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A Study on the Relationship between QoE of Audiovisual Content and Heart-rate Variability

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Abstract– This research investigated the relationship between QoE (Quality of Experience) of audiovisual content and heart-rate variability using wearable heart-rate sensor. As the analysis method of heart-rate variability, the LF ratio obtained by frequency analysis of RRI (R-R Interval), the distance from the origin to the center of the ellipse by which the Lorenz plot is approximated and the area of the ellipse were used. First, based on Russell's circumplex model this research investigates the subject's emotional shift when subject watches various audiovisual contents. It can be seen that the pleasantness depended on the resolution of audiovisual content. However, emotional shift did not occurred when subjects did not notice the degradation of contents. Next, heart-rate variability was measured for audiovisual contents that were affected by quality degradation due to video stop. There was a partial relationship between QoE of audiovisual content with quality deterioration and heart-rate variability.

1. Introduction

Mainly QoS (Quality of Service) has been used for evaluating the quality of communication services. However, the quality of communication services which users feel may be different depending on the psychological condition of users even if QoS of the communication service is same. Hence, QoE has become also important for evaluating the quality of communication services.

QoE is measured by subjective evaluation. However, it takes long time to perform subjective evaluation, and subjective evaluation involves a significant cost. Hence, a technique for estimating QoE is needed. QoE depends on the psychological condition of users. The psychological condition can estimate from the biological information. Hence, investigation of the relationship between the biological information and QoE is needed for estimating QoE.

This research is focused on streaming video service as a communication service. This research assumes that human beings are stressed by the degradation of the quality of audiovisual contents and then QoE decreases. Hence, this research investigates the relationship between QoE and biological information related to stress. Human stress conditions are known to relate to the autonomic nervous system. As a means of estimating how much the autonomic nervous system is affected by stress, there is a method using salivary amylase activity value. As another means, there are some methods using pulse[1], heart-rate variability[2] and electrical resistance of skin surface[3]. These methods are non-invasive methods. Among these related studies, only the electrical resistance of skin surface is studying the relationship with the QoE of the video content, and there is room for investigation on the relationship between the QoE of the audiovisual content and the heart-rate variability. Hence, this research focuses on heart-rate variability.

Since the sympathetic and parasympathetic nerves have an affect on the action of heart, it is possible to know the degree of influence of sympathetic nerve and parasympathetic nerve by analyzing heart-rate variability. Frequency analysis and Lorenz Plot (LP)[4][5] are often used for quantifying the degree of influence of sympathetic nerve and parasympathetic nerve. Specifically, power spectrum of RRI which is a heartbeat period, is obtained by frequency analysis. And then, low frequency component (LF) whose frequency range is from 0.04 [Hz] to 0.15 [Hz] and high frequency component (HF) whose frequency range is from 0.15 [Hz] to 0.4 [Hz] are obtained as indices of the influence of autonomic nerve system. Here, LF is affected by both sympathetic and parasympathetic activity, and HF is mainly affected by parasympathetic activity. Hence, the degree of stress can be quantified using LF and HF. Lorenz plot is approximated by an ellipse, and then the distance from the origin to the center of the approximated ellipse and the area of the approximated ellipse were used for quantifying the degree of influence of sympathetic nerve and parasympathetic nerve.

2. Measurement and analysis of heart rate

2.1. Measurement method of heart rate

Electrocardiogram (ECG) is a periodic wave shown in Fig. 1. ECG has some peaks called P-wave, Q-wave, R-wave, S-wave and T-wave, respectively. From these peaks, only R-wave is extracted and R-R interval (RRI) is obtained from the difference time between R-waves. RRI is always fluctuating and is affected by the function of autonomic nerve system. Fig. 2 shows an example of RRI variability obtained in 60 seconds. From this figure, it can be seen that RRI is always fluctuating.

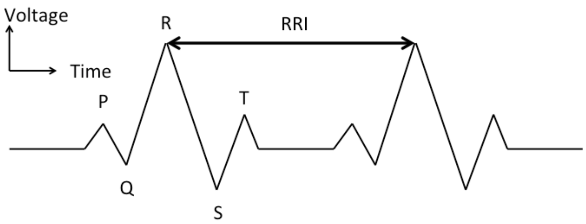

Fig. 1 A contour of ECG

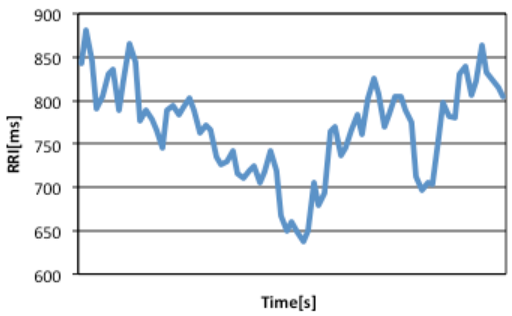

Fig. 2 An example of RRI variability obtained in 60 seconds

This research employs a wearable heartbeat sensor myBeat (WHS-1) manufactured by Union Tool Co., Ltd. to obtain ECG. With myBeat, biological information such as heart rate, body surface temperature, and triaxial acceleration can be detected, and stress state and posture can be evaluated by dedicated software.

Heart-beat sensor is fixed to chest by a dedicated electrode band. The placement position is around the epigastrium, but before the start of experiment, appropriate position is determined by confirming the ECG and the RRI. However, RRI may become extremely large because the sensor cannot correctly detect the heartbeat due to movement of the subject etc. Hence, RRI outside the range of ±3σ (σ is the standard deviation) from the average value of the detected RRI is an abnormal value. Also, since RRI is constantly fluctuating, it is sampled at unequal intervals. Hence, interpolate with a cubic spline function and resample at 10 [Hz] to obtain data at even intervals. Simultaneously, the abnormal value of RRI is replaced by interpolation. Fig. 3 shows an example of interpolation by spline function.

The following section shows the analysis methods of RRI obtained by myBeat.

2.2. Frequency analysis of RRI variability

Power spectrum of RRI is obtained by DFT (Discrete Fourier Transform). The frequency range from 0.04 [Hz] to 0.15 [Hz] is set as the low frequency range (LF) and the frequency range from 0.15 [Hz] to 0.4 [Hz] is set as the high frequency range (HF). LF component and HF component are obtained from power spectrum of each frequency range. Here, LF is mainly used as an indicator of sympathetic activity, and HF is mainly used as an indicator of parasympathetic activity. In order to measure

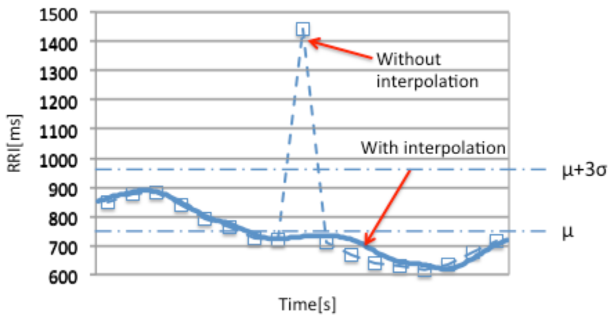

Fig. 3 An example of interpolation by spline function

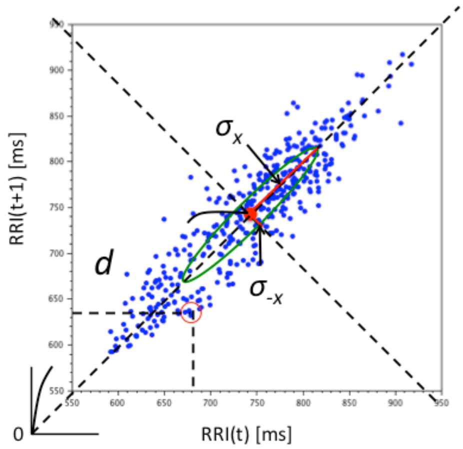

Fig. 4 An example of Lorenz plot

the activity of sympathetic nerve, LF / (LF + HF) * 100, which is the LF ratio, is used rather than simply using LF and HF as indices.

2.3. Analysis of RRI variability by Lorenz plot[4]

The Lorenz plot is obtained by plotting RRI on a plane with RRI at time t as x-coordinate and RRI at time t+1 as y-coordinate. An example of Lorenz plot is shown in Fig. 4. In order to analyze Lorenz plot quantitatively, Lorenz plot is approximated by an ellipse. The major axis of the ellipse is assigned to $y = x$, and the minor axis of the ellipse is assigned to a perpendicular straight-line to $y = x$. The center of ellipse is determined by the average distance of all plots projected onto the major axis. This average distance is referred as d. The length of major axis is determined by the standard deviation of plots projected onto the major axis. This standard deviation is referred as σ_x. The length of minor axis is determined by the standard deviation of plots projected onto the minor axis. This standard deviation is referred as σ_{-x}. The area of approximated ellipse is represented by Eq. (1).

$$S = \pi \sigma_x \sigma_{-x} \quad (1)$$

It is known that the distance d from the origin and the area S of the ellipse are related to the activity of the sympathetic nerve. It is said that the activity of the sympathetic nerve becomes active when d and S become small.

2.4. Normalize[5]

Since the measured data depends on the subject, it is not possible to directly compare the data. For this reason, the distribution of the reference data is normalized to the distribution with the average 0 and the variance 1.

3. Experiments

This research verifies whether subjects feel stress when subjects watched audiovisual contents whose quality has deteriorated due to deterioration of communication quality, and whether the degree of stress can be detected by RRI variability. However, depending on the audiovisual content, there is a possibility that the subject feels stress even if there is no deterioration in quality due to the subject's preference. For this reason, this research investigates the subject’s emotional shift when subject watches various audiovisual contents. Next, heart-rate variability was measured for audiovisual content that was affected by quality degradation due to video stop.

These experiments were carried out in an anechoic chamber inside of the Nippon Institute of Technology. The audiovisual contents are displayed on a 32-inch monitor (manufactured by Asus), and the audio signal is transmitted from the audio interface (Dr. DAC 2 manufactured by Audio Truck Co.) via a driver unit (SRM-006 tS manufactured by STAX Corporation). And then, it is reproduced from an ear speaker (SR-407 manufactured by STAX Co., Ltd.). Subjects were adjusted to volume that was easy to hear by the audiovisual contents not used for experiment before starting the experiment.

3.1. Investigation of emotional shift

In this experiment, Russell’s circumplex model[6] is used to investigate the emotional shift. Emotion is modeled by two-dimension plane as shown in Fig. 5. The right half of this plane represents pleasant emotion. On the other hand, the left half of this plane represents unpleasant emotion. The upper half of this plane represents high arousal. On the other hand, the bottom half of this plane represents low arousal.

Subjects indicate their emotion using an android application. This application samples coordinate value at 10 [Hz]. Subjects are required to watch nine types of audiovisual contents. The duration of these contents is 300 seconds, and the time interval between contents is 120 seconds.

Figure 6 shows the emotion when a subject watched nine audiovisual contents. From this result, it can be seen that subject’s emotion for each content varied even if there is no deterioration in quality. And also subject’s emotion was different depending on how deterioration occurred. “Classic Halt” and “Classic Change” were unpleasant contents. On the other hand, “Classic Low” was a pleasant content.

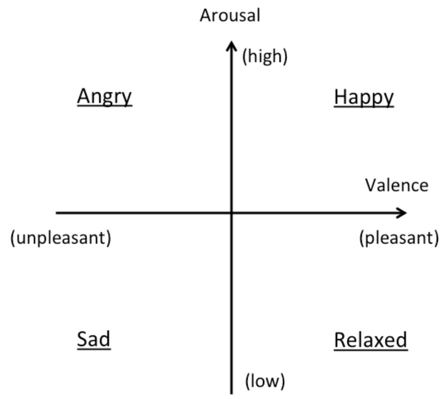

Fig. 5 Valence-Arousal plane based on Russell’s circumplex model

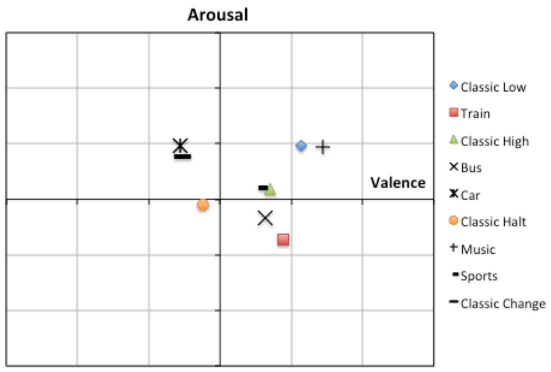

Fig. 6 Emotion when a subject watched nine audiovisual contents. “Classis Low” indicates classic music content whose resolution is 854x480 pixels. “Classic High” indicates classic music content whose resolution is 1280x720 pixels. “Classic Halt” indicates classic music content that includes 20-seconds halt. “Classic Change” indicates classic music content whose resolution changes frequently.

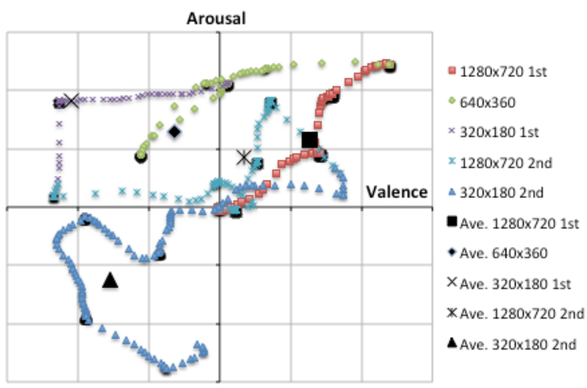

Fig. 7 Emotional shift when a subject watched “Classic Change”. Subject watched audiovisual contents in order as follows: “1280x720” pixels, “640x360” pixels, “320x180” pixels, “1280x720” pixels, and then “320x180” pixels.

Figure 7 shows the emotion shift when a subject watched "Classic Change". It can be seen that the pleasantness depended on the resolution of audiovisual content.

3.2. Investigation of the relationship between QoE and heart-rate variability

In this experiment, subjects are required to evaluate audiovisual contents whose resolution is degraded and/or that include 15-seconds halt. The resolution was set to 1280 × 720 (original size) or 854 × 480. Subjects are required to watch a total of 8 kinds of audiovisual contents. During the video viewing, each subject constantly evaluates the QoE for the audiovisual contents by the tablet in 5 levels (Poor ~ Excellent). On the tablet, a number line corresponding to 0 to 100 is displayed, and subjects can evaluate by dragging the knob in the screen. The evaluation value is sampled at 10 Hz.

Table 1 shows the time average of QoE for audiovisual contents. From Table 1, it can be confirmed that QoE decreased with respect to the halt of video, whereas a marked decrease of QoE in resolution was not confirmed.

Table 2 shows the average value of each indicator calculated for each of the four conditions. From Table 2, the normalized LF ratio when subjects watched a video whose resolution is 854x480 was higher than the original content. Hence, the sympathetic nerve is dominant. However, there was only partial relationship between QoE of audiovisual content with quality deterioration and heart-rate variability.

4. Conclusions

In this study, we investigated the relationship between QoE and heart-rate variability when viewing video content using wearable heart-rate sensor. As the heart-rate variability, the LF ratio obtained by frequency analysis, the distance d between the center of the ellipse approximating the Lorenz plot and the origin, and the area S of the ellipse were used.

First, Russell's circumplex model was used to investigate the emotional shift. It can be seen that subject's emotion was vary from content to content even if there is no deterioration in quality. And also subject's emotion was different depending on how deterioration occurred. It can be seen that the pleasantness depended on the resolution of audiovisual content. However, emotional shift did not occurred when subjects did not notice the degradation of contents.

Next, we investigated the relationship between QoE and heart-rate variability when viewing video content with degraded quality assuming deterioration of communication quality. There was a partial relationship between QoE of audiovisual content with quality deterioration and heart-rate variability.

As future works, a time-series analysis technique will be employed for analyzing heart-rate variability.

Table1 QoE for four conditions
（The number in a parenthesis is Standard deviation.）

Condition	QoE
Resolution : 1280×780 Halt : 0[s]	70.9 (12.4)
Resolution : 1280×780 Halt : 15[s]	49.1 (16.6)
Resolution : 854×480 Halt : 0[s]	68.4 (10.3)
Resolution : 854×480 Halt : 15[s]	54 (21.7)

Table2 Stress index for four conditions

Condition	d	S	LF ratio
Resolution : 1280×780 Halt : 0[s]	0.225	-1.976	0.054
Resolution : 1280×780 Halt : 15[s]	1.426	-2.221	-0.139
Resolution : 854×480 Halt : 0[s]	0.512	-1.951	0.331
Resolution : 854×480 Halt : 15[s]	0.997	-1.559	0.297

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