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VR Application of Sensory Display and Effector Actuation by Transcutaneous Electrical Stimulation

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ABSTRACT

Transcutaneous electrical nerve stimulation is a noninvasive (or low-invasive) method that stimulates the human nervous system. Transcutaneous electrical nerve stimulation requires only a lightweight, small-sized, and reasonable device; it can be used for virtual reality interface systems regardless of the usage situation. This paper provides an overview of this technology.

1 Introduction

Virtual reality (VR) is a technology that allows users to experience various computer-generated worlds. To experience the virtual world, humans receive multimodal sensory inputs, make decisions, and response the world via muscle and secretion gland actuation.

In the VR field, many types of sensory displays have been developed, such as head-mounted displays (HMD). A recent commercial HMD can induce visuo-audio sensations and measure rip and eye movements with a light weight and reasonable device. However, commercial HMDs are heavy and can only present audiovisual sensations. Furthermore, general VR devices cannot actuate the human effectors.

Transcutaneous electrical nerve stimulation (TENS) has the potential to resolve these problems. TENS stimulates the peripheral and central nervous systems with weak electrical currents from surface electrodes on the skin. TENS requires thin and lightweight surface electrodes and fine cables on the skin. Therefore, TENS can be an ideal interface for inducing multimodal sensations and actuating effectors for VR. This paper describes various TENS methods and their applications in the field of VR, mainly based on our previous research.

2 Transcutaneous electrical nerve stimulation (TENS)

TENS is a noninvasive method for stimulating the human nervous system. The stimulated nerve determines the different types of TENS. Galvanic vestibular stimulation (GVS), galvanic taste stimulation (GTS), galvanic sight stimulation (GSS), galvanic olfactory stimulation (GOS), electrical skin stimulation (TSS), electrical tendon stimulation (ETS), electrical muscle stimulation (EMS), and electrical salivary gland stimulation (ESS) are technologies that stimulate the vestibular, taste, eye, intranasal chemosensation, skin, tendon, muscle, and salivary gland nervous system, respectively. In this section, TENS methods are briefly described.

2.1 Galvanic Vestibular Stimulation (GVS)

The vestibular system receives sensory input evoked by the acceleration and angular velocity of the head. Four-pole GVS, with electrodes attached to bilateral mastoids and temples, induces lateral, front-back, and yaw directional vestibular sensations as well as body swaying [1].

Although motion chairs are conventionally used for vestibular displays, they are heavy, large, and expensive. By contrast, GVS requires a light weight, small size, and a reasonable device. Therefore, GVS can be used in VR display technologies.

Previously, we built a VR application that allows users to experience a first-person view of a roller coaster ride and a vestibular sensation synchronized with motion in the VR world [2].

2.2 Galvanic Taste Stimulation (GTS)

Eating and drinking are essential for human survival. Taste is an important sensation in the eating experience. The strength of the taste sensation in food and drinks depends on the concentration of the taste materials. Then, unless they spit out food, humans ingest such materials in their eating experiences.

GTS can modify the taste strength of foods and drinks without changing the amount of material. Previous studies have shown that cathodal GTS, with only a cathodal electrode attached in or near the mouth, inhibits taste induced by the electrolyte solution during stimulation and quickly enhances the taste when stimulation ends [3,4]. Furthermore, our recent study revealed that chin anodal and back of neck cathodal stimulation strongly enhance the salty taste during stimulation [5].

Because these methods can modify the taste of food, they are expected to be applied to diet and food augmented reality technology.

Although these technologies are used to modify taste, taste induction display technologies using electrical stimulation exist. Ranasinghe et al. proposed a tongue-mounted interface with electrodes attached to the tongue that stimulated various frequencies and changed the electrode temperature [6]. Miyashita proposed the Norimaki Synthesizer, which has five vegetable gelatin electrodes that taste salty, sweet, bitter, acidic, and umami [7].

2.3 Galvanic Sight Stimulation (GSS)

Recently, HMDs have become higher quality and lighter in weight. However, commercial HMDs with wide viewing fields are still heavy.

GSS can induce visual sensations with only extremely lightweight devices. When electrical stimulation was applied near the eye, a white flashing sensation was observed. This phenomenon was reported by Kanai et al. [8]. The sensation of a white flash is called phosphene.

Our research group conducted an experiment to determine where the user sensed the phosphene when the electrode position moved away from the eyes. We found that the user felt the phosphene at angles well beyond 100° to the left and right. This suggests that GSS has a wide viewing angle [9].

To show the use case of VR applications, the VR system in which users are beaten by VR characters were developed. In this system, users watch VR movies in which VR characters are beaten by VR characters, and when users are beaten, GSS and GVS are applied to match the movie [10].

2.4 Galvanic Olfactory Stimulation (GOS)

Olfactory sensation is perceived by the interaction between olfactory and trigeminal inputs. Trigeminal inputs specifically induce stinging and burning sensations.

We developed a GOS method in which electrodes were attached to the nasal bridge and back of the neck and revealed that GOS can induce stinging intranasal chemosenstion with a high probability [11]. Although GOS cannot induce a good fragrance, it can be used in bad odor display technology.

2.5 Electrical Skin and Muscle Stimulation (ESS and EMS)

ESS is a technology that induces tactile sensations using TENS. Although it is commonly known as electrical tactile stimulation (ETS), we referred to it as ESS in this paper because here ETS refers to electrical tendon stimulation. EMS is the most commonly used TENS method and induces muscle contractions.

Our research group previously developed an AirTap system in which users perceive the sensation of tapping an object in mid-air. In this system, users synchronously perceive tactile and force sensations induced by the ETS and EMS. Although EMS induces muscle contraction, it does not induce a sense of force. This system generates a sense of force by contracting antagonist muscles in response to the finger bending motion in mid-air.

2.6 Electrical Tendon Stimulation (ETS)

The tendon connects the muscle and bone. The tendon contains the Golgi tendon organ, which measures the tension of the tendon. Takahashi et al. showed that electrical stimulation of the tendon on the wrist induces a sensation of force [12].

Our research group has focused on the ETS of the leg tendons. In the VR experience, the ground has a variety of slopes, although users usually use VR devices in rooms with level floors. Thus, it is considered that the gap between the slope of the VR ground and the real floor spoils the reality of the experience. Therefore, our group proposed a method for modifying the ground tilt sensation by applying ETS to the four tendons, which are the front, back, left, and right sides of the leg [13]. Our group expected this method to bridge the gap between VR and the real world.

2.7 Electrical Salivary Grand Stimulation (ESS)

Salivary grand produces saliva. Saliva has many important functions for oral health, eating experiences, and speech. Most saliva is secreted by the major salivary glands, such as the parotid, sublingual, and submandibular glands.

In the oral health area, a previous study showed that electrical stimulation to the parotid gland, which is the largest salivary gland promotes saliva secretion [14]. Our research group considered that when all three salivary glands were stimulated synchronously, more effects on salivary secretion could be obtained. Electrodes were then attached to the area of the face adjacent to the bottom of the ear and the base of the mandible on the same side. An experiment conducted by our research group indicated that the proposed method effectively promotes salivary secretion [15].

ESS can be applied as a method to maintain and promote oral health, and our group considered it an effective tool that changes food moisture and resolves eating experience.

3 Discussion and Conclusions

As described in this paper, the TENS method can induce a multi-modal sensation and actuate the multi-effector function of a human with only a lightweight and small device. Therefore, TENS can be used in any situation and with existing VR equipment. It is possible that some TENS may be embedded into the HMD.

Although TENS induces multimodal sensations, the quality of the sensation is still low. For example, unintended tactile sensation is induced just under the electrodes. In addition, some types of TENS do not induce strong sensations. Although TENS still has problems with VR usage, it has the potential to become a major novel interface in the VR area.

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