リアルタイムで推定された副交感神経活動に連動する CG の生成と評価

Evaluation of the interactive computer graphics that reflects cardiac vagal activity estimated in real-time

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Abstract: Autonomic nervous system is important to maintain homeostasis and respiratory sinus arrhythmia (RSA) is known as a selective index of cardiac vagal activity. In this paper, we proposed an interactive system of computer graphics (CG) that Growth Model was regulated by the amplitude of RSA estimated in real-time, and evaluated how CG and human autonomic nervous activity interacted with each other. In the first experiment, the subject was asked body motion and mental arithmetic. As a result, the amplitude of RSA decreases under body motion and mental arithmetic. It is confirmed that the proposed method extracts the amplitude of RSA in real-time and Growth Model is regulated by it. Then, the second experiment was performed to investigate how CG affected human autonomic nervous activity precisely. The subject was asked to watch Growth Model with various motions. The amplitude of RSA increases as a reaction of the abrupt motion, while it decreases under watching fast and continuous motion.

Keywords: respiratory sinus arrhythmia, vagal activity, interactive CG, Growth Model

1. Introduction

Autonomic nervous system is important to maintain homeostasis. Therefore, the evaluation of autonomic nervous activity is very important not only for medicine, but also for the optimisation of man-machine interface. For this purpose, respiratory sinus arrhythmia (RSA) is known as a selective index of cardiac vagal activity [Katona75] and frequency analysis of heart rate variability is conventionally used for evaluating it [Hayano94]. On the other hand, we have proposed a method for evaluating RSA by respiratory-phase domain and illustrated that the respiratory-phase domain analysis extracts RSA more accurately than the conventional frequency analysis [Kotani00, Kotani07a, b]. In addition, the proposed method is suitable for real-time estimation of the amplitude of RSA. In this paper, by using the respiratory-phase domain analysis we proposed an interactive system that the motion of computer graphics (CG) reflected human autonomic nervous activity, and evaluated how CG and human autonomic nervous activity interacted with each other. For CG of this study, we used Growth Model, which had been proposed by Kawaguchi [Kawaguchi82] (Fig. 1). First, we applied respiratory phase domain analysis for interactive CG system and regulated the CG by the subject’s amplitude of RSA estimated in real-time. Second, we evaluated how Growth Model affected the subject’s autonomic nervous activity.

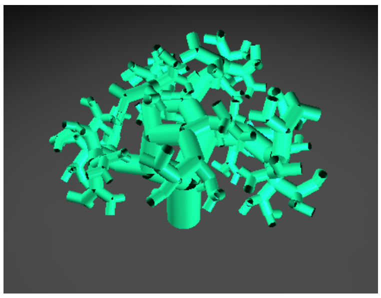

Figure 1: Growth Model.

2. Construction of the connection from autonomic nervous activity to computer graphics

2.1. Experimental Procedures

Healthy male was studied in the sitting posture and asked body motion and mental arithmetic during some sessions whose length is 120 s. The experimental conditions are shown in Fig. 2. As a physiological measurement, R-R intervals (RRI) by electro-cardiogram (AC-601, Nihon-Koden), information about respiration by elastic chest band (TR-755T, Nihon-Koden) and thermistor (TR-761T , Nihon-Koden) were recorded continuously. The electro-cardiogram was digitised at a sampling frequency of

1,000Hz, while ILV were digitised at a sampling frequency of 100Hz.

2.1. Signal Processing

A schematic diagram of the signal processing procedure is shown in Fig. 3. First, RRI was interpolated by Berger's method [Berger86]. Second, the starting and ending point of inspiration was identified. In order to identify them accurately even in case of body motion, two different types of sensors, elastic chest band and thermistor was used and analyzed. For the starting and ending point of inspiration, we detected the points of minima and maxima of signal in elastic chest band, and also that of second derivarive signal

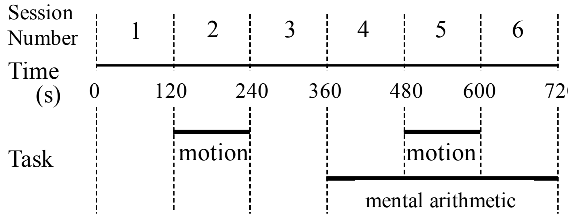

Figure 2: Time table of the experiment for the real-time RSA extraction with interactive CG.

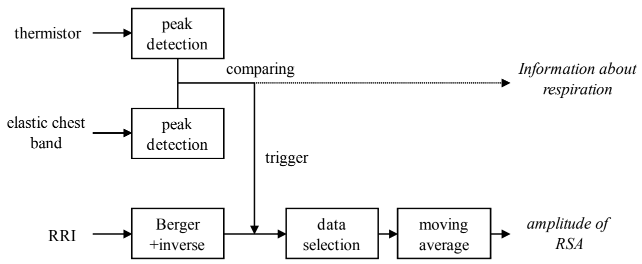

Figure 3: Schematic diagram of the real-time signal processing method for extracting RSA amplitude, which is adoptive under the condition of body motion of the subject.

in thermistor. We adopted the points of elastic chest band when the time differences of the detected points by two sensors were within 300 ms, while we adopted that of thermistor when they were from 300 to 1000 ms. In addition, we skipped the procedure for calculation of the amplitude of RSA when the time differences were over 1000 ms. Third, the raw RSA amplitude was obtained by subtraction of instantaneous RRI in the starting point of inspiration from that in the ending point. Finally, the amplitude of RSA was calculated by the procedure of moving average with the range of 24 respirations after physiologically inappropriate data (e.g. the data containing too slow respiration) was removed.

2.3. Motion of Growth Model

In this experiment, Growth Model reflected the amplitude of RSA for its color, morphology, and motion. The value of the amplitude of RSA was transmitted by UDP. As for the color, 0 ms and 100 ms in the amplitude of RSA corresponds to 0 (red) and 255 (purple) degree of the HSI color space, respectively. As for the depth of fractal, 0 ms and 100 ms in the amplitude of RSA correspond to 10 and 0, respectively. As for the motion of Growth Model, it moved fast when the amplitude of the RSA was small.

2.4. Results and discussions

The results of experiment are shown in Fig. 4. The amplitude of RSA during experiment is shown in Fig. 4 (a). The amplitude of RSA decreases in the sessions of 2, 4, 5, and 6, which corresponds to the sessions of body motion and mental arithmetic. It is considered that the cardiac vagal activity is decreased by these tasks and the proposed method evaluates the amplitude of RSA enough even in real-time. The amplitude of RSA in the sessions of body motion does not extremely decrease but almost the same degree as the mental arithmetic. Therefore, by using the data of thermistor in addition to that of elastic chest band, the proposed method avoids the exceed decrease of the extracted value due to the sensor errors by body motion.

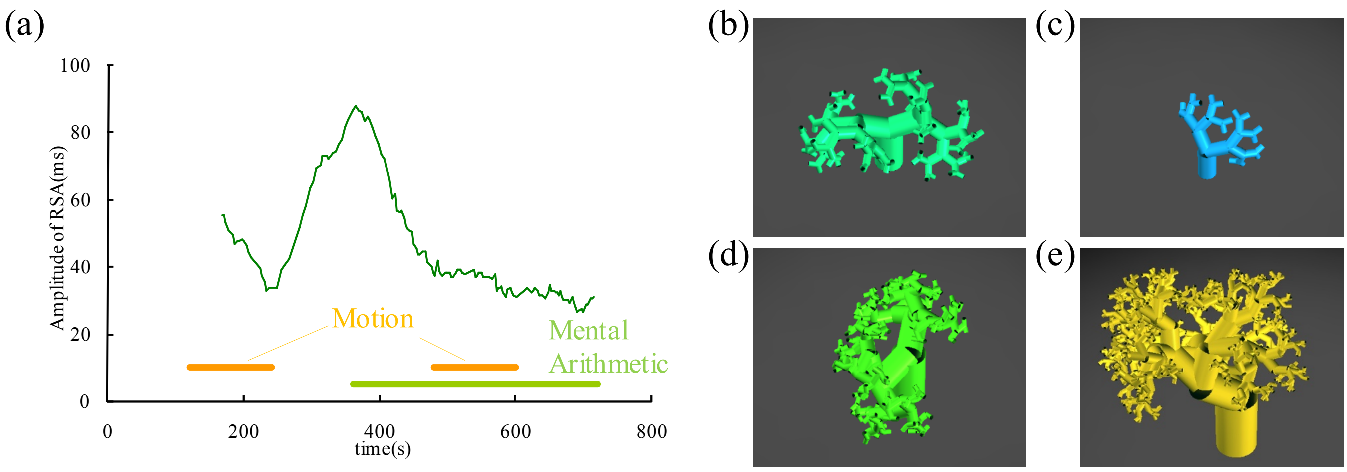

Figure 4: Results of the experiment for real-time RSA extraction with interactive CG. (a) The amplitude of RSA by the proposed method. (b) 200 s, (c) 300 s, (d) 550 s, and (e) 700 s snapshots of CG that reflect the amplitude of RSA.

The snapshots of Growth Model of this experiment are shown in Fig. 4 (b)-(e). In Fig. 4 (c), small and blue model is observed, which is the snapshot when the subject is under the rest condition. On the other hand, in Fig. 4 (e), large and yellow model is observed, which is the snapshot when the subject is under the mental arithmetic task. Therefore, it is confirmed that the model can be well regulated by the extracted amplitude of RSA in real-time. In the session 3, the amplitude of RSA is relatively high and this is considered that the subject is getting relaxed when he watches Growth Model of downsizing and getting slow. This phenomenon indicates the positive feed-back effect from CG to human autonomic nervous system. Regarding this, the further experiment is described in the next section.

3. Evaluation of the connection from computer graphics to autonomic nervous activity

3.1. Experimental Procedures

Healthy male was studied at rest in the sitting posture and asked to watch the CG (Growth Model) displayed by the projector. In this experiment, the motion of the model was arranged as shown in Fig. 5. In Session 7, basically slow and continuous motion was displayed for 720 s (Fig. 5 (b)), while abrupt motion was inserted every 120 s. As for this abrupt motion of Growth Model, the color turned red, the depth of fractal increased, the tip of each branch became large, and the speed of each branch increased in short time (Fig. 5 (c)). In Session 8, fast and continuous motion was displayed. As for this motion, although the magnitude of change was smaller than that of abrupt motion, it sustained in the session (Fig. 5 (d)). In Session 9, Growth Model was not displayed (Fig. 5 (e)). As a physiological measurement, RRI and respiration by elastic chest band were recorded continuously.

3.2. Signal Processing

In this section, in order to evaluate RSA precisely respiratory-phase domain analysis was not performed in real-time but off-line as shown in Fig. 6. Here, the Hilbert transform was used instead of the diagram of peak detection and the derivative of cubic spline interpolation (DCSI) was used instead of Berger's interpolaion method. The detailed algorithm for signal processing was the same as that of [Kotani07b]. We extracted the amplitude of RSA under the condition of watching Growth Model with slow and continuous motion (Session 7-slow), reaction to abrupt motion of it (Session 7-abrupt), watching Growth Model with fast and continuous motion (Session 8), and watching background (Session 9). As for the evaluation of the amplitude of RSA in Session 7-abrupt, after-one breathing of each abrupt change occurance was extracted.

3.3. Results and discussions

The amplitude of RSA under each condition is shown in Fig. 7. the amplitude of RSA in Session 7-abrupt is larger than that in Session 7-slow. This is supposed to be caused by startle reaction. As for a startle reaction, Yoshino et al. reported that heart rate decreased in the startle state [Yoshino07]. Both of our results and the results of [Yoshino07] can be illustrated by the increase of cardiac vagal activity.

In addition, the amplitude of RSA in Session 8 is smaller than that in Session 7-slow. This is due to decrease of cardiac vagal activity by watching CG with fast and continuous motion. Furthermore, the amplitude of RSA in Session 9 is the largest of all sessions.

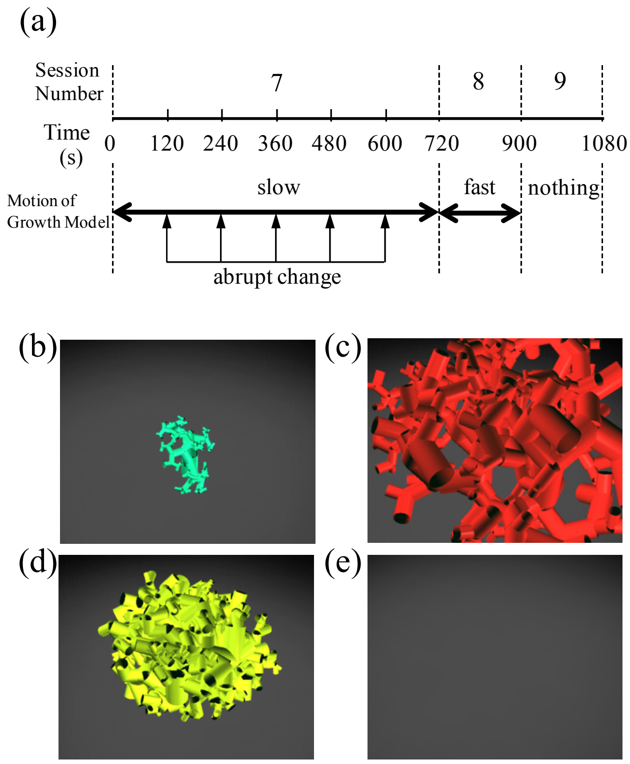

Figure 5: The motion of Growth Model. (a) Time table of the experiment. (b)-(e) Snapshots of the conditions of experiment, (b) slow and continuous motion, (c) abrupt motion, (d) fast and continuous motion, (e) background.

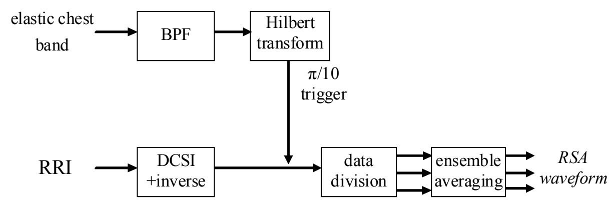

Figure 6: Schematic diagram of the signal processing method for extracting RSA waveform. The BPF box refers to band-pass filtering.

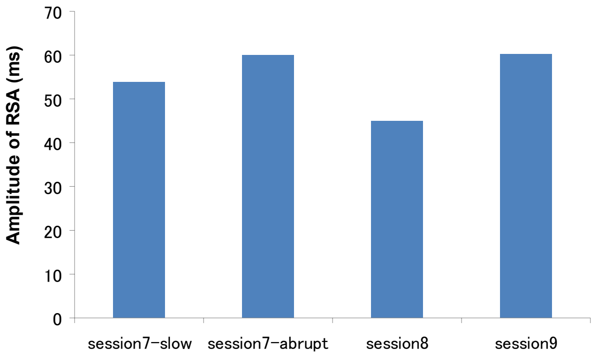

Figure 7: The amplitude of RSA in each session.

These results indicate that the autonomic nervous activity is changed by the motion of CG. and it is important to optimise human interface or design interactive systems. But physiologically, many things remain unkown about the response of autonomic nervous activity against the motion of CG. Therefore further experiments and statistical analyses are required about it.

Acknowledgement

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