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The Sound of the Smell (and taste) of my Shoes too: Mapping the Senses using Emotion as a Medium

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ABSTRACT

This work discusses basic human senses: sight; sound; touch; taste; and smell; and the way in which it may be possible to compensate for lack of one, or more, of these by explicitly representing stimuli using the remaining senses. There may be many situations or scenarios where not all five of these base senses are being stimulated, either because of an optional restriction or deficit or because of a physical or sensory impairment such as loss of sight or touch sensation. Related to this there are other scenarios where sensory matching problems may occur. For example: a user immersed in a virtual environment may have a sense of smell from the real world that is unconnected to the virtual world. In particular, this paper is concerned with how sound can be used to compensate for the lack of other sensory stimulation and vice-versa. As a link is well established already between the visual, touch, and auditory systems, more attention is given to taste and smell, and their relationship with sound. This work presents theoretical concepts, largely oriented around mapping other sensory qualities to sound, based upon existing work in the literature and emerging technologies, to discuss where particular gaps currently exist, how emotion could be a medium to cross-modal representations, and how these might be addressed in future research. It is postulated that descriptive qualities, such as timbre or emotion, are currently the most viable routes for further study and that this may be later integrated with the wider body of research into sensory augmentation.

CCS Concepts

• **Human-centered computing~HCI theory, concepts and models** • *Human-centered computing~Accessibility theory, concepts and paradigms* • Human-centered computing~Mixed / augmented reality • Human-centered computing~Interaction design theory, concepts and paradigms

Keywords

Human senses; sonification; interaction; sensory perception; cross-modality.

1. INTRODUCTION

There are several scenarios where it is useful to be able to represent information, based on a particular sensory stimulus, using an alternate form. In the field of audio this is commonplace in audio editing tasks, where a Digital Audio Workstation (DAW) operator will manipulate sound using a visual waveform representation or an engineer will inspect audio phenomenon using an oscilloscope. But the mapping of other sensory stimulants to and from sound is much less explored, particularly when dealing with the senses of taste and smell. Such mappings have utility in the enhancement of virtual environments and in providing enhanced quality of life for people with one or more sensory impairment.

It should be clear to the reader that this work is interested in the two-way relationship between sound and the other four senses of smell, taste, sight, and touch. Namely: how can sound be used to represent these other four senses if they are not present and, equally, how could each of the other four senses represent sound if it is not present? This is the central enquiry at the core of this discourse.

The remainder of the paper is organized as follows: section 2 provides a summary of existing literature in this field, crucially setting out the definitions and work carried out to date in discussing how senses might be used to represent one another. In section 3 mappings and relationships between the five primary senses, which could be taken forward for development, are proposed and discussed. These are primarily oriented around the role of sound and emotion. Finally, in section 4, a summary of the main points of discussion, and suggestions for future theoretical and empirical research, are presented.

2. BACKGROUND

2.1 Definition of the Senses

First, it is necessary to make some definitions. Sound is dealt with as a physical phenomenon, whilst hearing is regarded as the perception of sound. It is clear that within this classification sound from the physical world, perceived by a listener, and imagined sound with no real-world physical manifestation, are still 'heard' by the listener, since this is their own individual perception. This presents clarity as to the condition of perception; it is audio as it occurs 'in the head' of a listener [1]. This definition extends to the senses, whereby real world stimuli manifestations like odour, texture, and flavour are caused by some disturbance or physical property that can be scientifically quantified. Like sound, these will be interpreted via the physiology of the individual, their nervous system and neurology, to arrive at a perception located, as with sound, 'in the head' of the individual. In all of these cases, it is reasonable to argue that perception might be generally shared and understood amongst a group, although in some cases there may be no group norm. To simplify this challenge, we focus this discussion upon the experience and perception of the individual.

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Moreover, for the purposes of this work, it is useful to be clear in the choice of human senses that are being addressed. This article adopts the historic and traditional view of there being five human senses, as credited to the work of Aristotle [2], namely: sight, sound, touch, taste, and smell. It is recognized that this definition is much debated and challenged in the modern world of science and that there exists work that proposes other senses beyond the five defined in the classical model, such as senses of pressure, heat, balance, hunger, time, and so on. However, for the sake of maintaining focus, and since this work is intended to be generalizable and scalable, this article will focus upon the five traditionally defined senses. It is worth highlighting at this stage that the combination of senses being stimulated at, or around, a moment in time, is also considered important to this work.

2.2 The Need for Alternate Sensory Representations

The ability to represent information in a variety of alternate forms is not a new concept and not one that is exclusive to the senses. Subtitled television and film, for example, are effective ways of communicating audio information to those who suffer a type of hearing loss or to provide a translation in a language other than the original audio feed. Infographics have been a longstanding way of conveying large amounts of numerical and logical data in a quick and easy-to-understand way. Finally, consider the example of editing audio data, a task that is much easier to accomplish when the audio can be conveyed in a visual and/or physical form, such as a waveform on a screen or, more traditionally, a piece of marked magnetic tape.

Clearly then, there are a variety of applications for any mechanisms that permit alternate presentation forms of sensory stimuli. Two current and large impact scenarios that can be considered are: (a) as an assistive mechanism for a person who has sensory impairments and (b) to enrich virtual and augmented reality experiences by representing aspects of sensory experience that cannot be conveyed in an equivalent modality.

In the case of assistive technologies the markets are significant. The World Health Organization estimate, for example, that worldwide 285 million people have some form of visual impairment [3] and 360 million people have some type of hearing loss [4]. Data regarding smell and taste debilitation is less prevalent on a global scale, but in the case of data from North America the US Department of Health and Human Services indicate that between 1 to 2% of North Americans suffer a smell function disorder [5] and that it is possible that up to 15% of adults in North America suffer from some form of taste dysfunction [6]. Notably, though perhaps unsurprisingly, the likelihood of occurrence of each of these conditions increases with age and recent research has shown that a significant proportion of the ageing population encounter one, or more, sensory impairment and that loss of taste is most common of the five senses [7].

As for the enhancement of virtual and augmented reality experiences, entertainment technologies, particularly computer games, have been a primary driver for greater realism and immersion. This might include making a game or virtual environment more realistic or even hyper-real, in order to connect on a deeper level with the user and, ultimately, to extend their attention, longevity, and experience of the game or other form of entertainment. Game technology has evolved from the simple visual and audio coupling that emerged from its infancy in the 1960's and 1970's. During the 1980's and 1990's game manufacturers experimented with touch and tactile feedback, such as vibrating control devices and the augmentation of visuals in the game with images of the user and from the real world. Recent estimates suggest that the global video games revenue for 2014 was 46.5 billion US Dollars [8] and that 45.3 million games consoles units were sold in the same year [9]. Since the turn of the 21st Century, a limited amount of research has been undertaken regarding smell and synthetic olfactory stimulation devices [10, 11]. Initial work on the artificial replication of taste has also been carried out, such as Ranasinghe, Nakatsu and Nii's development of a tongue-mounted interface that simulates taste through electrical and thermal stimulation of the human tongue [12]. Nonetheless, this remains a relatively underexplored area of research and there we have yet to see any such devices research a mass market.

2.3 Conventional Representations

2.3.1 Sound and Vision

Classical uses of DAW software exemplify the way in which sound and image can be mapped back and forth with one another. Visual representations of sound such as waveform traces, spectrograms, level indicators, frequency histograms, and phase meters. Equally, these forms of visual information can be converted back to sound, although in the case of direct sound conversion from an image (such as a photograph) they may be less meaningful. However, information conventionally presented in a visual form can be represented using sound, such as in audio books and through the use of Earcons [13]. These links are well known and discussed in detail by many media theorists when presented in combination [14]. However, this use in combination indicates that often, it is not necessary to use the 'true' representation of a visual and audio counterpart. Sound and vision, although well studied and conventional, when compared to the proposed representations between taste and smell in this work, demonstrate that direct correspondence between the two does not have to exist in order for the audience to perceive a convincing relationship between the two. This is a large market in itself through the television, movie, and computer games industries, and manifests itself there through the role of Foley artists and mixers. Foley artistry itself demonstrates the pre-condition of the listener to hear audio as it is caused by actions represented visually; it is not necessary for the sound to be directly recorded from the physical action taking place, provided it has sufficient timbral and synchronous properties associated with the visual source [15]. Consider also the viewing of a silent movie: as the viewer watches the on-screen action audio can be internally imagined and perceived by the viewer, who is now also listening, though there is no physical sound in the air around their ears.

2.3.2 Sound and Touch

Sound and the sense of touch, although not as commonly encountered as sound and vision, is a field that has received sustained attention. Existing work on this topic has often concerned itself with the way in which textures might be represented and generated using sound [16].

A wider example of the application of these concepts can be attributed to work by Grill [17], who sought to apply the broad conventions of sound generation of textures to soundscapes or sonic environments. Nevertheless, this work provides the reader with a useful overview of the desired qualities of sound textures: namely that they should be broadly similar, not exhibit significant deviation over a period of time, and that the main features of textures should be apparent relatively soon after the sound is heard.

Other research that has considered the way audio can be used in cross-modal scenarios highlights the application of audio as a mechanism to help train physical motor response of users. This is mainly direct in a rehabilitation capacity, but does support the notion that there can be a connection between physical movement and sound [18]. By extension, it might seem reasonable that the sense of touch too could be explored within this paradigm.

In all of these scenarios, it is worth making the observation that the desire to create a sonic texture, is often to complement some existing visual stimuli, such as the presence of rustling trees in a computer generated forest environment or the sound of gravel underfoot.

2.4 Underexplored Representations

Now, to consider the less investigated notions of the ability for sound to represent, and be represented by, other sensory systems, namely those of smell and taste. These concepts feel perhaps less intuitive since, from a media perspective, the combination of vision of sound is a long-standing relationship but smell and taste are not. Although audio-visual media can be used to communicate aural and visual stimuli with some equivalence, the use of these media to convey sensations such as taste or smell, which are not inherently aural or visual, is less understood.

2.4.1 Sound and Smell

To demonstrate this 'oddness' by way of such a media-centric, popular culture example, consider an infamous quote, familiar to die-hard fans, of the 1984 comedic fiction movie *Ghostbusters*: Whilst investigating paranormal disturbances in the New York City Library, one of the film's central protagonists, Dr. Ray Stantz, utters the phrase: "*Listen... do you smell something?*" [19]. The phrase is comical and lightly jarring to the audience upon their further reflection. It seems ludicrous that someone would somehow connect those two senses to form this kind of conclusion or statement. But, is it?

Although not directly exploring the relationship or mapping of smell to sound, existing research has shown that smell can be a useful tool in human-computer interaction scenarios, such as in navigating a large collection of photographs [20]. This work supports the generally held opinion that smell is less understood than many of the other human senses and that it can be difficult to arrive at any direct technique for modeling human smell response in a descriptive way. But, it does advocate the strong relationship of the sense of smell to memory and, more relevant to this work, emotion.

Similarly, Ghinea and Ademoye conducted experiments with odour where multimedia content was presented to a group of users and evaluated against a control group, where odours were not present. It was found that in the conditions where smells were used it enhanced the experience of the user group. However, this work did not directly address the mapping exercise between the audio and visuals in any detail other than by the authors selecting odours that, in their opinion, intuitively mapped to the scenarios being depicted [21].

The relationship between sound and smell was recently considered by Grimshaw and Walther-Hansen [22]. Their work on this subject has heavily influenced the theories and concepts presented in this paper. Their work particularly advocates the exploration of these relationships within the context of virtual environments. Significantly, we owe them for their excellent discussion of perhaps the most common relationship encountered between sound and smell in the everyday world: that of flatulence! Of particular interest however, is their proposal that it would be possible to map a smell, in their case a pair of trainers, to a sound. Some initial suggestions are given, based upon the work of Boevé and Giot [23] and Belkin *et al.* [24], but this concept is not the main focus of their paper.

2.4.2 Sound and Taste

A sustained body of works has been carried out with regard to enhancing user experience by way of stimulating the sense of taste. In one study, the authors themselves recognize this as a difficult and challenging field, describing it in one case as "*...one of the final frontiers of immersive media...*" [25]. Equally, this stresses the value that being able to represent the sense of taste would have in virtual environments and, by extension, other fields of technological development for accessibility. Similarly to the research outlined in the previous section, their work is focused around using apparatus to replicate tastes via the tongue and mouth receptors and, as such, is not directly trying to recreate these sensations using other senses. A limitation of this approach, is that it requires similar apparatus and materials as would be encountered when presenting the intended taste. In another development, other work by these authors had considered the combined stimulation of taste and smell, as one would encounter when eating or drinking [26].

In a more radical piece of research, the concept of taste is indirectly considered in work that seeks to augment the eating experience by enhancing and augmenting the textural qualities of food using filtered audio. This process employs filtering techniques upon near real-time captured audio of a person eating to generate a hyper-real audio experience. The authors claim that this is suitable to enhance and improve the eating and, by inference, taste experience. Although not directly trying to create sounds that will recreate taste or texture, the authors demonstrate that audio signal filtering and manipulation may well be part of any such process. However, it should be noted that this work is limited by the fact that it is primarily concerned with food sounds that may be implemented by high pass filtering (such as crunchiness and crispiness) and that there is no formal evaluation of the success of this approach. Nevertheless, this is one school of thought that supports the notion that sound can be used to stimulate senses of taste and touch (food texture) [26].

3. SOUND AND THE OTHER SENSES

3.1 Representing Sound using the other Senses and Vice-Versa

By examining the classical example of sound and vision, we encounter a generally agreed upon way to map sound properties to visuals and back again. This is described in section 2.3.1, by translating physical sound properties to visual properties: converting amplitude to the height of a waveform or the brightness in a spectrogram, for instance.

Another alternative, that is more immediately accessible and less reliant upon direct mapping, would be to consider a notion used frequently in sound and music studies; that of *timbre*. Defined loosely when used in audio, timbre typically refers to the colour or textural qualities of a sound. For example: "*The trumpet was brash but the flute was smooth and piercing".* Using such descriptions exemplifies the use, or at least the perceptual use, of the other senses to describe a single medium. To take another example, humans can visually perceive rough and smooth textures by alternate modes of sight or sound (if the material interacts with another) before confirming this theory by applying the sense of touch. Taste and smell are another two senses that are closely linked: often the smell of a particular food is similar, or holds strong association, with the taste of that item. From this perceptual perspective then, it is reasonable to suggest that somehow 'getting the idea' of another sensory stimulus to the brain might elicit a sympathetic or complementary response, likely to be supported by memory recall. However, there are some obvious counter arguments to these examples. For example: many reptiles, such as lizards and snakes look slimy, when in fact their texture may be rough or smooth. Some foods taste quite different to their look or smell. As such, caution needs to be applied with this approach. But this situation leads to another realization: that the sensory stimulation leads to perception and the perception then leads to some kind of emotional response, such as joy, pleasure, repulsion, or dismay. To mediate between the senses further, is there value in taking an emotionally led approach, rather than one relying solely upon physical properties from the real world?

3.2 Mapping Sound and the Other Senses using Emotion as a Medium

The majority of the literature discussed in section 2 describes scenarios where it is desirable to gain insight from alternative forms of sensory stimulation, typically for the purposes of improving some kind of user interaction, experience, or immersion within a virtual or real world scenario. Indeed, many of these articles go further and cite specific emotional impact that is likely to occur within users of such systems. This brings forward an additional useful concept: that emotional response to these stimuli may be an important piece of the jigsaw, which must be addressed, or at least considered, if one is to attempt to represent other sensory stimuli, when the primary response is not present or perceptible.

To help illustrate this hypothesis, consider the following example, which demonstrates the ease with which all five senses will comfortably sit together, having been mediated by emotional interpretation and classification. Utilizing Russell's two-dimensional model of emotion, known as the Circumplex Model of Affect, [28] as a simple method for graphically illustrating emotion. Figure 1 is created from the first author's own constructivist and personal perspective and includes: two smells; two sounds; two tastes; two textures (touch); and two sights. As per Russell's system, the horizontal axis represents valence (negative to positive emotional state) and the vertical axis indicates a level of arousal (emotional intensity).

As demonstrated in this example, the ability to describe these stimuli using an emotional model is straightforward and can be done easily with the minimum of guidance.

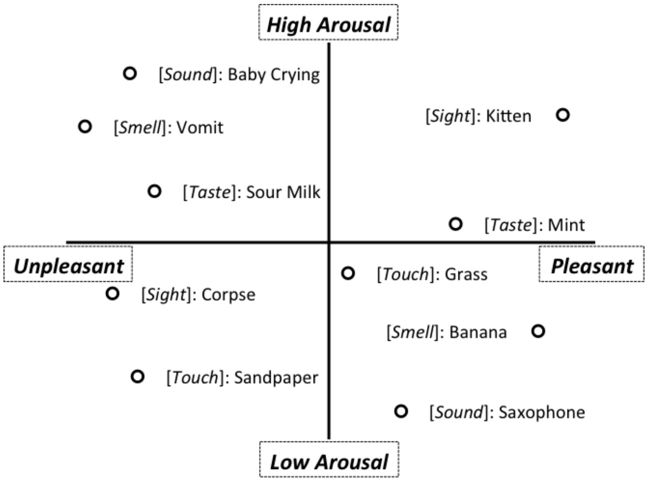

Figure 1: Emotional Representation of Five Sense Stimuli

This leaves an interesting residual question: rather than attempt to directly map physical qualities or properties from the other four senses to and from sound, should the design of these materials be influenced by emotional categorization along or even in combination with other shared factors such as context?

4. DISCUSSION

A key consideration comes to light, which is that all of the five classes of sense discussed in this article are dependent upon a human organ or physiological receptor for interpretation: ears, eyes, nose, tongue and mouth, and skin and nerves. As such, these are directly activated by properties of the stimulus, whether these may already be caused by a mechanical wave (sound), electromagnetic waves (sight), chemical composition (smell and taste), or pressure (touch). Due to this, attempting to map or recreate these parameters to another sense is intrinsically difficult, such as in converting a smell or a taste to sound. As such, it comes as no surprise that the majority of interactive systems that seek to work with senses such as taste and smell do so by attempting to directly present these stimuli through chemical or electronic manipulations that directly stimulate taste and smell receptor organs in users.

However, each of these stimuli is eventually perceived and interpreted by the brain. The cognitive process of perception leads to associations of sound with other types of multi-modal information and sensations [29]. Among these, emotion is significant, and this paper has outlined how sounds might be classified according to dimensional models of emotion, such as Russell's 'circumplex model of affect'. Extending the premise, we could begin to assign sounds, tastes and smells with information that describes their semantic associations across the modalities and according to emotion. We can conceive of such techniques leading to more sophisticated computational systems that utilise this data in order to design experiences involving sounds that take our associative interpretations into account.

As future work that might inform such systems, it is suggested that all of the discussed approaches should be explored in empirical studies. Simple card sorting and matching exercises, for instance, would allow participants to match tastes and smells to audio and visual representation of common everyday objects: ideally those that are representative of a broad suite of emotions, such as food and drink. These matches could then be emotionally annotated, to build initial models of emotion and multi-sensory stimuli. Such a method will become multi-dimensionasl and so would lend itself to extraction through techniques such as repertory grid and principal components analysis. This initial model could then be tested and evaluated and, if shown to be valid, lead to the development of a series of recommendations or artificial intelligence systems that could be employed to mediate between the senses and automatically generate sensory stimuli to enhance virtual environments and heighten the experience of the everyday world for people who might suffer some type of sensory impairment.

Some of our own previous work, that has relevancy to this theme, has undertaken feature analysis of musical audio recordings, resulting in a model that allocates a piece of music to a location on Russell's circumplex model [30]. It is reasonable that similar exercises could be carried out in domains relevant to the non-sound senses. Following a process like that in [30], self-report studies could be carried out to rate sounds according to smell, taste, and properties of sight and touch such as brightness, temperature, pressure, and so on. As such, playlists of music could then be formed that conform to one or more sensory perceptions: providing an innovative method of being able to navigate a large music collection or produce a playlist that could complement each course of a meal. Extrapolating this model further to on-chip, mobile device solutions, it would then be possible to link electronic sensors and stimulators of smells and taste [12, 21, 25, 26, 27], for example, to an auditory system that operates with sounds or music, which could be of great value to someone with a sensory impairment in a real-time, real world scenario.

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