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Percutaneous Electrical Stimulation for Virtual Reality

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Abstract

Percutaneous electrical stimulation (PES) is a technology that induces various sensations by electrically stimulating sensory nerves and organs non-invasively. PES induces various sensations, such as vestibular, visual, taste, and haptic sensations, using small, lightweight devices with reasonable cost. This technology is expected to be used in sensory display systems in the fields of virtual reality. This paper aims to introduce these technologies and methods, with a focus on vestibular sensation and gustatory sensation. Our research group developed a sensation display and applications using these technologies. This paper introduces our previous studies and applications, and the prospect of using these PES technologies for sensory displays in VR is discussed.

1. Introduction

Sensory display technologies are ones of the most important technologies in virtual reality (VR) and augmented reality (AR). Conventional sensory displays, including visual sensory displays, monitors, and head-mounted displays (HMDs), attempt to replicate physical phenomena. These visual displays include a light source and replicate physical phenomena such as optical waves. In another example, a motion chair is used for vestibular sensation in 4D theaters. This technology replicates physical phenomena such as acceleration and angular velocity by jerking, shunting, and rolling the chair.

Because human sensory systems such as vision, haptics, vestibular, taste, and others detect physical phenomena, these methods can induce natural sensation. However, devices that replicate those various phenomena requires large and heavy hardware, and they incur high costs. For example, a motion platform for vestibular display is extremely large, heavy, and incurs high costs, and, while HMDs have become lighter, they are still heavy.

Percutaneous electrical stimulation (PES) may resolve these challenges. PES is a technology for stimulating nerves and organs non-invasively. This technology only requires devices with light weight, small, and reasonable electrical stimulation, and it could become a cost-efficient sensation display.

Recently, PES was used in neuroscience and brain research. Three types of PES technologies, i.e., transcranial direct current stimulation (tDCS), transcranial alternate current stimulation (tACS), and transcranial random noise stimulation (tRNS), are used to modulate brain activity. Different stimulation waveforms are used in these technologies. The waveforms used in tDCS, tACS, and tRNS are direct current, alternate current, and random current wave, respectively[1]. Although these methods can modulate brain activities, these do not induce perceptible effects. Currently, these brain stimulation methods cannot be used with virtual reality (VR), where users perceive sensations and experience the world simultaneously.

Our research group expects that these technologies could be applied in sensory displays for VR. Two kinds of PES stimulation methods for inducing sensation, i.e., galvanic vestibular stimulation (GVS), and galvanic gustatory stimulation (GGS) are introduced and discussed in this paper. GVS is used to induce vestibular sensation, including acceleration and angular velocity or virtual head motion, and GGS can be used to electrically modulate taste.

2. Galvanic Vestibular Stimulation

GVS is a technology to induce virtual acceleration (or virtual head motion) by electrically stimulating the vestibular organ [2]. Conventional GVS uses electrodes attached on the bilateral mastoids, which induces lateral directional vestibular sensation. GVS has historically been used to diagnose vestibular diseases, and this technique is now used in VR systems, especially because GVS requires only a small, lightweight, and inexpensive electrical stimulation device to reproduce vestibular sensation. Since vestibular sensation is closely related to reality, GVS would be a key technology for providing highly realistic experiences.

The conventional GVS method only induces lateral directional vestibular sensation. It is not enough the controllable degrees of freedom for direction of the vestibular sensation. Previous studies indicate that the lateral acceleration is induced by applying a lateral directional current to the head and anteroposterior directional acceleration is induced by applying an anteroposterior directional current to the head. From these studies, we considered that an opposite directional anteroposterior current applied to each side of the head induces yaw directional acceleration. Then, we developed a four-pole GVS to provide such stimulation. Four-pole GVS consists of three isolated bi-polar current stimulators. Each stimulator is connected to either the bilateral mastoids or the temple and the mastoid on one side [3].

Our previous studies verified that this method induces three-directional virtual vestibular sensations along the lateral, front-back, and yaw directional directions [3].

3. Galvanic gustatory stimulation (GGS)

Galvanic gustatory stimulation (GGS) is a technology to induce, inhibit, and enhance taste sensation by applying electrical current stimulation to or near the mouth. Conventionally, electrical stimulation has been used for gustatory testing for the medical purpose and recently it used to modify taste sensation. This technology was used for a taste display in VR and human computer interaction in some previous studies. The study by Nakamura et al. (2013) proposed methods for applying electrical current to the mouth using a stimulation device whose electrode form is like folk and cup [4]. Ranasinghe et al. (2013) invented a method for inducing salty, sour, sweet, and bitter tastes by applying an electrical pulse through electrodes on the tongue [5]. Regarding the effect of inhibition and enhancement in GGS, we showed that GGS inhibits or enhances five basic tastes. In the work, we investigated the inhibitory effects of GGS. We thought ionic migration in taste material water solution causes taste suppression. Then we tested whether GGS is effective with non-electrolyte (caffeine) and electrolyte ($MgCl_2$) water solutions as both materials are perceived as bitter. Taste suppression with GGS was only effective with an electrolyte water solution. This result supports the adequacy of ionic migration as the mechanism for taste suppression [6].

GGS may be used for a gastronomy display to control taste sensation. It would help solve obesity and hypertension by supporting dieting. For instance, it could help people reduce their salt intake. In order to address such diseases, reducing salt intake requires modifying dietary habits.

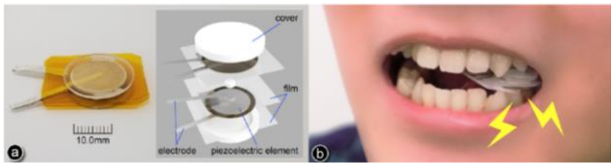
Conventional GGS methods have a problem that these require electrodes or wires in the mouth, which disturb eating and drinking - a very large disadvantage in terms of supporting dietary habits.

To solve the problem, we invented two stimulation method i.e., galvanic jaw stimulation (GJS) and Unlimited Electric Gum. In GJS, stimulation electrodes are attached on the jaw and behind of the neck. Our previous study showed that GJS induces, inhibits and enhances the taste of the water solution in the mouth. The approach of this method is to control the taste sensation by external stimulation from the mouth.

On the other hand, the approach of the Unlimited Electric Gum is to attach all stimulation apparatus in the mouth. Conventional methods used in previous studies require external power supply, and these are inconvenient for everyday use. For example, one would hesitate to use an eye-catching device and have cables around their mouth when eating at a restaurant [7]. A rational solution would be to attach a small battery and stimulation circuit inside the mouth of a user. However, this will give rise to another problem: harmful chemicals may leak from the battery into the mouth of the user.

Considering humans eating situation, they chew food to soften and reduce the size of the food particles. Therefore, we invented the electrical stimulation system which generate the electric power by chewing it. We used a wrapped piezoelectric element, which produces electricity on being chewed. Through the use of piezoelectric elements, an electric taste apparatus, which does not require power supply, can be designed. Thus, we invented a novel device named "Unlimited Electric Gum." Our previous study verified that the device generates an enough high electric current to reproduce GGS, and participant felt bitter and salty sensations on chewing the device. The results indicate that this method can be applied to electrical taste devices.

Fig. 1 Unlimited Electric Gum.



3. Conclusions

In this work, we introduced the-state-of-the-art PES technologies for sensory displays in VR applications. We especially focused on GVS, a technology to induce vestibular sensation using a small, lightweight and inexpensive electric circuit, and GGS, a technology to induce gustatory sensation using a wired electric stimulation device or a chewing-gum-like portable device. We are confident that these technologies will be a key for very realistic and affordable VR systems.

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References

[1] G. Ambrus G, W., Paulus, A., Antal, Cutaneous perception thresholds of electrical stimula-tion methods: comparison of tDCS and tRNS. Clin Neurophysiol, **121**, 1908–1014 (2010).

[2] R., J., S., George, B., L., Day, R., C., Fitzpatrick, Adaptation of vestibular signals for self-motion perception. The Journal of Physiology 589(4), 843-853 (2011).

[3] K., Aoyama, H., Iizuka, H., Ando, T., Maeda, Four-pole galvanic vestibular stimulation causes body sway about three axes. Scientific Reports **5**, 10168 (2015).

[4] H., Nakamura, H., Miyashita, Proposition of Single-pole Electric Taste Apparatuses for Drink and Food and Evaluation of Changing Taste Quality of Polarity Change. In: Infor-mation Processing Society of Japan **54**(4), 1442-1449 (2013).

[5] N., Ranasinghe, A., Cheok, R., Nakatsu, E., Y., Do, Simulating the sensation of taste for immersive experiences. In: ImmersiveMe '13 Proceedings of the 2013 ACM international workshop on Immersive media experiences, 29-34 (2013).

[6] K., Aoyama, K., Sakurai, S., Sakurai, M., Mizukami, T., Maeda, H., Ando, H, Galvanic Tongue Stimulation Inhibits Five Basic Tastes Induced by Aqueous Electrolyte Solution, Frontiers in Psychology (2017).

[7] N., Ooba, K., Aoyama, H., Nakamura, H., Miyashita, Unlimited Electric Gum: A Piezo-based Electric Taste Apparatus Activated by Chewing, 31st ACM User Interface Software and Technology Symposium.