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Five-Sense Engineering and Cross-Modal Effects Associated to XR Technology

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ABSTRACT

I will talk about five-sense engineering which is critical for developing XR systems aiming at the ultimate sensory reproduction. Actually, XR equipment is an ideal tool for studying five senses too. In addition, I will introduce several kinds of cross-modal effects focused on vision in relation to XR technology.

1 Introduction

We obtain physical information about the external world in real time through the five senses (sight, hearing, touch, smell, and taste). In daily life, there are actually not so many times or situations in which only one sense is used. The recognition of an object using multiple senses is called multi-modal information processing, and complex multi-modal information processing is often carried out during arousal. Therefore, research on multi-modal information processing is very important to quantitatively investigate how multiple sensory inputs are processed and integrated in the brain. On the other hand, there is also the term "cross-modal". Cross-modal" is an adjective that describes the change (modulation) of one sensory information by another information, for example, when visual and auditory information occur at the same time. In other words, it refers to the phenomenon in which one sensory information interferes with other sensory information (mechanism), causing the sensory information itself to change. This interference effect can be quantitative or qualitative, with increasing quantitative changes (gain amplification) or decreasing (gain compression) the output value, and qualitative changes causing a "shift" in value or a change in attributes. The two terms, cross-modal and multi-modal, are sometimes used interchangeably or without clear distinction, and in many cases both effects occur phenomenologically, and in some cases it is ambiguous or unclear which effect is occurring. In this article, we will focus on cross-modal information processing, i.e., the phenomenon and effect of one sensory information modulating the other sensory information. In human interface (HI) design, cross-modal effects can cause errors in which the actual tactile perception is altered by visual information even when haptic information is accurately provided by a haptic device. On the other hand, it has the potential to generate a "perception" beyond the limits of the device hardware by controlling other senses, which is an essential factor to be considered in the design and development of HI. Here I describe specific examples of tactile/haptics and gustatory sensations modulated by visual information and discuss the effectiveness of XR in cross-modal research and future prospect for cross-modal HI research.

2 Cross-modal effects between visual and tactile senses

When a mouse is moved at a constant speed while looking at a PC screen, if the speed of the mouse cursor on the screen is reduced by software without being noticed by the operator, the operator feels as if the mouse is moving on a desk surface with strong friction, as if the resistance from the mouse has increased in terms of tactile sensation [1]. This is one of the phenomena/techniques called "pseudo-haptics" [2] in which tactile perception can be generated by visual information alone without changing the force itself, and functions by combining the movement of the human sensorimotor system and visual feedback given in synchronization with it. It works by combining the movement of the human sensory-motor system with visual feedback given in synchronization with it. Haptic devices are usually difficult to miniaturize due to the need to control force, and their complex structures make them inexpensive and difficult to produce. However, pseudo-haptics, in which haptic sensations are modulated by visual information, is one application of cross-modal effects that is attracting attention because it enables the presentation of tactile sensations that exceed the limitations of the device. It is one of the applications of cross-modal effects that have been attracting attention.

The "size-weight illusion (also known as the Charpentier effect) [3] is another cross-modal phenomenon in which the sense of touch is affected by vision. This is an illusory phenomenon in which an object of the same mass is visually perceived to be heavier when its size (volume) is smaller. There is also a similar phenomenon called the "brightness-weight illusion" [4] in which a white (bright) object is perceived to be heavier than a black (dark) object, even if they have the same mass and the same size. By the way, this weight illusion phenomenon (cross-modal effect) has qualitatively

different characteristics from other cross-modal effects. It is that the larger (or darker) an object appears to be, the lighter it feels when you actually hold it. This phenomenon is called the "contrast effect" because it is the opposite of what is predicted when the object is seen. Such a phenomenon cannot be explained by the “averaging effect” which can explain the general cross-modal effect or the usual Bayesian model [5].

3 Cross-modal effects between vision and taste

It has long been known that the color of foods and beverages affects the sense of taste, and there are many related papers. For example, a study [6] showed that when white wine was colored red and drunk, even wine connoisseurs mistook it for red wine, suggesting that the wine was red wine based on visual information and that visual information has a strong influence on our perception of foods and beverages. On the other hand, few studies have quantitatively and systematically investigated what exactly affects color and how (e.g., how hue, saturation, and lightness contribute to taste and texture perception of food). One of the reasons for this is that the color of food cannot be precisely controlled. We developed a marker-less projection-type food XR system using projection mapping technology. Then we psychophysically measured the change in sweetness of a cake when the user ate the cake with only the saturation of the color of the cake modulated in real time. As a result, it was quantitatively shown for the first time that the evaluation of sweetness at the time of eating increased monotonically with an increase in saturation [7].

We have also developed a food XR system using an HMD, and have shown that it can transform Sushi ingredients (visual textures) in real time without using markers, and change the food texture and taste when the sushi is consumed. AI can also be used to extract target foods to be converted from multiple foods [8]. Appearance transformation can also be applied to beverages, such as modulating the milkiness of coffee [9]. Furthermore, it has been shown that the appearance and texture of food can be changed simply by changing its luminance distribution [10]. By utilizing XR in this way, it is possible to freely change only the appearance of food, which is originally difficult to do, and it is possible to extract the effect of purely visual information.

4 Conclusions

We introduced representative examples of cross-modal effects on tactile and gustatory sensations induced by visual information and explained that cross-modal effects have different modes of averaging and contrast. XR technologies are key technologies for cross-modal research on tactile and gustatory sensations. By quantitatively measuring and formulating human cross-modal characteristics, the effects of these characteristics can be specifically incorporated into human interface design, enabling the development of devices that transcend the limitations of the hardware itself. The fact that visual information can change the taste of food without changing the food itself suggests that it can be applied to the realization of virtual five-sense communication. Research on cross-modal effects, including auditory and gustatory effects, which are not introduced here, new knowledge on cross-modal effects in humans will be obtained by incorporating XR technologies in various forms, and these technologies will be widely used as one of the essential technologies for human interface development. In addition, five-sense engineering on multi-modal and cross-modal effects is critical for developing XR systems aiming at the ultimate sensory reproduction.

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