Multi-sensorial Virtual Reality and Augmented Human Food Interaction

Takuji Narumi
Graduate School of Information Science and Technology,
The University of Tokyo
7-3-1 Hongo Bunkyo-ku, Tokyo, JAPAN
+81-3-5841-6369
narumi@cyber.t.u-tokyo.ac.jp

ABSTRACT
In the field of virtual reality (VR) research, media technologies to create a realistic feeling of being present in a real/virtual world by duplicating multi-sensory information have been studied over a long period. Recently, technologies for multi-sensory feedbacks achieved a major breakthrough by utilizing cross-modal interactions. By changing sensory stimuli through only one modality using these technologies, the impression from our experience can be modified significantly. These novel technologies have a great potential in changing our food consumption experience and behavior. For example, "MetaCookie" is a flavor augmentation system that enables us to change the perceived taste of a cookie by overlaying visual and olfactory information onto a real cookie. "Augmented Satiety" is a system that enables us to control the perception of satiety and food intake implicitly by changing the apparent volume of food with augmented reality and computer vision techniques. This paper introduces such novel techniques that augment our eating experience by using multimodal VR techniques and discusses the future of Human Food Interaction.

CCS Concepts
• **Human-centered computing→Virtual reality**

Keywords
Human Food Interaction; Virtual Reality; Augmented Reality; Multi-sensory; Cross-modal effects

1. INTRODUCTION
Our perception of reality is determined by our senses. In other words, our entire experience of reality is simply a combination of sensory information and sense-making mechanisms related to that information in our brain. This implies that if a person's senses are exposed to computer-generated information, their perception of reality would also change in response to it.

Technologies that duplicate multi-sensory information and simulate a realistic experience of being present in a place in the real or virtual world have been studied over a long period. Virtual Reality (VR) and Augmented Reality (AR) are some examples of such technologies. Particularly, AR has recently been the focus of significant growth in numerous fields. VR entails the simulation of our senses with a computer generated virtual environment, which we can explore in some fashion. On the other hand, AR enhances and modifies our perception of reality by presenting computer-generated virtual sensations in a semantic context with real environmental elements. The latest VR/AR offerings deal primarily with visual experiences that are displayed either on the screen of a mobile device or through head-mounted displays. However, they have great potential to change perceptions in applications other than that of vision.

In order to realize multi-sensory feedback, multi-sensory information associated with a place must be simulated. Thereafter, the stimuli associated with each simulation and sensory organ are generated using specialized display systems for each measured modality. This simulation and feedback via multi-modal display is normally performed separately for each modality. This modularity leads to the design of complex multi-modal systems.

Traditionally, perception has been regarded as a modular function. It has long been thought that the different sensory modalities operate independently of each other. This is because multi-modal systems deal with each modality separately. However, recent behavioral and brain imaging studies suggest that cross-modal interactions play an important role in our perception [1]. Cross-modal interactions are a type of perceptual illusion. In cross-modal interactions, the perception of a sensation through one sense is changed by stimuli received through other senses simultaneously. For example, the ventriloquist effect involves an illusory experience about the location of a sound that is produced by the sound's apparent visible source. The effect is neither inferential nor cognitive; instead, it results from cross-modal perceptual interactions. However, cross-modal interactions are not limited to the impact of vision upon the experience perceived through other sense modalities.

By utilizing this illusionary effect, we might be able to provide people with a multi-modal experience with a combination of limited sensory feedbacks. In this context, since VR/AR changes our perception by providing sensory information in a semantic context, these technologies can be used to induce cross-modal effects.

Eating is a perceptual experience that involves the integration of various sensations including vision, hearing, olfaction, and trigeminal sensations. Different flavors and palatability are experienced by different people when consuming the same food or even by the same person at different times. Moreover, flavor and palatability perception are based not only a food's ingredients,

MHFI'16, November 16 2016, Tokyo, Japan

DOI: http://dx.doi.org/10.1145/3007577.3007587

but also on various factors such as physiological states, eating environment, understanding of the food, and previous experiences related to food [2-5]. By eliciting such effects using media technologies, we can realize novel “Human Food Interaction” techniques that induce people to experience different flavors and palatability without altering the food itself. In this paper, I introduce a novel multi-sensorial VR/AR system, which is capable of changing user perception related to eating experiences.

2. VIRTUAL FLAVORS WITH AUGMENTED HUMAN FOOD INTERACTION

Humans receive gustatory inputs through sensory organs called taste buds, which are concentrated on the top surface of the tongue. Taste is physiologically defined as a minor sensory modality, comprising a limited number of sensations: sweetness, sourness, bitterness, saltiness, and umami. Thus, a taste can be duplicated if the basic constituent taste components are combined in the quantities measured. Using this as the underlying concept, Maynes-Aminzade [6] proposed the idea of "edible user interfaces" and developed several low-resolution gustatory simulations. More recently, a number of researchers have tried to make a “Food Printer” that can “print” food by combining basic taste components [7]. However, synthesizing a specific taste on demand by combining basic tastes is difficult because the sense of taste is a multi-modal sensation and is not determined solely by a combination of the basic tastes.

The term "taste" signifies a perceptual experience that involves the integration of various sensations. When we use the common word "flavor" in place of taste, we refer to what is a very multi-faceted sensation. Auvray et al. reviewed the literature on multisensory interactions underlying the perception of flavor. They concluded that flavor is not defined as a separate sensory modality but as a perceptual modality that is unified by the act of eating, and it should be used to describe the combination of taste, scent, touch, visual cues, auditory cues, and the trigeminal system [8]. These definitions suggest that the flavor experience can be modified by changing the stimuli received through modalities other than the sense of taste.

Based on this knowledge, some flavor simulation systems have been developed. Iwata et al. developed the "Food Simulator" [9] using an interface that integrates and simulates biting force, auditory information, and chemical sensation of taste. In this, the chemical sensation of taste is evoked by the release of prepared taste components using a micro injector. Even though this study did not focus on the various tastes synthesized by using this system, it revealed that texture has an important role in identifying food. Another example is Hashimoto’s “straw-like user interface,” which allows users to experience the sensations of drinking by representing data in terms of actual pressures, vibrations, and sounds produced when drinking through an ordinary straw [10]. The experimental results indicate that users can experience the sensation of drinking, even though they are not consuming any liquid. “Chewing Jockey” [11] uses the cross-modal effect between sound and haptics to change the perceived food texture. It measures bites using a photo reflector and presents a filtered and designed sound effect through a bone-conduction speaker. This auditory feedback evokes the cross-modal effect that changes the perception of food texture without any complex mechanical structures to represent the biting forces.

Under most conditions, humans have a tendency to rely on vision more than the other senses. Several studies have explored the effect of visual stimuli on our perception of flavor. However,

Figure 1. MetaCookie+: Flavor display based on cross-modal interaction among vision, olfaction, and gustation.

according to Spence et al., the empirical evidence regarding the role that food coloring plays in the perception of the intensity of a particular flavor or taste to which it is attributed is rather ambiguous, although food coloring certainly influences how people identify flavor [12].

Nevertheless, their survey results suggest that it is possible to change the flavors perceived by changing the appearance of the food. Many studies support the claim that the identification of flavor is influenced by the color of the food. For example, DuBose et al. showed that people attempt to identify the flavors of a variety of fruit-flavored drinks using their different colors, to the extent that some participants misidentified the flavor of the drinks when the color was inappropriate (e.g., when an orange-flavored drink was colored purple) [13]. Narumi et al. designed a pseudo-gustatory simulation that allows users to feel various tastes without changing its chemical composition by superimposing virtual color onto a drink [14]. In this system, they used light-emitting diodes (LEDs) to change the color of the drink interactively. They showed that our perception of the intensity of fundamental tastes is not changed by the variation in the appearance, but that the identification of the flavor is changed when the color of the drink is changed, whether using LEDs or using dyes.

Among the other senses, the sense of smell is most closely related to our perception of taste. This relationship between gustatory and olfactory sensations is commonly known and is illustrated by the fact that we pinch our nostrils when eating food that we find displeasing. One method that utilizes this effect is “Meta Cookie+” (Fig. 1), proposed by Narumi et al. [15]. It is an AR system that changes the flavor of a real cookie by overlaying visual and olfactory information onto it. The results of a user study they conducted indicated that the system can change the perceived taste, with over 70% of their participants associating various flavors with a plain cookie. This was achieved by simply changing of visual and olfactory information without changes to the chemical ingredients of the cookie.

Although these pseudo-gustatory simulations allow us to experience various flavors by changing only the visual and olfactory stimuli, conventional simulations require one olfactory stimulus for each flavor, which imposes a limit on the number of flavors that can be stimulated. A method to simplify the olfactory simulations for the pseudo-gustatory simulation based on the work by Nambu et al. [16] was also proposed by Narumi et al. In their simulation, they built a map of perceived similarities among scents and selected a few aromatic chemicals as the set of key aromatic chemicals based on the clustering of scents. In the experimental evaluation, various pictures and select key aromatic chemicals were presented to subjects who were then asked to identify the scent. The results demonstrate that the participants experienced a greater number of scents than the actual number of selected key aromatic chemicals because of the effects of visual stimulation. Although they used only four key aromatic chemicals, the participants identified 13 kinds of scents on an average. Based on this knowledge, Narumi et al. proposed visual-olfactory simulation method which can present more patterns of scents than the actual number of key scent components because of the visual-olfactory cross-modal effect and similarity-based replacement of scent, and proved its effectiveness [17].

Some other technologies try to change the flavor and palatability perception by changing a person's physiological state. People regard food as being more appetizing when they are hungry. Similarly, people regard drinks as being more appealing when they are hot and perspiring. It is believed that the body makes demands to avoid shortages and unhealthy or dangerous conditions by providing cues to eat and drink. In particular, our body changes our flavor perception in order to return the physiological state to a proper condition. When people consume food, their physiological state changes. For example, a solution including fat, sugar, and *umami* is believed to stimulate the secretion of pleasure-producing chemical substances [18]. When people experience this, pleasurable feelings are evoked directly and people exhibit stronger perceptions of food palatability.

Physiological change is not only a matter of nerve system communication. Recent physiological research has demonstrated that there are some specific bodily reactions associated with flavor perception. A representative example is the temperature change of the skin around the nose. Asano et al. demonstrated the possibility of quantitative evaluations of flavor and palatability based on measured changes in nasal skin temperature because these can be considered as types of pleasant or unpleasant feelings experienced during eating [19].

In the field of cognitive science, numerous researchers argue that changes in physical and physiological responses can unconsciously evoke an emotion. W. James aptly expressed this phenomenon, stating "We don't laugh because we're happy—we're happy because we laugh" (James-Lange Theory [20]). Many works based on the James–Lange theory demonstrate that changes in physiological states affect feelings. For example, Yoshida et al. constructed a system that manipulates an emotional state via visual feedback from artificial facial expressions [21]. By using this system, they arrived at the conclusion that not only our emotions but also preference assessments can be affected by the system.

Based on this knowledge, Suzuki et al. developed an "Affecting Tumbler," which induces thermal sensations on the skin around the nose to simulate the skin's temperature response during drinking [22]. Their user study suggested that flavor richness and aftertaste strength were significantly improved by heating up the skin around the nasal region.

Some researchers have also tried to display/change the taste by changing the physiological state with electric stimulation. For example, Nakamura et al. proposed a method to change the perceived taste of foods and drinks by using the electric taste evoked by electrically stimulating the tongue [23]. Ranasinghe et al. digitally simulated multiple taste sensations using electrical and thermal stimulations on the tongue [24]. Sakurai et al. demonstrated the inhibition of sweet, salt, and umami perception by applying cathodal current electrical stimulation to the tongue. By focusing on the electrophoresis of ions generated by the dissolution of taste-inducing substances in water, they demonstrated how human gustation is inhibited by electrical stimulation. This is a key addition to the knowledge base for achieving control of the five basic tastes. These kinds of emerging technologies may become a key component in simulating taste in a future virtual environment.

3. PLEASURE AND SATISFACTION IN HUMAN FOOD INTERACTION

The purpose of eating is not limited to the intake of energy. Pleasure and satisfaction are also important factors that motivate human consumption. Consequently, many researchers have studied the enhancement of pleasure and satisfaction in eating by augmenting Human Food Interaction.

Contemporary humans enjoy gourmet food. Humans have improved culinary techniques and the food production system in pursuit of delicious food. On the other hand, obesity has become a serious public health issue worldwide, with one of the major causes being overeating. Consequently, systems that make diners aware of the amount of food being consumed have been developed. However, adequately sustaining a highly conscious effort to control the amount of food consumed is difficult because eating a meal is a daily activity and is often pleasurable.

To decrease rates of obesity, many researchers have developed systems to change our eating behavior. Mankoff et al. developed a system that analyzes individuals' food purchases at grocery stores and suggests a method for users to make healthier selections from logs of receipts [25]. Noronha et al. developed a crowdsourcing nutritional analysis system that estimates users' food intake (and the types of food eaten) in order to change their eating habits [26]. One limitation of these methods is that they are based on conscious education. This requires continuous effort on the part of the consumer to change their eating habits. Sustaining highly conscious effort when performing an intended behavior can be difficult.

On the other hand, humans cannot accurately assess the volume or nutrition value of the food they consume. Therefore, humans estimate their fullness by using indirect cues such as distension in the stomach and bowels, elevated blood-glucose levels, and apparent amount of food. This estimation is inaccurate because some types of cues are evaluated relative to an individual's surroundings. Recent studies in psychology and economics have revealed that the amount of food consumed at a given time is influenced by characteristics of the food itself as well as environmental factors during eating. These include plate size, package size, type of food, lighting, and social company [27-30]. These indicate that the satisfaction of eating can be modified by changing these environmental factors using VR/AR.

Narumi et al. utilized this finding in their "Augmented Satiety" system, which controls nutritional intake by changing the apparent size of food (Fig. 3) [31] or volume of a cup of liquid [32]. This system uses a method for food-volume augmentation using shape deformation processing in real-time [33] to simulate the cross-modal effects between vision and the perception of satiety. Their user study showed that the system could change the consumption volume of a food item by changing only its apparent size with augmented reality. This suggests that the technology will enable us to control the perception of satiety and nutritional intake while providing the satisfaction of eating. Moreover, Sakurai et al. constructed a tabletop system called "CalibraTable" that projects virtual dishes around a food platter in order to change the perceived food volume interactively [34, 35] (Fig. 4). This system

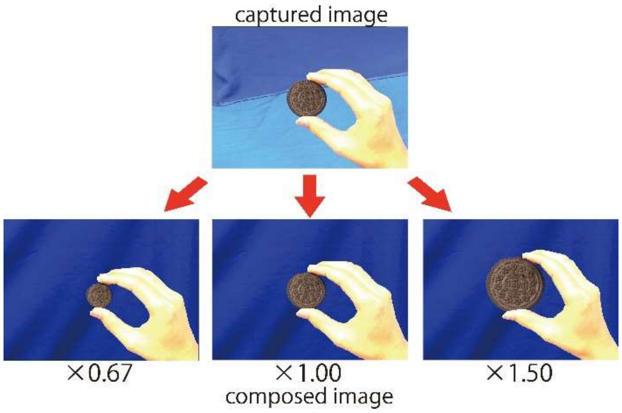

Figure 3. Augmented Satiety: An AR system to control our food consumption by changing the visual size of food.

also increases/ decreases the amount of food intake unconsciously without compromising on the perceived palatability and satisfaction of the food. The size of the virtual dish can be variedto control the amount and types of food consumed, thereby appropriately balancing the nutritional intake. This enables us to use the system with any kind of solid food. It also eliminates the need to use a wearable device. Interactive projection techniques at a table can also be used for making meals appetizing or for facilitating communication.

Meal satisfaction is influenced not only by the food itself, but also by external factors such as the location of restaurants, public reputations, and so on. Particularly, social influence is an important factor in determining the pleasure and satisfaction of eating. The term "food porn" refers to images of food across various social media platforms such as television, cooking magazines, online blogs, and websites [36]. People share food porn to derive satisfaction by demonstrating conspicuous consumption.

This type of behavior changes our satisfaction and eating behavior since the satisfaction derived from a meal is influenced not only by taste but also by external information. In behavioral science, findings on Expectation Assimilation (EA) have revealed that the imagined palatability of a meal changes one's perception of the actual meal. Wansink described EA as the unconscious expectation about how satisfactory or appetizing a meal will be, which affects how appetizing it is [37]. He noted that something that was anticipated to be delicious was perceived as being more delicious than was something that was not anticipated to be delicious.

Takeuchi et al. proposed a social media system, Yumlog (Fig. 3), for improving eating habits without conscious effort using EA [38]. They focused on others' evaluations on social media as a trigger of EA. Social media has become increasingly popular in recent years, and many users share their meals with others virtually. Good evaluations by others please a user and the user's satisfaction with the meal increases. In addition, others' evaluations are versatile as they can be added to all meals uniformly. An interesting feature of Yumlog is the secret replacement of a "Looks healthy" evaluation with a "Looks yummy" one. For example, if others evaluate a shared meal as having a score of +1 yumminess and +3 healthiness, an evaluation of +3 yumminess is delivered to a person who eats the meal. This manipulation enables the user to experience greater satisfaction with healthy meals. The researchers confirmed the efficacy of their proposal through a controlled user study as well as a real-world user study by releasing their system on a smartphone application store. They also revealed that a feedback method corresponding to individual taste for meals further improves users' eating habits [39].

4. CONCLUSION

Our perceptual experience involves the integration of various sensations including vision, hearing, haptics, olfaction, gustation, and other sensations. Moreover, external information such as the reputation of the food also changes our perception of the eating experience. The studies discussed here indicate that Human Food Interaction techniques that modify not only the taste/flavor but also external information related to food have a potential to augment our eating experience. Hence, I believe that Human Computer Interaction studies should be considered in Human Food Interaction research along with cognitive science, phycology, and economics. While research on Human Food Interaction in HCI is currently in its infancy and has its limitations, I believe that these technologies can enhance the well-being of humans. For example, augmented Human Food Interaction techniques will help individuals control their food consumption more effortlessly without losing the pleasure of eating and have significant effects in promoting nutritional health. I hope that Human Food Interaction research brings about a new interest in multi-sensory systems and VR/AR technologies and contributes to the promotion of human happiness.

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