Latest Trends in Biometric Sensing Head Mounted Displays

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ABSTRACT

Measuring biometric information helps us estimate the users' excitement degree and their negative and positive emotions. By measuring a person's biometric information while experiencing virtual reality (VR), it is possible to interactively change the content according to the estimated emotional state of the person. However, the hassle and discomfort of wearing the sensor interfere with the VR experience, and the body motion caused by the VR experience prevents accurate measurement. Therefore, some studies have developed devices incorporating biometric measurement sensors into Head Mounted Displays (HMDs). Since we use HMDs by pressing them against our faces, biometric sensing by HMDs is resistant to body movements and can reduce the discomfort of sensor attachment. This paper introduces our research on HMDs with embedded sensors and our previous study as part of this project. This paper presents the various biological sensing HMDs including our research, and discusses VR applications using those HMDs.

1 Introduction

With the development of sensing technology, it has become possible to calculate various biological indices such as heart rate, respiration rate, and perspiration rate by measuring biological information. Various studies have suggested the possibility of estimating arousal, which indicates the degree of excitement, stress, and emotional valence, negative and positive states, using these biological indices.

In Virtual Reality (VR), many systems incorporate biological measurement. They mainly use VR systems as devices that reproduce situations, present specific sensory stimuli, and verify the stimulus's effects on the user's body by measuring and analyzing the biological responses [1]. In addition, by measuring the user's biological information during the VR content experience, we can estimate the user's level of arousal and interactively change the difficulty level and other aspects of the VR content accordingly.

Attaching a sensor directly to the user's body is common when measuring biometric information. During the VR experience, it is necessary to attach a sensor in addition to the Head Mounted Display (HMD) to acquire an electrocardiograph (ECG), photoplethysmogram (PPG), and respiratory waveforms, which are effective in estimating emotional state. In addition, many VR content experiences involve body movement, and the biometric sensor may shift due to the user's motion. Therefore, fixing the sensor to the body while experiencing VR contents is necessary for stable measurement. As described above, it isn't easy to measure biometric data using existing wearable sensors while experiencing VR.

Several studies have attempted to place sensors directly on the HMD to solve the problems of measurement load and body motion. Integrating the measurement sensors into the HMD makes it unnecessary to wear other wearable sensors, thus reducing the burden on the user. Moreover, when the user wears the HMD for VR experience, the HMD should be placed close to the face, not shifting even when the user moves their body. For this reason, we can reduce the wearing load of the sensor, which is used in close contact with the skin, and avoids misalignment of the sensor due to body movement. In addition, because we always fix the HMD in the same position to focus on the presented image, there is no need to fine-tune the sensor position every time the VR content experience starts. Existing wristband-type wearable biometric measurement devices also satisfy the requirements for biometric sensing during VR content experience regarding low sensor wear load. However, biometric measurement with HMDs has the advantage of obtaining information such as respiratory waveforms and facial expressions, which cannot be obtained with wrist measurements. Due to the above benefits, various biological sensing HMDs have been developed.

This paper introduces the various biological sensing HMDs including our research, and discusses VR applications using those HMDs.

2 Types of Biological sensing HMDs

We can measure various types of biological information from the face and head where the HMD is worn, such as pulse waves, respiration, electro-encephalogram (EEG), and cerebral blood flow. For each biometric, the researchers have been developing methods to measure it with the HMD. This section summarizes the advantages of measuring each biometric in VR and the research of biological sensing HMDs.

2.1 Gaze and pupil diameter

The market's most common biometric measurement function of HMDs is eye tracking. By measuring the eyesight and gaze of the VR user wearing the HMD in real-time, it is possible to construct a more expressive and natural avatar and realize intuitive object selection and information input by gaze [2,3]. In addition, since the system can track where the user is focused, it can evaluate whether or not the user is interested in some virtual objects. In this way, we can generate a saliency map of the user in space so that it is also used to analyze purchasing behavior. The pupil diameter is an autonomic indicator, and we can estimate the level of excitement and stress from it.

2.2 Heart rate and pulse wave

Indices obtained from heartbeats and pulse waves are used to evaluate the autonomic nervous system. It has been confirmed that the R-R interval (RRI) and the R-R interval variability (RRV), calculated from the R-wave interval of the ECG and its variance, change significantly with mental stress load [4]. Using the pulse wave, we can also estimate the mental stress load with the peak interval of the PPG. Frequency analysis of the pulse wave yields the frequency spectrum of the RRI, and the area ratio between the 0.04-0.15Hz (LF=Low Frequency) and 0.15-0.4Hz (HF=High Frequency) regions is related to the autonomic nervous balance [5]. When the sympathetic nervous system is dominant, the HF component is suppressed, and the area ratio LF/HF becomes large. Conversely, when the parasympathetic nervous system is dominant, LF/HF becomes small. Thus, many research reports that the more relaxed a person is, the smaller the LF/HF value becomes. By measuring the pulse wave and calculating these physiological indices, we can estimate the emotional state of the VR user in real time.

Considering the ease of integration into HMDs and the reduction of the effects of body movements, HMDs are often equipped with reflective PPG sensors that employ green light [6]. In addition, some research has confirmed that the peak interval and variance of the PPG vary significantly with mental stress load and use these features to estimate the arousal level [7]. In many cases, the measurement position is the forehead, where the HMD is in contact with the skin, and stable measurement is possible due to the large flat contact area [8].

2.3 Respiration

Indices obtained from respiratory waveforms also evaluate the autonomic nervous system. The difference between the peak frequency of the power spectrum of the respiratory waveform and the center-of-gravity frequency indicates the instability of respiration. It can be used as an indicator of the degree of tension. There are two methods for measuring respiratory waveforms: one is to indirectly calculate respiratory waveforms by measuring body movements caused by breathing, and the other is to measure exhalation information directly. The doppler radar and piezoelectric sensors were used to measure the displacement of the chest and changes in chest circumference to measure body movements caused by breathing. These methods are not suitable for use in HMDs. On the other hand, there are some methods to measure exhalation information: breathing sound, Co2 concentration, the temperature of exhaled air, and so on. These methods are uncomfortable for measurement in daily life because the sensors are placed near the face, but they are suitable for use in HMDs.

Hernandez et al. estimated heart rate and respiration rate using the accelerometer, gyroscope, and camera of google glass [9]. However, in addition to heart rate, variations in peak intervals of ECG or PPG, respiratory depth, and the ratio of exhalation to inhalation are necessary to estimate emotional states such as arousal. On the other hand, Kodama et al. focused on the fact that the temperature of the air inside the nose changed due to breathing and used a device that can insert a thermistor into the nostrils to measure the respiratory waveform of a person wearing glasses [10]. Although this method targets people wearing glasses, we can apply it to people wearing HMDs, as most HMDs are worn with the nose exposed to the outside.

3 Biological Information Measurement Device that can be attached to various HMDs

We have developed a method of estimating biometric data by integrating a sensor for biometric measurement into the HMD. As described above, there are several methods to measure biometric information while wearing an HMD, such as incorporating a sensor for biometric measurement in the HMD. However, since many HMDs are already available in the market, rather than developing a new HMD with a built-in biometric sensor, it is better to build an external biometric sensing device that can be installed easily. It will reduce the cost of introducing sensing and help biometric sensing HMDs to be used in many scenes. Therefore, we have developed a photoelectric volumetric pulse wave and respiratory waveform measurement device that can easily attach to many HMDs.

Fig.1 shows the biometric sensing device we have developed. This device can measure photoelectric volumetric pulse wave and respiratory waveform, easily attached to an HMD using hook-and-loop fasteners (Fig.2). The photoelectric volumetric pulse wave is measured by applying an optical pulse wave sensor (SFE-SEN-11574, Switch Science) to the nasal area. The wavelength used was green light of 565nm. A sponge was placed on the backside of the photoelectric volumetric pulse wave sensor so that the inclination

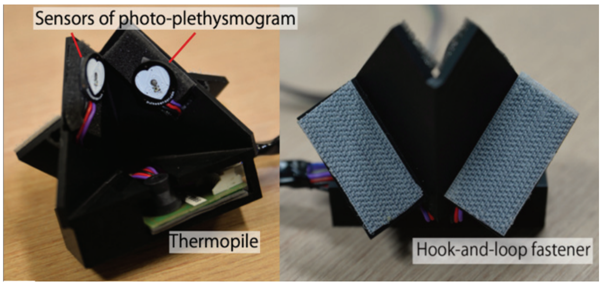

Fig. 1 Easy attachable biological information measurement device for Various HMDs

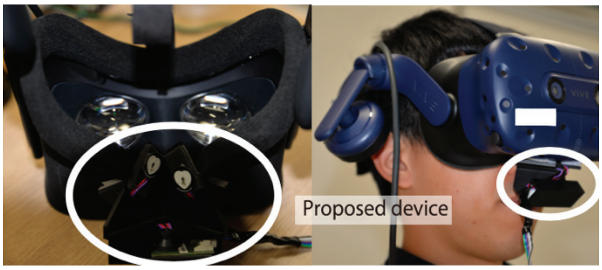

Fig. 2 Proposed device can be easily attached to HMDs using hook-and-loop fastener

angle of the device and the user's nose may deviate slightly. In addition, since the size of the nose varies from person to person, two photoelectric volumetric pulse wave sensors were placed in different positions. As a result, this device can measure the photoelectric volumetric pulse wave robustly to the nose shape.

We focused on the temperature change near the nostrils due to breathing and measured the respiratory waveform by placing a thermopile (10TP583T, SEMTEC Inc.) at the position where the exhaled air hits the nasal area. The reason for selecting the thermopile is that the changes in the respiratory waveform are usually less than 1 Hz, so it was necessary to use a temperature sensor with a time constant of less than 0.5 seconds. The thermopile used in the proposed method satisfies this condition with a time constant of 15 ms. If a temperature sensor with a short time constant is used, there is a possibility that even a thermistor can measure respiration. Other methods of obtaining respiration include measurement of respiratory sound and measurement of Co2 concentration. The method using respiratory sound is not appropriate for measurement during VR experience because the sound of VR contents can be mixed as noise. In addition, co2 concentration has the disadvantage that it is difficult to change the concentration during shallow breathing. For these reasons, we selected the method of acquiring the change in temperature of exhaled and inhaled air.

We compared the biological waveforms measured with our proposed device with those with commercially available devices widely used for biometric measurement. The waveform peak should be measured with detectable accuracy for photoelectric volumetric pulse waves. An index based on the frequency analysis of the waveform

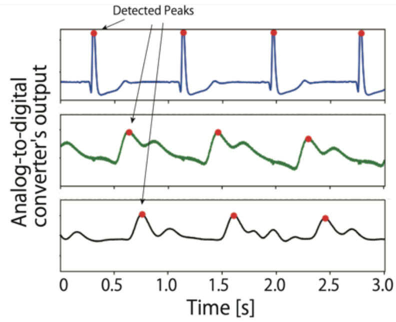

Fig. 3 Upper: ECG measured by commercially available sensors. Middle: pulse wave measured by commercially available sensors. Lower: pulse wave measured by proposed device.

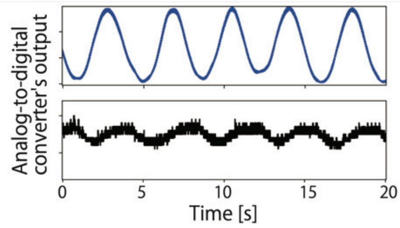

Fig. 4 Upper: respiration measured by commercially available sensors. Lower: respiration measured by proposed device.

peak interval is widely used as an autonomic nerve index to evaluate a person's level of arousal and other emotional states. Fig.3 shows the proposed device can measure with the same accuracy as the ECG and the photoelectric volumetric pulse wave measured with commercial devices. Similarly, Fig.4 shows that the period of the waveform measured by the commercial device and measured by our proposed device are almost the same for the respiratory waveform. As a result of the user study comparing the features calculated from the waveforms obtained from our proposed device with those obtained from commercial devices, the photoelectric volumetric pulse wave features could be calculated with an accuracy of less than 1% for the measurement data of 9 out of 14 users. As for respiration, it was possible to measure the respiratory peak frequency useful for evaluating arousal with an error of less than 0.6% when participants did not move. You can find details of the experiments and results in our paper [6].

Since this device is used in close contact with the face, it can incorporate biometric sensors other than the photoelectric volumetric pulse wave and respiratory waveform obtained from the face. For example, some research suggested that nasal skin temperature indicates pleasant and unpleasant emotions. The nasal skin temperature rises during pleasant feelings and falls during unpleasant emotions. By incorporating a thermistor in this device, we can measure the nasal skin temperature while wearing the HMD, and it may be possible to estimate the pleasant and unpleasant states during the VR experience.

4 Application potential of biological information measurement during VR experience

The ability to easily measure biometric information during a VR experience can develop interactive VR content based on human states estimated from biometric information and verification related to measuring human states during VR experiences. For example, Ueoka et al. measured a user's heartbeat in horror VR content [11]. They presented a faster-than-average pseudo-heartbeat by vibration to manipulate the impression of fear and increase the actual heartbeat. We have created VR content that interactively changes the degree of fear of horror VR based on heart rate and respiration rate measured using our proposed device [12]. These systems assess the user's fear level based on biometric data and adjust the fear level of the horror VR content accordingly, thereby generating acceptable content for various users with different horror tolerance. The interactively changing content is mostly horror-related, but we look forward to developing relaxing VR and other content in the future.

In addition to these entertainment applications, there is a possibility that we can use biometric data for VR training applications. Many training applications apply a mental load on the trainee, such as customer service training, which may prevent the trainee from proceeding to the end of the training process or damage the trainee's mental health. Therefore, we propose an approach to estimate the stress level of the trainee during VR training based on the information obtained from the biometric sensing HMD, and adjust the training level accordingly [13]. We developed a VR simulator for interpersonal customer service training and constructed a system that adjusts the training level by changing the customer avatar's attitude according to the trainee's mental load.

As described above, the number of applications where biometric information is actively used in VR systems increases. Therefore, installing biometric sensors in HMDs is expected to become even more popular.

5 Conclusion

This paper summarizes the various approaches in the research field of biological sensing HMD. Moreover, we introduce our research on biometric sensing HMDs. This biometric sensing device can be attached to various HMDs and measures respiratory waveforms, pulse waves, and skin temperature around the user's nose. We also discussed the VR application of the biometric sensing HMD. The estimation of emotions from biometric information varies significantly among individuals, making it difficult to estimate from a single index. Therefore, it is necessary to construct an HMD that can measure brain activity and autonomic index to estimate the emotional state in an integrated manner from multiple biometric data. The future development of biometric sensing HMDs is expected to expand the possibility of dynamically generating content according to the user's emotional state and to help develop VR content with a higher sense of immersion.

References

[1] Sullivan, Candice, et al. "The effect of virtual reality during dental treatment on child anxiety and behavior." ASDC journal of dentistry for children 67, no. 3 (2000): 193-6.

[2] Pai, Yun Suen, et al. "Assessing hands-free interactions for VR using eye gaze and electromyography." Virtual Reality 23,2 (2019): 119-131.

[3] Gupta, Kunal, et al. "Do you see what I see? The effect of gaze tracking on task space remote collaboration." IEEE transactions on visualization and computer graphics 22, 11 (2016): 2413-2422.

[4] Rattanyu, Kanlaya, et al. "Emotion recognition based on ECG signals for service robots in the intelligent space during daily life." Journal of Advanced Computational Intelligence and Intelligent Informatics 15, no. 5 (2011): 582-591.

[5] Billman, George E. "Heart rate variabilitya historical perspective." Frontiers in physiology 2 (2011): 86.

[6] Inazawa, Masahiro, et al. "Development of Easy Attachable Biological Information Measurement Device for Various Head Mounted Displays." In CW2019, pp. 1-8, 2019.

[7] Mohan, P. Madhan, et al. "Stress measurement from wearable photoplethysmographic sensor using heart rate variability data." In ICCSP2016, pp. 1141-1144, 2016.

[8] Luong, Tiffany, et al. "Towards real-time recognition of users mental workload using integrated physiological sensors into a VR HMD." In ISMAR 2020, pp. 425-437. IEEE, 2020.

[9] Javier Hernandez et al. "Bioglass: Physiological parameter estimation using a head-mounted wearable device." MOBIHEALTH, pp. 55-58. 2014.

[10] Kodama, Ryosuke et al. "A context recognition method using temperature sensors in the nostrils." In Proc. of the 2018 ACM International Symposium on Wearable Computers, pp. 220-221. 2018.

[11] Ueoka, Ryoko et al. "Emotion hacking VR: Amplifying scary VR experience by accelerating actual heart rate." In HCII, pp. 436-445. Springer, 2018.

[12] Inazawa, Masahiro et al. "Biofeedback Interactive VR System Using Biological Information Measurement HMD." In SIGGRAPH Asia 2019 Emerging Technologies, pp. 5-6. 2019.

[13] Tanikawa, Tomohiro et al. "Semi-automatic Reply Avatar for VR Training System with Adapted Scenario to Trainee's Status." In HCII, pp. 350-355, 2021.