) has been utilized widely as a vital sign to keep one's health in good shape by monitoring load of exercise or work. Long-term and detailed HR monitoring is also expected to be useful for prognostic observation in relation to diseases (Dyer et al., 1980; Jensen et al., 2013). However, a typical way using contact sensor device onto subject's skin is not suitable for HR monitoring in daily life because it makes them uncomfortable and inconvenient. For that reason, a non-contact measurement method is preferred. Recently, methods using face images were reported (Takano and Ohta, 2007; Poh et al., 2010; Poh et al., 2011; Kwon et al., 2012; Balakrishnan et al., 2013; Li et al., 2014). Balakrishnan et al., directly detected small head moving amount caused by the blood circulation for measuring HR. Others detected face colour or brightness changes which is also related to blood circulation. In these reports, high accuracy results were obtained under well-controlled conditions. However these methods do not satisfy continuous HR monitoring in daily life. People frequently have various large and small movements, and it makes the extraction of pulse waves from brightness change difficult. Therefore methods which need to accumulate data, such as independent component analysis (ICA) are not suitable because accumulation of data is often interrupted by large motion in daily life, and the method with shorter measurement time is required. In 2013, we demonstrated continuous HR monitoring in daily life by the Real-time Pulse Extraction Method (RPEM) (Sakata et al., 2013). In this paper, we describe RPEM and we corroborate the theoretical efficacy of RPEM by the investigation of brightness change on face images with three fundamental experiments. Continuous real-time HR monitoring with RPEM in office is also performed as an example of applications.

Mori, T., Uchida, D., Sakata, M., Oya, T., Nakata, Y., Maeda, K., Yaginuma, Y. and Inomata, A.
Continuous Real-time Heart Rate Monitoring from Face Images.
DOI: 10.5220/0005682400520056
In *Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2016) - Volume 4: BIOSIGNALS*, pages 52-56
ISBN: 978-989-758-170-0

2 REALTIME METHOD

In this section, the framework to measure HR from face images in real time is explained. It has 5 steps. (1) Face images are captured by a RGB camera (webcam) and (2) face detection is performed in each frame. (3) Averaged red, green and blue signals are calculated from region of interest of face images, respectively. (4) Filtering process is performed in order to extract pulse waves due to the blood circulation. (5) Calculation of HR is performed.

In this 4th step of the framework, we focus on the green signal, which is assumed to include pulse components, and remove the noise caused by face movements to obtain the pulse signal. Our method assumes that small head movement affects reflection light from face only in the brightness and not in the colour. Therefore, the intensity ratio between green and red/blue signals stays constant in all frequency range except at the frequency of pulse. We defined the intensity ratio as a, and red and green signals in pulse frequency as g_{signal} and r_{signal}, respectively. We calculate the ratio a in the lower frequency range than the pulse frequency, then we estimate the noise included in green signal g_{signal} by the multiplication of the ratio a and the red signal r_{signal}. We obtain the pulse signal $g_{pulse}$by subtracting the estimated noise ar_{signal} from the green signal g_{signal} as shown in (1).

$$g_{pulse} = g_{signal} - ar_{signal} \quad (1)$$

With the described method, the noise derived from the large movement cannot be removed. Thus we also use the confidence indicator with the autocorrelation and remove the HR with small indicator value. The calculation of HR is performed by averaging signals for consecutive 4, 8 or 15 beats with confidence indicators larger than a threshold. With this method, the HR can be measured in several seconds, which is much shorter time than that of conventional HR extraction method such as Discrete Fourier Transform (DFT) method.

3 FUNDAMENTAL MECHANISM

In our method in the section 2, we assumed that green signal has stronger pulsatory component than other colours (hypothesis 1). Also, we assumed that the ratio between green and red signals stays constant in all frequency range except at the pulse frequency (hypothesis 2). In this section, we experimentally validate these hypothesises by clarifying the contribution of surface reflection and light absorption caused by blood circulation to brightness change of the face images.

Firstly, the effect of the surface reflection from the face was investigated. The face images (video) were captured and two regions at right and left cheeks were compared. The right cheek was covered with a thin copper film (Figure 1). The frequency characteristics of the red, green and blue signals obtained by fast Fourier transform (FFT) from the copper surface and skin surface are shown in Figure 2 (a) and (b), respectively. In Figure 2, there are peaks around 75 cycles per minute (cpm) in both of (a) and (b). Note that this peak value is the same as the finger pulse rate of 75 bpm simultaneously measured by photoplethysmography (PPG).

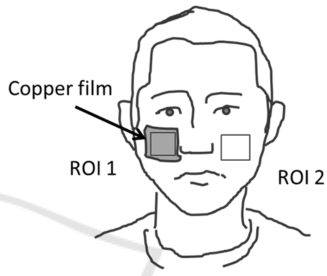

Figure 1: The region of interests (ROIs). ROI 1 is at a copper film attached on the surface of right cheek.

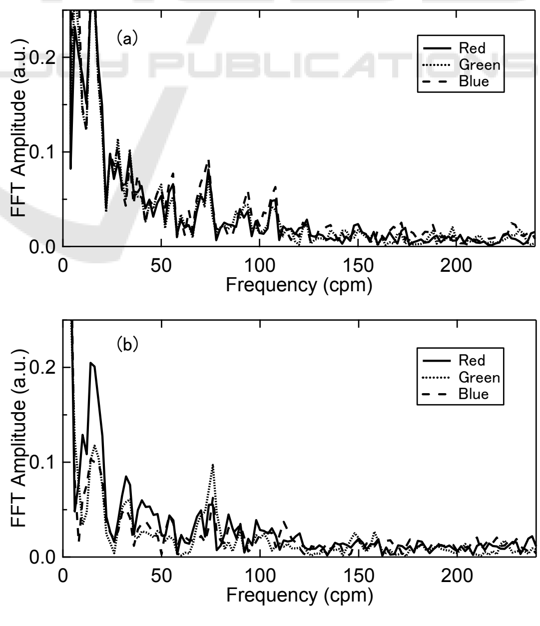

Figure 2: RGB spectra of face images at (a) ROI 1 and at (b) ROI 2. Frequencies are shown as cycles per minute (cpm).

Since complete light reflection from the copper surface and no reflection from face skin surface are expected in Figure 2 (a), this peak indicates the contribution of pulsatory movement of the head at 75 cpm caused by the blood circulation. These reflection peaks and profiles in all frequency range are very similar for all RGB signals in (a). On the other hand, the green signal at the peak frequency is stronger than red and blue signals in Figure 2 (b).

In order to clarify the colour dependency of the signal from skin surface, a spectroscopy experiment was performed. To create similar circumstance with the RGB camera measurement, the distance between a spectroscope and subject's face is about 50 cm and the face was exposed by the intense light using an incandescent lamp. The raw spectra were divided by the incandescent light spectrum. Characteristic peaks were observed around 540 nm and 570 nm. These peaks are consistent with the peaks of oxy-haemoglobin absorption at around 540 nm and 570 nm (Steknke and Shephered, 1992). Since the wavelength of the green light is around 500 nm – 570 nm, the strong peak for green signal in Figure 2 (b) is contributed by the absorption by the oxy-haemoglobin under the face skin. Therefore, it is assumed that the absorption variation by pulsatory blood volume change is causing the strong peak for green signal in Figure 2 (b).

We also carried out a simultaneous measurement of face images by RGB camera and blood flow images by laser speckle imager (Forrester et al., 2004). Laser speckle imager detects the mobility of red blood cells in a measurement area, and the phases of blood flow wave and time differential green signal wave are expected to match.

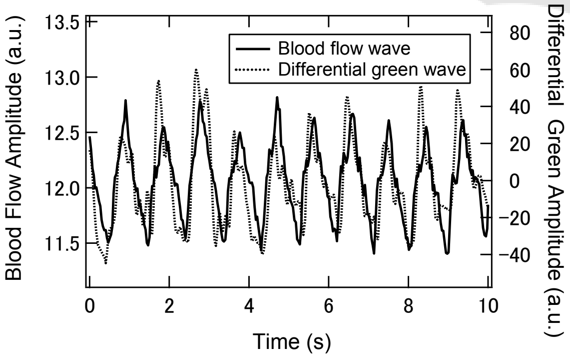

Figure 3: A comparison of the differential green wave with the blood flow wave obtained by a laser speckle imager.

Figure 3 shows a time differential green wave and blood flow wave obtained simultaneously by averaging signals at the centre area of the face. The phase of differential green wave is in agreement with that of the blood flow wave.

From these experiments and results, the causes of the brightness change on face are combined effects of the oxy-haemoglobin absorption variation by pulsatory blood volume change and the surface reflection variation caused by pulsatory movements. These results validates the hypothesises of our method by the facts that the absorption rate in green is higher than red or blue by the spectroscopy experiment (hypothesis 1), and the influence of movements have no dependence on colour channel in any frequency as shown in Figure 2 (a) (hypothesis 2). Therefore RPEM extracts pulse waves due to the blood volume changes from green light by cancelling the effect of head movements.

4 WAVES UNDER MOTION

Figure 4 shows a comparison of waveforms when the face is moving. In Figure 4 (a), raw red, green and blue (RGB) signals averaged in the region of interest (ROI) are shown. The ROI is determined by choosing a centre part of face detected area. Motions almost equally affect all RGB signals.

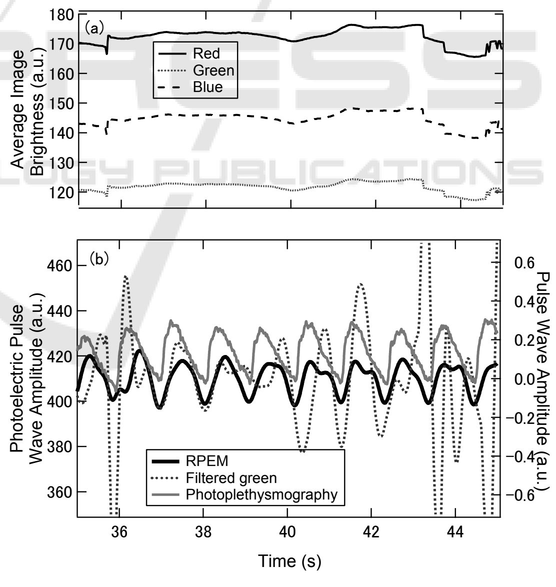

Figure 4: A comparison of waveforms when the face is moving: (a) raw RGB signals from face images, and (b) RPEM, filtered green, PPG wave.

In Figure 4 (b), an extracted pulse wave by RPEM, filtered green wave and ear PPG wave are shown. The filtered green wave is extracted by a conventional method of infinite impulse response (IIR) filter applied on green signal at frequencies between 50 and 150 bpm. The filtered green wave is largely affected by the motions and the waveform is distorted. On the other hand, the extracted pulse waveform by RPEM is similar to the ear PPG wave without major distortion.

From these results, the effectiveness of RPEM for HR measurement is corroborated especially when the filtered green waveform is affected by motions.

5 CONTINUOUS MONITORING

We applied RPEM to continuous monitoring of HR during daily office work under non-controlled conditions. In the experiment, seven participants (A, B, C, D, E, F and G) aged from 24 to 55 years old were monitored. Commercially available web cameras were attached on top of the computer display on their desk to capture their face during desk work. Also, an electrocardiograph (ECG) device was on their chest as a reference. All of them were requested to do their work as usual for five days. Face image data for approximately 133 hours was obtained in total for seven participants.

Figure 5 shows the HR trend calculated from the results of RPEM for the participant D. The trend of HR in one day is in good agreement with the HR from ECG. The data missing period around noon is because the participant left his desk for lunch, and the large change after the lunch break is due to the effects of running during the break.

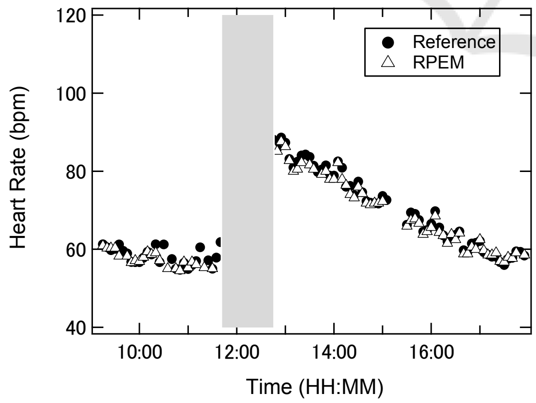

Figure 5: HR trend during office work compared with HR calculated from ECG (reference).

During the continuous measurements, the face detection is frequently chopped because people frequently move their face to execute their tasks, such as phone calls, conversation with colleagues, or leaving for lunch or breaks. In one case as an example, only 33 % of the sum of the face detection time is for the continuous detections with more than 30 seconds, and about 90 % is for the detections with more than 4 seconds. Therefore the shorter measurement time is required to increase the chances to measure HR.

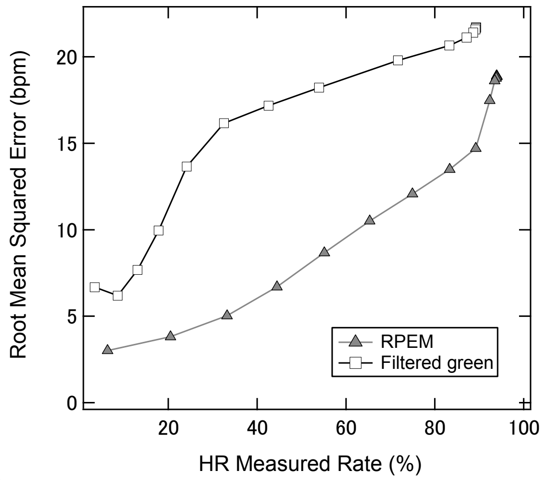

Figure 6: The trade-off relationship between the HR measured rate and RMSE for RPEM and filtered green.

The result of HR measured rate and root mean squared error (RMSE) is shown in Figure 6. The result is an average for seven participants and the signal averaging is for 4 beats. The HR measured rate is defined as a ratio of the number of beats measured from face images to the number of referential ECG beats while face is detected. The rate can be controlled by changing the threshold of the confidence indicator with autocorrelation.

Smaller RMSE are found at lower HR measured rate, and there is a trade-off relationship. Our method achieves both higher measured rate of HR and higher accuracy than filtered green method. HR measured rate = 44 % at the confidence indicator = 0.6 with RMSE = 6.7 bpm are obtained as the mean result of seven participants for five days.

The results of each participant are shown in Table 1. The RPEM result shows 1.5 - 6.7 times higher HR measured rate with almost equal or higher accuracy than filtered green in 4 averaging beats. By increasing the averaging beats from 4 to 8 or 15, the RMSE improves although HR measured rate decreases.

6 CONCLUSIONS

We propose a real-time pulse extraction method for continuous heart rate monitoring from face images.

Table 1: HR Measured rate and RMSE for seven participants. RPEM is compared with filtered green for different averaging beats.

Paticipants	HR measured rate (%)				RMSE			
	Filtered Green	RPEM			Filtered Green	RPEM		
	4 beats	4 beats	8 beats	15 beats	4 beats	4 beats	8 beats	15 beats
A	6	40	24	15	11.1	7.2	3.5	2.1
B	19	50	30	16	6.4	4.9	1.9	0.8
C	13	49	30	17	7.9	5.9	2.3	1.7
D	15	45	24	13	18.8	6.7	2.9	1.5
E	9	33	15	7	12.1	9.0	3.3	1.8
F	38	58	40	26	5.1	5.4	3.3	2.8
G	20	37	16	7	7.3	7.6	2.4	0.7

The investigation of fundamental mechanisms experimentally revealed that the main cause of the brightness change of the face image is both the light absorption variation due to the blood volume changes and the face surface reflection generated by pulsatory movements.

Our method enables to extract the differences between red and green absorption derived from oxy-haemoglobin absorption characteristics by cancelling the effect of head movement. The comparison of RPEM with ear PPG under motion ensured the effectiveness of RPEM. We also applied RPEM to HR monitoring in office under non-controlled condition. The HR trend obtained by RPEM is in agreement with the reference ECG result. Our method achieves HR measured rate = 44 % with RMSE = 6.7 bpm even in 4 averaging beats measurement. These results indicate that RPEM enables HR monitoring in daily life with high accuracy without losing much data even under non-controlled conditions.

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