Heart Rate Synchronization with Spatial Frequency of Visual Stimuli

Jiwon Im, Min Woo Park and Eui Chul Lee

Abstract Recently, life-logging technology has been adapted to user-supplied data that can be collected from various aspects of daily life. Using this technology, images captured by the camera of a smart device should be continuously processed in order to extract meaningful data applicable to human life and emotion. In this paper, to verify a correlation between emotion synchronization and spatial frequency, images with different spatial frequencies were submitted as visual stimuli to subjects, and heart rate was measured. The results confirmed that heart rate was synchronized with delay in increment and decrement for the spatial frequency of a presented image sequence.

Keywords Heart rate · Spatial frequency · Life-logging · Emotion

1 Introduction

Recently, life-logging technology has been applied to a variety of aspects of daily life through collection and analysis of user-supplied data. The growth of wearable smart devices rapidly pushed life-logging technology into the limelight [1]. Currently, several life-logging technologies are commercially available for healthcare and user experience applications. However, images captured by cameras of smart devices are still not widely used for intelligent life-logging services.

To combine captured images with a user's emotions or experiences, the images should be processed and analyzed to extract meaningful features. Visual information such as color and frequency can affect human emotion [2]. Studies in the fields of psychology and marketing showed that specific color or packaging design patterns can affect a consumer's purchasing needs [3,4]. However, there is no research

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D.-S. Park et al. (eds.), *Advances in Computer Science and Ubiquitous Computing*,
Lecture Notes in Electrical Engineering 373,
DOI: 10.1007/978-981-10-0281-6_31

verifying a correlation between human emotion and the complexity of images of environmental scenes. The complexity of images can be represented as spatial and temporal frequencies.

In this paper, we focus on increment and decrement of spatial frequencies of image sequences. As experimental visual stimuli, 9 checkerboard images of different frequencies were used. To simulate increment and decrement of spatial frequency, 18 checkerboard images were successively presented. Heart rate was also recorded by a photoplethysmography (PPG) sensor on the index finger.

2 Experimental Method

2.1 Visual Stimuli

Nine checkerboard images with different spatial frequencies were used as visual stimuli, as shown in Fig 1. The images were automatically generated as an 8-bit

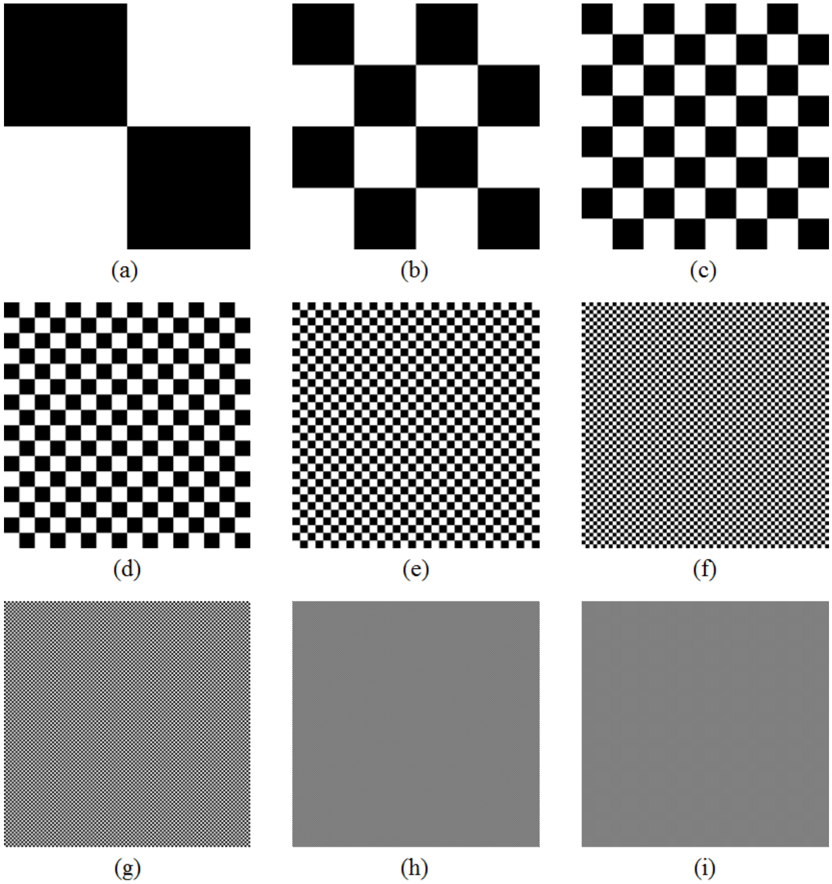

Fig. 1 Sequence of the 9 checkerboard images (a–i) used in experiments. Details of (g), (h), and (i) may be different because of image resolution)

grayscale 1024 × 1024 bitmap by using self-made recursive algorithm-based software. To remove the effect of noise such as semantic content or color on heart rate, no other factors were included in the images. Fig. 1 (a) shows the lowest spatial frequency image used, and is comprised of four squares (each square is 512 × 512). In the sequence progression from Fig. 1 (a) to (i), the spatial frequency is twice that of the previous image horizontally and vertically. Thus, the number of squares in Fig. 1 (i) is 262,144 (= 512 × 512).

2.2 Heart Rate Measurement

Generally, heart rate can be measured by using PPG or electrocardiogram (ECG) sensors. Because ECG sensor attachment is relatively complicated, our experiment used a simple USB-type PPG sensor for estimating successive heart rate information. This device does not need to use a signal amplifier. It acquires and transports 250 blood flow intensity samples per second through the USB interface.

To calculate heart rate, the R-peak (zero crossing position from positive to negative gradient) was detected, followed by the time interval between two successive R-peaks. Consequently, the heart rate can be calculated by dividing 60 seconds by the RRI (Interval between two R-peaks). For example, if RRI is 0.5 seconds, the heart rate is 120 beats per minute (= 60 seconds/0.5 seconds).

Fig. 2 A commercial PPG sensor used in the experiment [5]

2.3 Experimental Procedure

The experimental configuration including one PPG sensor and a monitor is shown in Fig. 3. Ten graduate students (male = 6, female = 4, mean age = 25.7) participated in this experiment. Environmental noise and outdoor sunlight were blocked.

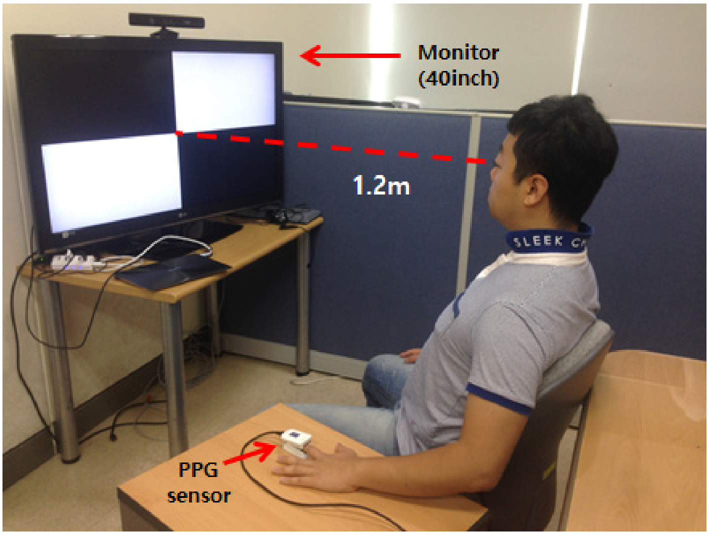

Fig. 3 Experimental configuration

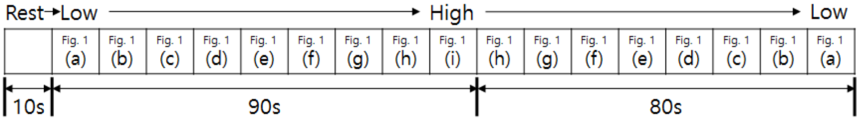

Fig. 4 Experimental procedure

Total experimental duration for each subject was 180 seconds. As shown for “Rest” in Fig. 4, reference heart rate data were recorded during an initial 10 seconds by showing a completely black image. For the next 90 seconds, incremental spatial frequency images are successively presented in a sequence from Fig. 1 (a) to (i). Then, decremental spatial frequency images are sequentially shown during the next 80 seconds, in order from Fig. 1 (h) to (a), which is the reverse of the prior 90 seconds. Thus, a total of 170 seconds of heart rate data are recorded with visual stimuli.

To regularize the size ratio of black and white regions, the visual stimuli (1024 × 1024) are resized to conform to monitor resolution (1920 × 1080), as shown in Fig. 3.

3 Results

PPG data for one subject were excluded because of motion artifact, but the data for the 9 other subjects were used for heart rate analysis. To correct for individual variation, heart rate values were normalized by subtracting reference data (calculated from the "Rest" stage in Fig. 4) from the values. Then, the normalized data of the 9 subjects were averaged for every stage (10 seconds). The results for the average normalized heart rates are shown in Fig. 5.

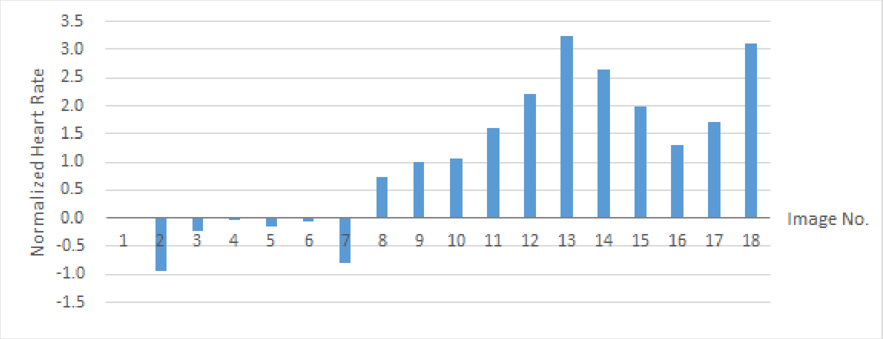

Fig. 5 Experimental results of normalized heart rate tendency according to the visual stimuli presented with different spatial frequencies

Fig. 5 shows an incremental tendency for the heart rate during 110 seconds. After that, the heart rate decreased for 30 seconds, but increased again in the last 20 seconds. Except for the last 20 seconds, the tendency for heart rate change was almost synchronous with the presented image frequencies. The interval between the highest spatial frequency (image No. 10 in Fig. 5) and the highest heart rate (image No. 13 in Fig. 5) may be due to the delay of conversion into heart rate by visual stimuli. Moreover, the heart rate increment in the final 20 seconds may be due to fatigue or stress from prolonged observation of a very high contrast pattern. However, we did confirm delayed synchronization of the heart rate with spatial frequencies of visual stimuli.

4 Conclusion

In this study, images of different spatial frequencies were presented to subjects as visual stimuli, and heart rate was measured. We confirmed that heart rate was synchronized with delay in increment and decrement for the spatial frequency of a presented image sequence. Based on these results, the complexity of edge and motion of environmental images captured by a wearable camera can be used as features to affect and evaluate human emotion and experience.

In future work, we will use scenes of actual environmental images to confirm the correlation with heart rate or other biometric features. In addition, image components such as color and brightness will be considered as affective features.

Acknowledgement This work was supported by the ICT R&D program of MSIP/IITP. [R0126-15-1045, The development of technology for social life logging based on analysis of social emotion and intelligence of convergence content].

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