Heart Rate Monitoring by A Pulse Sensor Embedded Game Controller

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***Abstract*—If player condition during video game playing could be measured in real time, it would become possible to develop a new game interaction system. Since heart rate (HR) has been used for various psychological state estimation, it can be used for player condition estimation. The present work consists of two parts: the development of a new game controller that can measure player HR naturally based on a photoplethysmogram (PPG), and simultaneous monitoring of player condition by using the newly developed game controller.**

The experiment result demonstrated that the newly developed game controller could measure the player HR with sufficiently high accuracy. In addition, it showed that the correlation coefficient between HR and the game score varied according to player condition. This indicates that player condition during video game could be estimated by monitoring HR and the game score simultaneously.

I. Introduction

Player condition estimation during video game playing has been attempted for a new game interaction design. Castellar *et al.* showed that HR fluctuation of players became large when they acted aggressively in a role-playing game [1]. This indicates that video game experience can be enhanced if player heart rate (HR) can be measured in real time during video game playing.

In fact, some video game interaction systems based on player HR measurement have been proposed. For example, Masuko and Hoshino developed a fitness game that can adjust fitness load according to feedback from the player HR monitored by a chest HR sensor [2]. In addition, the game difficulty was controlled by monitoring player HR in order to fill the game score gap between players because such gaps sometimes make bad players give up the game [3].

Since these game systems require extra devices for HR measurement, such devices may spoil player experience. A new HR measurement method using a smartphone camera was proposed for a smartphone game [4]. Although this method can calculate HR by detecting changes in the transparency of a player fingertip via a camera, players are required to touch the camera lens during game playing for HR measurement.

In this work, a new photoplethysmogram (PPG) sensor-embedded game controller was developed. Since PPG can be easily measured from a fingertip, it can be used for HR measurement. The newly developed controller enables natural HR measurement during video game playing, and does not spoil any game experience. The HR acquisition accuracy of the new controller was validated by comparison with that of an HR telemetry device through experiments. In addition, the relationship between player HR measured by the newly developed controller and the game score was analyzed for player condition estimation.

II. Photoplethysmogram

A pulse wave is a biological signal that represents blood flow volume change in a peripheral artery such as a fingertip or an earlobe. Since the pulse wave is affected by the autonomic nervous function, it has been used for various psychological state estimation such as stress, fatigue, and drowsiness [5]–[8].

PPG, in particular, is the pulse wave signal acquired by an optical technique. The intensity of reflected light from skin fluctuates according to the amount of hemoglobin change, which is caused by capacitance variation of blood vessels. Near infrared light (600nm - 1000nm) is suitable for PPG measurement because it permeates the skin and is absorbed into bloodstream hemoglobin. Therefore a PPG sensor consists of an LED that emits near infrared light to the skin and a phototransistor that measures the intensity of reflected light. As shown in Fig. 1, they are located close to each other so that the phototransistor can receive the reflected light from the skin. Finally, PPG is obtained as a voltage value of the phototransistor.

III. Video Game Controller with PPG Sensor

A video game controller with a PPG sensor was developed for measuring HR during video game playing. Figure 2 shows a prototype of the newly developed controller. There are two types of PPG sensors, a permeation type sensor and a reflective type sensor. The reflective type PPG sensor was used here because it can measure PPG without fixing a fingertip on the sensor. However, in order to allow a reliable contact with the

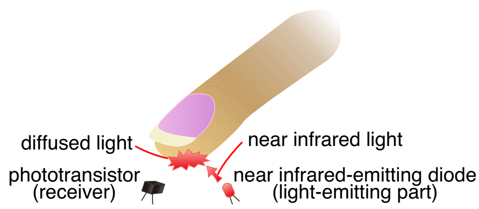

Fig. 1. Schematic diagram of PPG sensor

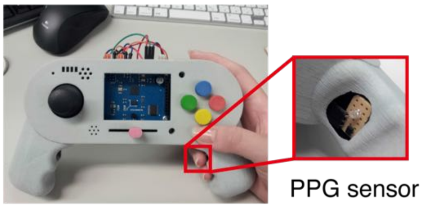

Fig. 2. Newly developed video game controller with PPG sensor

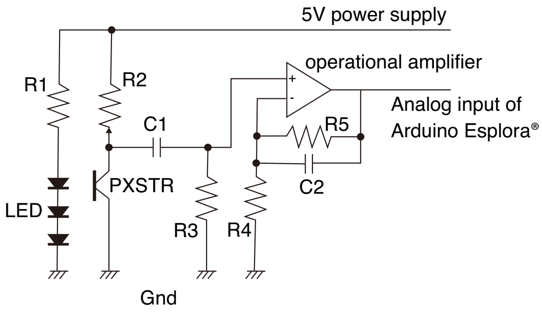

Fig. 3. Electronic circuit for PPG measurement

PPG sensor, the newly developed game controller has finger guides inside the grip, and the PPG sensor is embedded in the right middle finger guide, as shown in Fig. 2. This design realizes a stable PPG measurement because the right middle finger position does not change even when a player operates the controller aggressively, as long as he/she grips the game controller appropriately.

In the new controller, PPG can be measured through Arduino EspLora®, which is a microcomputer equipped with various input methods for game operation such as an analog joystick and switches. A schematic diagram of the PPG sensor circuit used in the new controller is shown in Fig. 3. The voltage value from the phototransistor is amplified by an operational amplifier and inputted into Arduino EspLora® and converted from an analog value to a digital value.

The instant HR [beat/min] is obtained from the measured PPG in real time according to the following procedure:

1) Calculate second derivative of PPG (SDPPG).
2) Detect the zero cross point where SDPPG changes positive values to values less than zero.
3) Calculate PPG-derived RR intervals (RRI) r[s], which is the time difference of the adjacent SDPPG zero cross points.
4) Obtain the instant HR as $60/\bar{r}_{10}$, where $\bar{r}_{10}$ is the ten-second moving average of the calculated r.

Figure 4 shows the PPG, SDPPG, RRI, and HR obtained by the new game controller.

IV. Experiment

The HR acquisition accuracy of the newly developed game controller was validated through experiments.

Experimental participants played a shooting game by using the new game controller for thirteen minutes. In addition,

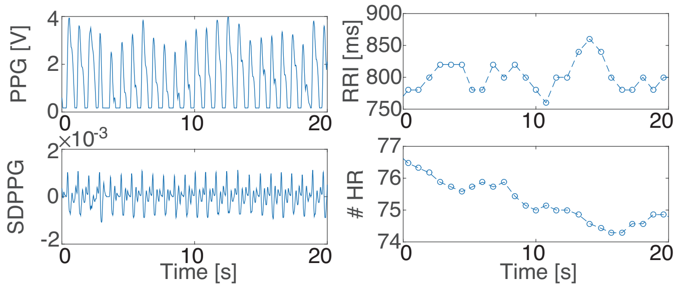

Fig. 4. PPG, SDPPG, RRI, and HR

Fig. 5. Experimental environment

participants were required to measure HR by using an HR telemetry device [9] as a reference during the experiment. The total number of the participants was eleven. Figure 5 shows the actual experimental environment. In this experiment, individual participant's consent was obtained.

The HR measurement accuracy of the newly developed game controller was evaluated on the basis of root mean squared error (RMSE). The mean and the standard deviation of RMSE of all participants were 2.0 and 2.5, respectively. This result shows that the new game controller can measure the player HR with sufficiently high accuracy.

Figure 6 shows an example of PPG, first derivative of PPG (FDPPG), SDPPG, RRI, and HR acquired by the new game controller during game playing. Although the absolute value of PPG was noisy around 5 - 15 s, its peak could be clearly acquired by calculating FDPPG. Although, in this case, a high frequency noise component caused RRI miscalculation, HR could be calculated appropriately since HR was calculated from the ten-second moving average of RRI.

Figure 7 shows the HR data of participant No. 7 and No. 11 obtained by the new game controller and the HR telemetry device. Although there were few errors between the new game controller and the HR telemetry device with participant No. 11, large HR acquisition errors occurred within the first 100 seconds in the participant No. 7. These errors could have occurred when a participant did not grip the game controller appropriately. This indicates that it is important to design the

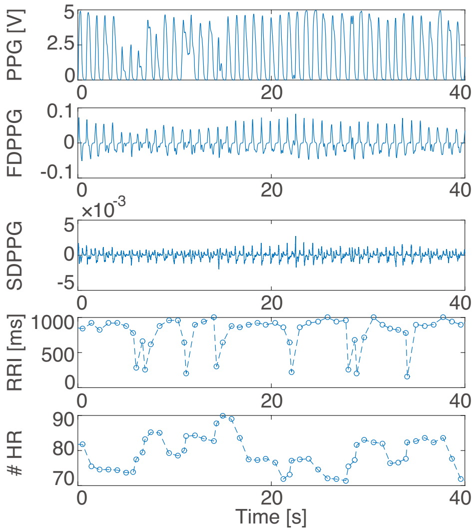

Fig. 6. PPG, FDPPG, SDPPG, RRI, and HR during experiment

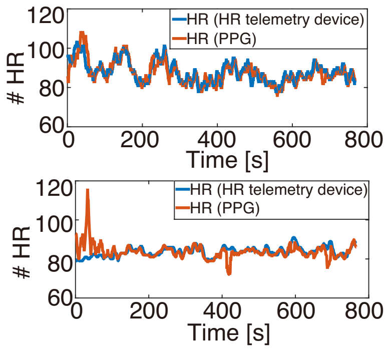

Fig. 7. HR calculated by PPG and HR telemetry device (top: the result of participant No.11, bottom: the result of participant No.7)

grip shape so that a player can touch the PPG sensor naturally.

V. Analysis

The relationship between the game score in the shooting game and the HR data obtained by the newly developed controller was analyzed.

In this experiment, the HR data and the game score in the shooting game were recorded, simultaneously. The game score increases when a player defeats enemies; however it returns to zero when a player vehicle is hit by an enemy bullet although the shooting game goes on. After playing the shooting game, the participants were required to evaluate twelve questionnaires by five scales (1: very high, 2: high, 3: moderate, 4: slightly, 5: never) . Table I shows the questionnaires, and they were made on the basis of the preliminary experiment result.

The correlation coefficients between HR and the game score were calculated. In this analysis, the 50 beats data obtained shortly after a player vehicle is hit by a enemy was not used for evaluation since it is assumed that HR does not follow sudden events. The calculated correlation coefficients of all participants are shown in Fig. 8. This figure shows some participants have positives correlation between HR and the game score while four participants do not have correlation. Figures 9 - 11 show that the HR data and the game scores of participants No. 8, 9, and 10 whose correlation coefficients between HR and the game score were 0.40, -0.27, and -0.03, respectively. In these figures, the colored band denote the periods that were not used for evaluation. From these figures, HR of participant No. 8 became high when his/her game score exceeded about 10,000 while that of participant No. 10 fluctuated regardless of his/her game score. In addition, the increase in the game score of participant No. 9 was accompanied with the decrease in HR around 300 - 500 beat.

In order to investigate the factor of the difference between participants whose correlation between HR and the game score were strong and weak, their questionnaire results were analyzed. Figure 12 shows the relationship between the correlation coefficients between HR and the game score and the answered scale of the questionnaire No. 5. In this questionnaire, the higher the scale, the less that the feelings of the participants changed during the game; that is, the participants kept calm. This result shows that players kept calm when the correlation coefficients between HR and game scores were more than 0.2. On the other hand, the participants whose correlation coefficient between HR and game scores was less than -0.2 answered the scale 2 to the questionnaire No. 5; this indicates that their feelings often changed during the game. Figure 13 shows the relationship between the correlation coefficients between HR and the game score and the answered scale of the questionnaire No. 7. The participants whose correlation coefficients between HR and game scores were from -0.2 to 0.2 answered the scale 1 or 2 to the questionnaire No. 7. This result shows that the correlation between HR and game scores was weak when the players were able to continue the game without getting tired till the end.

This analysis indicates that player conditions during video game can be estimated by monitoring the correlation between player HR and the game score although additional data and analysis is needed for confirmation of the present work.

TABLE I
Questionnaires

No.	questionnaire
1	I usually play video games frequently.
2	The game was difficult.
3	The game was fun.
4	I was excited by the game.
5	My feeling changed frequently.
6	I concentrated on the game.
7	I was able to continue the game without getting tired till the end.
8	I was satisfied with the game.
9	I want to try the game again.
10	The purpose of the game was to get a high score.
11	The purpose of the game was to escape from enemies and bullets.
12	I had no purpose of playing the game.

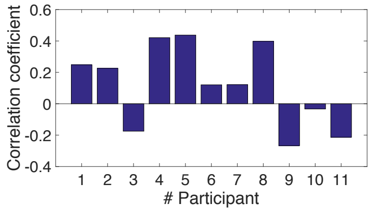

Fig. 8. The correlation coefficients between HR and game score

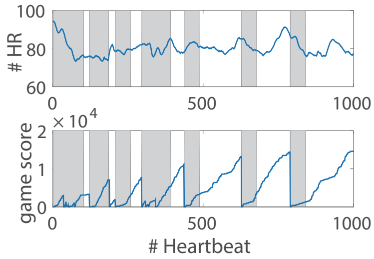

Fig. 9. HR and game score of participant No.8

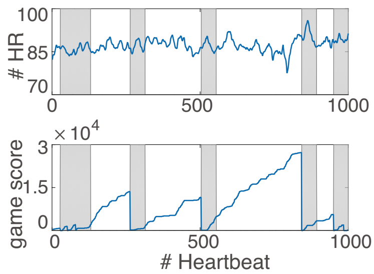

Fig. 10. HR and game score of participant No.9

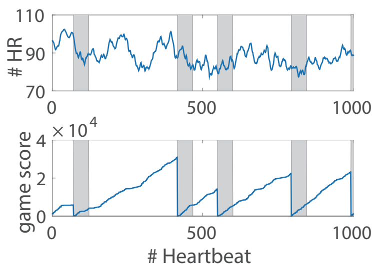

Fig. 11. HR and game score of participant No.10

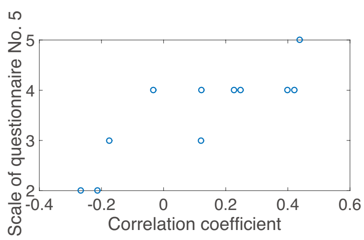

Fig. 12. The correlation coefficient between HR and game score versus scale of questionnaire No.5

VI. Conclusion

In the present work, a new video game controller with a PPG sensor for player HR measurement during video game playing was developed, and its HR acquisition accuracy was demonstrated through experiments. The experiment result showed that there was a positive correlation between HR of players and game scores when players kept calm. In addition, it was shown that the correlation coefficients between HR and game scores were low when the players were able to continue the game without getting tired till the end. This indicates that player condition during video game can be estimated by monitoring the correlation between player HR and the game score.

In future works, the grip shape of the game controller will be optimized for improving the HR acquisition accuracy, and a new video game interaction will be designed on the finding that there is a relationship between HR and player condition.

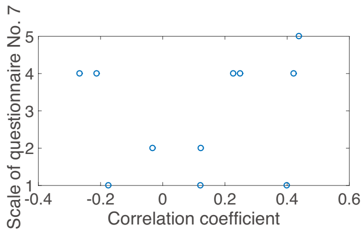

Fig. 13. The correlation coefficient between HR and game score versus scale of questionnaire No.7

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