Digital Taste and Smell Communication

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ABSTRACT

In this paper, we introduce a new technology, which allows people to share taste and smell sensations digitally with a remote person through existing networking technologies such as the Internet. By introducing this technology, we expect people to share their smell and taste experiences with their family and friends remotely. Sharing these senses are immensely beneficial since those are strongly associated with individual memories, emotions, and everyday experiences. As the initial step, we developed a control system, an actuator, which could digitally stimulate the sense of taste remotely. The system uses two approaches to stimulate taste sensations digitally: the electrical and thermal stimulations on tongue. Primary results suggested that sourness and saltiness are the main sensations that could be evoked through this device. Furthermore, this paper focuses on future aspects of such technology for remote smell actuation followed by applications and possibilities for further developments.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces and Presentation**]: User Interfaces: Input devices and strategies, Prototyping

General Terms

Design, Measurement, Experimentation

Keywords

Taste, Smell, User interfaces, Control systems, Virtual reality

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1. INTRODUCTION

Both human gustatory system (taste) and olfactory system (smell) perform a significant role in enhancing one's everyday life experiences through memory and emotions. The memory of taste or smell lasts longer than the memory acquired verbally. Forgetting of things seems to follow a much longer time course for taste and smell than for verbal memory. Some studies have suggested that taste and smell related memories have a stronger emotional content than those triggered by other sensory modalities. Taste and smell memories are considered to have proven qualities, commonly known as "Proustian characteristics", which includes resistance to interference, uniqueness, and independence from other modalities [1, 7]. Furthermore, Youngblut [30] has discovered that taste and smell senses are directly associated with one's mood, stress, retention, and recall functions.

By communicating these senses remotely and digitally, we can enrich interactive communications that are currently dominated by audio and video based interactions. Additionally, multimodel communication and virtual reality research fields are in need of digitizing taste and smell senses [13] thus to use them actively on those fields. Current technologies have only explored taste and smell senses to some extent with chemical compounds [5, 20]. The combinations of tastes and smells generated through these methods are limited and inadequate to achieve detailed communication.

As explained, the use of multisensory information is essential for remote communication. There are several key phases to be fulfilled for a successful communication of taste and smell sensations: detecting (sensing), coding (encoding as digital information and decoding), transmitting, and regenerating (actuating). In this paper, as the initial phase, we are focusing on the final stage of the communication, the digital actuation of taste and smell sensations, because there have been remarkably few research works conducted on actuation of taste and smell perceptions on human.

As the initial stage of developing a technical system which will be able to produce taste and smell sensations digitally, we developed a new control system to actuate taste sensations digitally on human. This is a novel device for human, which designed as a wearable or mobile system for everyday use. We are particularly interested in noninvasive stimulation methods to achieve these remote interactions success-

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fully. The system developed for actuating taste sensations digitally is based on electrical and thermal stimulation of the tongue. Researchers have found that applying small and controlled pulses of current [24], as well as heating and cooling the tip of the tongue [6], could generate taste sensations. The device is developed by combining those two stimulation methods to produce taste sensations digitally as illustrated in Figure 1.

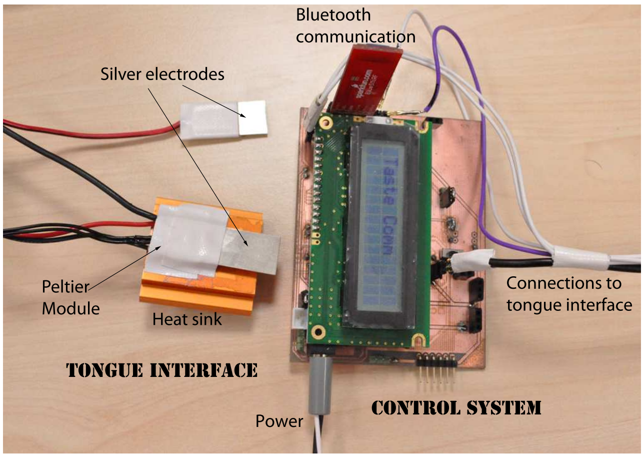
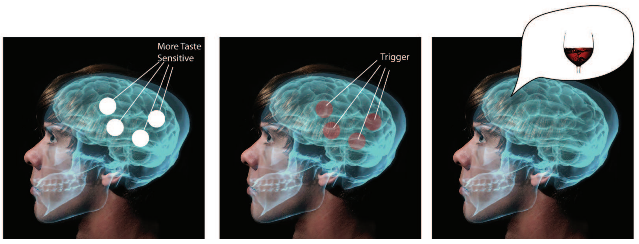


Figure 1: The digital taste (gustatory) actuating system

As the next step, we will incorporate magnetic stimulation (deep brain magnetic flux stimulation) on brain in order to digitally activate both taste and smell sensations. As shown in Figure 2, this will be achieved in two distinct phases. In the first phase, associated nucleus of basic tastes and smells in the brain will be identified through Electroencephalography (EEG) [12, 29], super high density scalp EEG system [22], and functional Magnetic Resonance Imaging (fMRI) [17] techniques. Natural food and smells will be used in this step such as sugar, chocolate, wine, mint, and lavender. After the completion of preliminary phase, the second phase will be started for the stimulation of both taste and smell sensations. The 'Transcranial magnetic stimulation' method is proposed for the brain stimulation and it operates by inducing weak electric signals by rapidly changing magnetic fields produced by the outside circuitry [4].



Identification – Identify corresponding areas (nucleus) in the brain by observing fMRI data induced by natural food and chemical compounds

Stimulation - Stimulate identified nucleus by magnetic stimulation to regenerate the brain activities

Perception - Create perception of tasting real food or smelling real scent

Figure 2: The high level system diagram for taste and smell brain stimulation

This paper is organized as follows. We will discuss the background of taste and smell senses with related works ranging from interactive systems to experimental works in section 2. In section 3, we will explain the technical details of digital taste actuating system, including initial results, and safety protocols. Section 4 presents the future work of this research. Finally, potential applications are discussed in section 5.

2. BACKGROUND AND RELATED WORK

This section provides an introduction to the taste and smell senses of human followed by a related works section which presents different kinds of interactive systems on taste and smell senses.

2.1 Background

Taste and smell sensory systems in human are based on chemical stimulations, and it consists of chemoreceptors, which are used to identify tastes and smells. In the sense of smell, chemoreceptors are stimulated by odorants and then they convey electrical impulses to the brain to identify the smell. Based on the patterns of electrical pulse, the brain recognizes relevant odors or olfactory sensations [2]. Six basic groups of smells are identified by the scientists [3], Putrid (Sweaty, Rancid, Sour), Vegetable (Green pepper, Cucumber, Cabbage), Floral (Rose, Lavender, Violet), Woody (Pine, Cedar, Sandalwood), Minty (Wintergreen, Peppermint, Menthol), and Fruity (Lemon, Orange, Strawberry).

There are five basic tastes known as sweet, bitter, sour, salty, and umami. Human tongue has unique cell structures called taste papillae to identify different tastes. There are three forms of taste papillae: fungi form, filiform and circumvallate papillae. Based on the latest research findings, it is theorized that each taste papillae has different sensitivity for different tastes and identifies all the primary tastes. Taste buds are situated inside the taste papillae, which have a number of gustatory cells. Gustatory cells send taste information detected by clusters of different receptors and ion channels to the brain [18].

The sense of smell is often the first response to most of the stimuli. The senses of taste and smell are highly interconnected and dependent on each other. The sensation of flavor is a combination of both taste and smell sensations [8]. Picking up the odorants, processing, and interpreting them as tastes or smells, are broad research topics which scientists are still exploring.

2.2 Related Work

Numerous research work already conducted on chemical stimulation of both olfactory and gustatory sensors. 'Sensorama' was one of the earliest multimodal experience delivery systems developed in 1960s. In this system, the user needs to be seated in front of a display screen, which equipped with several sensory actuators such as sound, wind, smell, and vibration [25]. The 'Virtual cocoon' [5] is a virtual reality headset which simulates all the five senses to provide experiences from the real world. A tube connected to a box of chemicals releases odors under the wearers' nose, while another device spray flavors directly into the mouth.

The 'Food Simulator' uses chemical and mechanical linkages to simulate food chewing sensations by providing flavoring chemicals, biting force, chewing sound, and vibration to the user [11]. It is designed to fit the users' mouth to deliver the force of the bite. Additionally, the 'TasteScreen' [20] let its users lick their screens to taste food items on their computer monitors. It consists of a monitor and a USB device on top, which contains flavor cartridges. These flavor cartridges mix and sprinkle the chemical flavors to the screen based on the contents. The users are then able to taste the flavors on their screens by licking their screens.

However, it is harder to find a system, which focuses on actuating the sense of taste digitally. There were few experiments conducted in the medical field on electrical stimulation of human tongue. Lawless et al. [16] presents another related research, the metallic taste generation from electrical and chemical stimulation. The presented study was designed to observe the similarities and differences of stimulations with metals, electrical stimulation, and solutions of divalent salts and ferrous sulphate in particular. In this experiment, they have investigated sensations occurred across oral locations using electrical stimulation with different metal anodes and cathodes. They have presented evidences of sour and salty tastes on users' tongues through electrical stimulation.

Moreover, actuating smells in human olfactory system using non-chemical methods is one of the least researched areas. In "Effects of electrical stimulation of the human olfactory Mucosa", Straschill et al. [26] explains electrical stimulation of the human olfactory mocusa by means of an electrode attached to a rhinoscope. In this piece of work, the stimulation of nasal mocusa did not invoke smell sensations, but it evoked suppressed smell sensations of presented odorants. In addition, improvements of smell and taste acuity were noted after repetitive transcranial magnetic stimulation on patients with phantosmia and phantageusia [10].

Although there were few experiments conducted on non-chemical stimulation of taste and smell senses, there are no evidences of an interactive system for stimulating those senses. Thus, in this research, we focus on gaining digital control of taste and smell senses through noninvasive stimulation methods such as electrical, thermal, and magnetic. The novelty behind the initial version of digital taste actuating device has two aspects over the existing literature: firstly, the control system that actuates the taste sensations digitally, secondly, the process of actuating taste sensations by combining electrical and thermal stimulations. Furthermore, we will evaluate this approach through source localization as explained in section 4.

3. RESEARCH DESIGN AND METHOD

This section presents the preliminary system on digital taste actuation to facilitate our proposal. The digital taste actuating system consists of three main subsystems as shown in Figure 3, the electrical stimulation module, thermal stimulation module, and the tongue interface module. The electrical stimulation module distributes small electric pulses to silver electrodes (which are connected to the tongue interface module) based on the instructions given to the system. Similarly, the thermal stimulation module controls the temperature using the Peltier module [19] thus on silver electrodes in the tongue interface module. The tongue module (as in Figure 4) is the interface between user's tongue and the device, which consists of a silver electrode (highlighted in the green circle), Peltier module (highlighted in the red circle), thermistor, and a small heat sink (highlighted in the blue circle). Silver electrodes are used for tongue stimulation through electric pulses and temperature. A Peltier module is used to implement rapid heating and cooling of silver electrode. Peltier modules are thermo electric elements serving the function by capitalizing on the 'Peltier Effect'. Therefore, it requires a heat sink for effective temperature control. An experimental setup of the device is illustrated in Figure 1.

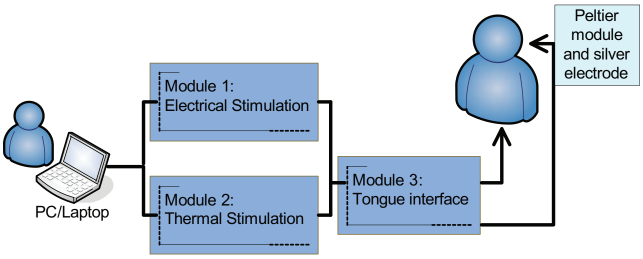


Figure 3: The system architecture of digital taste (gustatory) actuating device

The electrical control system provides square wave pulses to the silver electrode with diverse current from 0μA to 200μA and frequency from 50Hz - 1000Hz. The serial interface attached to the personal computer (PC) is used to command the system to adjust the properties of the output current. Similarly, by controlling the Peltier module, the temperature of the tongue can be changed between 20°C - 35°C, in both ways (heating and cooling).

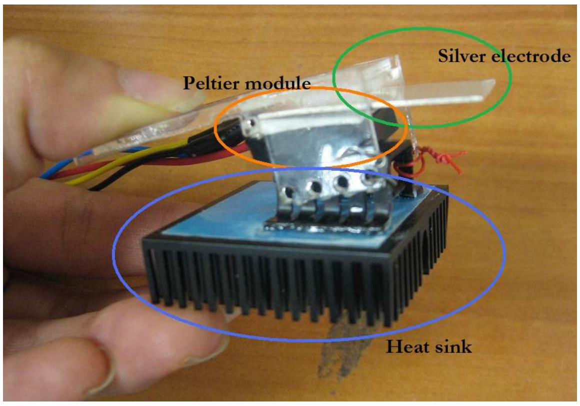


Figure 4: Set up of the tongue interface module

The impedance of the tongue is varying and it is personal due to the density of papillae on the surface [14]. We use a constant current source to overcome this problem thus to maintain a constant current to all the participants. To change the frequency of electrical pulses, a Pulse-width modulation (PWM) signal is supplied to the constant current source. With this overall setup, as shown in Figure 5, the hardware achieves the capability of varying current and frequency of the output current. Thus to facilitate the study of the effects of varying current and frequency on taste qualities.

In addition, through the thermal stimulation module, we exert a temperature change on silver electrodes using the attached Peltier module, as depicted in Figure 6. Again, the PWM technique was used to effectively control the Peltier module thus the temperature. The experiments were conducted within 20°C - 35°C (within the comfort range).

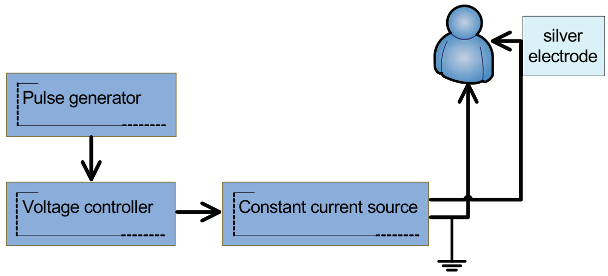


Figure 5: Block diagram of experimental set up for electrical taste stimulation

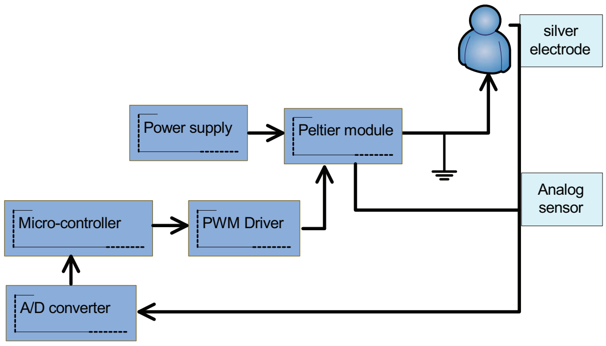


Figure 6: Block diagram of experimental set up for thermal taste stimulation

A proportional-integral controller (PI) algorithm was implemented to achieve the desired output on the microcontroller. The output of the microcontroller is used as an input to a driver circuit which provides power to the Peltier module where PWM was used to drive the Peltier module. Finally, this setup helps to test the effects using different ranges of applied temperature on the quality of thermal taste stimulation.

3.1 Preliminary Results

To examine and analyze the effectiveness of the system, a preliminary user experiment was conducted with eighteen subjects (ten males and eight females, age range from 21-27). Two sub systems, the electrical stimulation and thermal stimulation, were tested individually in this phase for analyzing and observing better results with minimum interferences such as electromagnetic field effect or noise on the output current. Participants were not trained before the experiment and they were in normal health condition. Electrical pulses with predetermined magnitude of current (20μA, 40μA, 60μA, 80μA, 100μA, 120μA, 140μA, 180μA, 200μA), frequency (50Hz, 100Hz, 200Hz, 400Hz, 600Hz, 800Hz, 1000Hz), temperature (cooling and heating between 20°C - 35°C), and duration (manual control through serial commands) of the stimulation were then applied to the tongue through the electrodes to produce taste sensations. Subjects rinsed their mouth with deionized water and rested 10 minutes between each stimulus. Besides, participants were asked to provide a verbal descriptor after each stimuli and rate their sensation in a 5 level Likert-type scale.

Figure 7 reveals the intensities of taste sensations reported during the electrical stimulation. The strength of sour and salty sensations increased when the magnitude of the current increased. Responses from all the participants were quite similar and continuous for sour sensation. However, 60% indicated that salty and bitter sensations were increased when the magnitude of the current increased. All the participants indicated that the change of frequency has not affected on the intensity of the sensation.

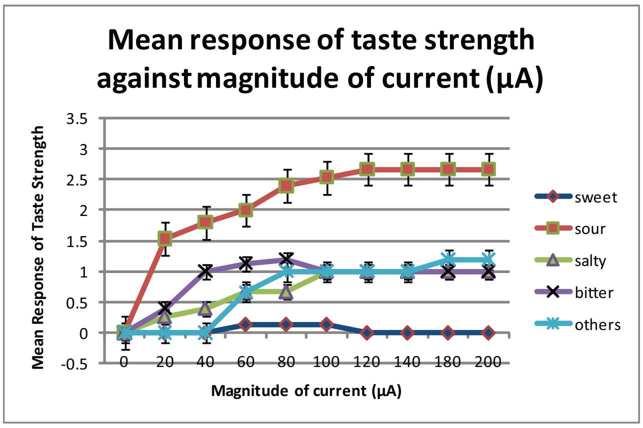


Figure 7: The perceived intensity of taste sensations during electrical stimulation based on the change of current

The results of thermal stimulation (Figure 8) implies the possibility of producing sweet sensation although the rate of successful generation was low. Furthermore, several subjects reported that they felt the minty taste, refreshing taste (when cooling down from 35°C to 20°C), and also slight spiciness (when heating up from 20°C to 35°C).

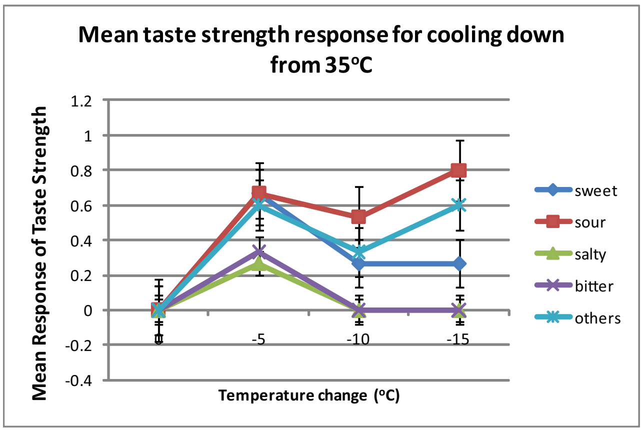


Figure 8: The perceived intensity of taste sensations during thermal stimulation based on the change of temperature from 35°C - 20°C

3.1.1 Safety

Efficacy of stimulation usually means the ability to obtain the desired physiological response, which can include initiation or suppression of action potentials. Judicious design of stimulation protocols involves acceptable compromises between stimulation efficacy, requiring a sufficiently high charge per pulse, and safety, requiring a sufficiently low charge per pulse. Waveform (square), current (20μA, 40μA, 60μA, 80μA, 100μA, 120μA, 140μA, 180μA, 200μA), frequency (50Hz, 100Hz, 200Hz, 400Hz, 600Hz, 800Hz, 1000Hz), and the material (silver electrodes) were selected appropriately. Additionally, we understood the ethical issues behind this research and already secured the necessary approval from the University Institutional Review Board (Approval No: NUS 1049) before the experiments.

(a) (b)

Figure 9: Future application scenarios: (a) digitized personal smell and taste experiences (virtual tasting) (b) remote family interactions through digital smell and taste (virtual dining)

4. FUTURE WORK

With a novel mechanism of ‘pulse magnetic flux nozzle’, a magnetically induced deep brain electrical stimulation system (Figure 10) is under development as the future direction of this research. It is proven that the human brains work by firing electrical impulses in specific functional units (clusters) of neurons [27]. Further, the human brain registers specific brain functions or perceptions as forms of neural firings at specific locations on the brain [23].

For example, when students practice a lesson, the clusters of neurons that control and drive certain function, fire repeatedly. When neurons fire frequently, they expand towards each other resulting in electrical signals [23]. It is the same for taste and smell perceptions. Understanding the firing in the brain for each of the brain perceptions could potentially provide the basis for modifying, reproducing, or creating the perception by modifying the neural firing with electrical means. Physically, such a neural firing can also be duplicated by applying electrical stimulation at the local field [21]. In this way, the taste and smell perceptions will be alleviated by modifying the neural firing with physical (noninvasive) means. The process requires three steps to be achieved:

1. To locate the neural firing on the brain for each of the concerned perceptions
2. To investigate and model the dynamic behaviors of the neural firings for each of the concerned perceptions
3. To identify and validate the critical conditions of the neural firings and accompanying local field potentials for each of the perceptions (by stimulating identified critical conditions we would stimulate the perception)

Proposed approach of actuating taste and smell sensations through magnetic stimulation is mainly divided into three phases.

Phase 1: Firstly, we are developing engineering tools required to establish intracranial imaging facilities [9]. A super high density 1024 channel scalp EEG system that uses novel dry EEG sensors [22] together with a novel EEG source localization imaging system is being developed for 3D localization of the electrical dipole sources in the brain (equivalent to a cluster of neural firings on the brain for a specific perception). Then, a single shank multichannel 3D micro intracranial electrode array for deep brain depth local field potential measurement will be designed and developed. Followed by a novel super precision device for implanting an array of single shank multichannel 3D micro intracranial electrodes individually deep into the brain at the targeted local field without damaging the neurons and their connections. Animal facilities for intracranial measurement of the neural firing of each of the concerned brain perceptions will also be established.

In addition, once implemented, we will be evaluating the digital taste actuating system using above described new imaging technology. The taste sensations stimulated by the device will be further compared with the taste sensations stimulated through real food with the incorporation of source localization technology on brain.

Phase 2: Secondly, we will be investigating and modeling the locations and dynamic behaviors of neural firings of the taste [28] and smell [15] perceptions. The neural firing will be localized using the super high density 1024 channel scalp EEG system and the EEG source localization imaging systems. The dynamic behavior of the neural firing will be investigated by measuring and monitoring the corresponding local field potentials using an array of single shank multichannel 3D micro intracranial electrodes (by precisely placing across the neuron units of the neural firings). In addition, a comprehensive physical model for the neural firing will also be developed.

Phase 3: Finally, we will focus on identifying and validating the critical conditions of neural firings of selected brain perceptions. Thus, to modify and reproduce those perceptions by modifying the neural firings with electrical means.

At the beginning, for brain stimulation, animal models such as mice and monkeys will be used to conduct testing procedures before test on humans. Performing such procedures indicate that the level of safety would be satisfied. The main reason for selecting animal models is because the anatomy of a mouse or monkey and their body functions are closer to humans. Providing tastes and smells of their favorite food and providing smells of their predators to observe their behaviors will be the two main approaches in conducting these experiments. Natural food and smells will be initially given to them, and their reactions to those will be measured through EEG experiments. Then the magnetic stimulation will be used to stimulate identified nucleus in the brain to simulate artificial tastes and smells. Finally, the results will be compared for further evaluations.

We have identified several limitations of this approach. For example, results of this technology could cause some cultural and ethical issues in the society, especially if we failed to develop and test the prototype in an appropriate manner. Furthermore, noninvasive brain stimulation might cause harmful effects on human when people use it for a longer period. More research works need to be conducted on the negative effects of transcranial magnetic stimulation for the human brain when people use it for longer periods.

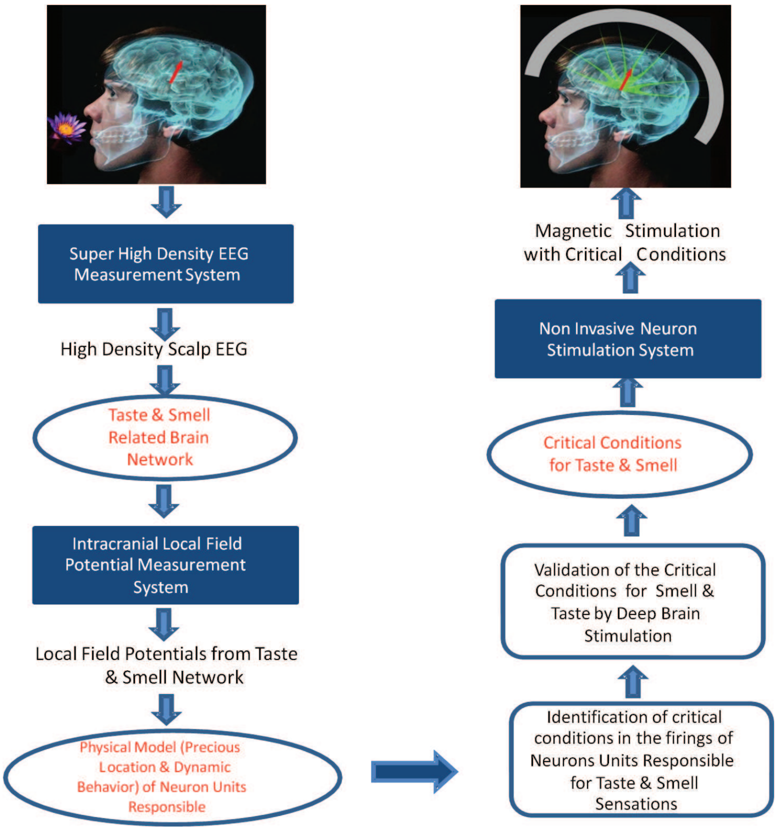


Figure 10: Flow of regenerating taste and smell perceptions by magnetic stimulation

5. POTENTIAL APPLICATIONS

There are various application possibilities that can be implemented through the presented system, especially related to education, communication, virtual reality, medical, and gaming fields.

In particular, the digitization of taste and smell senses allows for richer multisensory remote communication possibilities, which are harder to achieve with analog chemical stimulations. The system can be used in family communication, specially sharing of taste and smell sensations with loved ones who live in distant locations. Thus, this system may help people to share their experiences, enjoyment, and emotions which are blended with taste and smell sensations. This will re-combine the isolated nature of humans in the modern world and gives positive thinking of remote co-presence and co-living experiences through digital taste and smell communication.

Furthermore, chemical based smell interfaces has the difficulty of controlling the flow of odor molecules. They spread through the air and becomes difficult to control within the personal space. Therefore, the proposed methodology will be useful for developing applications to deliver personal experiences. For example, the proposed magnetic stimulation device would be used to provide rich experiences for movies or theaters. When there is a party on the screen or on the stage it will be possible to experience smells of food and wine. Similarly, it is also possible to simulate the smells of natural flowers on the screen such as lavender and jasmine.

Moreover, medical field will be one of the fields that would be benefited immensely through this system. For example, the taste actuation device has the potentiality of treating both diabetic patients and people with taste disorders. Diabetic patients may use this device to activate sweet sensation whenever they would like to, without increasing the existing sugar level in their bodies. If a patient could not taste any food due to cranial nerve failure, he will be able to use the deep brain magnetic flux stimulation device and experience the missing sensations, the taste and smell.

In addition, by integrating proposed system into virtual reality and gaming systems users may taste or smell virtual food or environment as they are in a natural environment (as illustrated in Figure 9). For example, the system lets the player experience different smells when the player is traveling through a virtual jungle, which are part of a real life jungle experience. We believe, in the future, these new digitized experiences will stimulate novel and innovative applications into the existing digital world. Possible extension of this research also includes amplifying the magnitude of taste and smell senses that are sensed by animals and plants but not by humans, thus increasing the human empathy for surroundings.

6. CONCLUSION

In conclusion, we presented a new methodology for actuating taste and smell sensations digitally on the human brain. We developed and presented a system which stimulates human tongue using electrical and thermal measures. Initial results suggested that the system produces sour (mainly), salty (mainly), and bitter (merely) sensations in a controlled and repeatable manner. In addition, we proposed a novel mechanism of pulse magnetic flux nozzle, a magnetically induced deep brain electrical stimulation system, which will be able to produce both taste and smell perceptions digitally. This technology can be adapted to a wide range of applications and will improve the quality of human life especially on digital multisensory communication, education, medical, and virtual reality domains.

7. ACKNOWLEDGMENTS

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