OLFACTION ENHANCED MULTIMEDIA: A SURVEY OF APPLICATION DOMAINS, DISPLAYS AND RESEARCH CHALLENGES

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Recently, the concept of olfaction-enhanced multimedia applications has gained traction as a step towards further enhancing user quality of experience. The next generation of rich media services will be immersive and multisensory, with olfaction playing a key role. This survey reviews current olfactory-related research from a number of perspectives. It introduces and explains relevant olfactory psychophysical terminology, a knowledge of which is necessary for working with olfaction as a media component. In addition, it reviews and highlights the use of, and potential for, olfaction across a number of application domains, namely health, tourism, education and training. A taxonomy of research and development of olfactory displays is provided in terms of display type, scent generation mechanism, application area and strengths/weaknesses. State of the art research works involving olfaction are discussed, and in addition, associated research challenges are proposed.

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1. INTRODUCTION

Nowadays, research in multimedia also considers sensorial media such as haptic [Danieau et al. 2012], smell [Ghinea and Ademoye 2012] and taste [Narumi et al. 2011a] alongside the traditional audiovisual components. The addition of these new modalities make multimedia applications more reflective of reality, resulting in enhancements in user Quality of Experience (QoE) levels e.g. face-to-face communication (audio, visual as well as touch), cooking program (audio, video

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including smell), etc. In multimedia applications and systems, user perception of multiple media components and the relationships between them is an active research topic. The ultimate criterion for judging an application's success is not a functional requirement, but rather the human impact measured by affective evaluation [Hughes et al. 2005]. A human's perception of an environment is significantly influenced by all our sensorial inputs [Calvert et al. 2004; Ebrahimi et al. 2003]. Among these inputs, olfaction (sense of smell) is one of the most intriguing, due to its complex nature and the fact that its perception by humans is not yet fully understood.

It is only in recent years that a better understanding of the recognition and perception processes of different odors was achieved by Buck and Axel [1991]. However, a generally accepted classification scheme for identifying smells does not yet exist. As Kaye mentioned in [2001][2004], there are no primary smells as exist for color. A number of proposed smell classification schemes were reviewed by Ghinea and Ademoye [2011], but these have been developed on a per industry basis e.g. perfume, food and wine. In addition, it is known that odors are perceived differently considering: a person's age [Murray et al. 2013b], their nationality/culture [Murray et al. 2014a], based on their gender [Shih and Blignaut 2011], their mood, and their life experiences as reviewed by Ghinea and Ademoye [2011]. There is further discussion on each of these aspects later in this paper. These works reinforce the view on the complexity of olfaction as a media component.

The potential uses and benefits of olfaction are gaining traction in rich media applications across a number of industries: entertainment [Puopolo et al. 2011], health [Spenser 2006], education [Shams and Seitz 2008], and tourism [Dann and Jacobsen 2002]. The review by Kannan et al. [2010] highlighted the potential for multisensory media ecosystems in marketing, health and learning modeling. From a health perspective, the addition of olfaction to an environment has been seen to reduce stress [Warm et al. 1991] and be used in disease diagnosis and treatment. A more detailed discussion is provided in section 4.3. From an educational perspective, olfaction has supported increased information processing, enhanced memory [Herz 1998; Morrin and Ratneshwar 2000], higher performance in problem solving tasks: reduced response times and increased information recall [Brewster et al. 2006]. This is also discussed further in section 4.3. It has also been shown that olfactory stimuli help enhance productivity, alertness, and physical performance [Washburn et al. 2003].

It is a reflection of the challenging nature of smell that there is relatively little work involving olfaction in the multimedia space. Reproduction of scents in terms of quality and at required intensity levels has proven particularly challenging. Whilst devices which emit scent have been commercially available for a number of years, difficulties remain in controlling scent emission in terms of the direction in which the scent is dispersed (susceptibility to air movement); quantity of scent emitted; length of time it takes to emit a scent; length of time the emitted scent lingers in the environment; and number of different scents which can be stored in an olfactory display at any given time. Additionally, multiple modalities must be presented, as they are present in real life [Harel et al. 2003], and hence multisensory multimedia synchronization (considering spatial and temporal aspects [Waltl et al. 2010]) is a challenging multi-dimensional problem.

Nakamoto [2013] provided a detailed synopsis of olfactory interfaces from the sensor and presentation aspects point of view. This work provides a welcome introduction for the reader to olfactory psychophysics and a review of initial works with respect to olfactory displays (OD) and sensors. More recent and advanced studies are also outlined. Ghinea and Ademoye [2011] provided a thorough review of perception of olfaction across age, gender, mood, and culture. They also discussed the use of olfaction across a number of different industries and highlighted research gaps in terms of olfactory displays, content association and synchronization between smell and audiovisual media. Yanagida reviewed and categorized the different types of technologies used in the development of modern olfactory displays in terms of scent generation and scent delivery [2012].

Table I. Overview of paper's principal aspects

Olfactory Psychophysics • Terminology • Phenomena	Olfactory Displays • Review • Classification
Olfactory in Industry: • Tourism • Health • Education & Training	Olfactory Research Directions: • QoE/Cross modal • Olfactory transmission over constrained communication networks

This article, as summarized by Table 1, complements the work of Ghinea and Ademoye [2011] by extending the olfaction-enhanced multimedia taxonomy. Unlike the previous work which tackled evident application areas such as the film industry, virtual reality, multimodal applications and entertainment, here the use of olfaction in less apparent application domains such as tourism, health, education and training is discussed. As such, it highlights the very significant potential for olfaction as a media component. This work also complements and extends the work of Yanagida by providing a comprehensive review of all commercial and research olfactory displays that have applied the technologies discussed in [2012]. It also extends the work of Nakamoto [2013], providing a broader review of works within the above mentioned application domains and technologies outlined in [Yanagida 2012]. A tutorial section on psychophysics and phenomena associated with olfaction is also provided, specifically with new readers to this area in mind. Finally the most up-to-date research challenges associated with olfaction-enhanced multimedia are introduced and discussed.

This article is structured as follows: Section 2 introduces olfactory psychophysics and related research. It describes works which have analyzed the perception of olfaction and explains how odors are perceived. Section 3 looks at olfactory display works from research and commercial perspectives. Section 4 reviews the use olfactory data in education, tourism and health industries and highlights the potential for olfaction as a media component in these areas. Section 5 identifies a number of research challenges for olfaction-enhanced multimedia QoE.

2. OLFACTORY PSYCHOPHYSICS & PHENOMENA

This section focuses on olfactory psychophysics, or how humans perceive scent, and presents explanations for relevant olfactory terminology and phenomena.

2.1 Olfactory Psychophysics

Psychophysics is the study of relationships between measurable stimuli and the corresponding sensory responses. Examples include how the body perceives sound loudness, light brightness or odor strength [McGinley and McGinley 2000]. Hence, olfactory psychophysics is the study of how humans perceive odors, and the sensation humans identify when the olfactory receptors cells are stimulated. This sensation is the psychophysical reaction resulting from a sensory stimulation. For such a sensation to occur, four conditions need to be present. Firstly, a stimulus must exist in the environment. Secondly, a sensory receptor must convert the stimulus into nerve impulses. Thirdly, these nerve impulses must be conducted from the receptors to the brain. Finally the brain must produce the sensation based on reception and integration of the nerve impulses. Tortora [2002] stated that sensory receptors are categorized considering their location on the body, the stimulus that activates them, and their degree of complexity. Smell receptors are classified as being within the *Exteroceptors* group, meaning that they are located at, or close to, the surface of the body. They provide information about a person's immediate surroundings. The sensation of smell is a result of stimulation of the smell receptors by a physical chemical stimuli, known as a chemoreceptor. The sense of smell is classified as a complex type receptor, due to the complex structures and neural pathways which are associated with the sense of smell.

Smells can be detected in two ways depending on the travel path of the scent: (a) through the nose, (*orthonasal* pathway) or (b) via the mouth and up a passage at the back of the mouth (*retronasal* pathway). Smell, like taste, is a chemical sense. Buck and Axel [1991] reported findings on the manner in which odors are detected. They are detected by means of a large multigene family which code for Odorant Receptors (OR) in the nose [Buck and Axel 1991]. Humans have approximately 400 ORs. These ORs work in a one-to-many or many-to-one manner in terms of how they encode individual odors [Buck 2004]. Due to this combinatorial receptor coding [Yeshurun and Sobel 2010], the detection of 10,000 to 100,000 different volatile compounds is possible. However more recent works have reported that our olfactory capability is much greater than this, with Bushdid et al. [2014] reporting the estimated detection of over 1 trillion odor stimuli i.e. making it more capable in terms of detection than the other sensorial stimuli. Bushdid et. al's work involved using combinations of 128 odor molecules and a total of 26 assessors. Each assessor performed 264 discriminatory tests. They were required to identify the 1 odor from a possible 3 that was different. The authors reported what they termed a conservative estimate of 1.72×10^{12} discriminable olfactory stimuli, as such indicating the power of olfactory capability compared with audio or visual sensing.

Significant differences exist between individuals in terms of olfactory sensitivity and perception. Ghinea and Ademoye [2011] reviewed works which looked at age, gender, culture, life experiences, emotions, mood and memory, and how these variables impact upon olfactory perception. In terms of age, MacFarlane reported in [1975] that newly born babies use smell to differentiate their mother from others. There is conflicting information in the literature in terms of the age at which olfactory development is considered to be fully established, with some works suggesting early childhood and others mentioning early adulthood. In terms of declining olfactory ability, Doty et al. reported this as being most noticeable at approximately 70 years [1984]. The authors of this work analyzed data from a small user study to examine the impact of age on user perception of olfaction enhanced multimedia synchronization and reported that age was not a major influencing factor in assessors' ability to detect inter-media skew [Murray et al. 2014a]. With respect to gender, generally females were reported to be more accurate than respective males in terms of sensitivity [Doty et al. 1984]. Indeed in our own exploratory study [Murray et al. 2014a], the female assessors were more sensitive to inter-media skews than males at smaller skew levels. Further information on these results is provided in section 5. Finally, considering culture, differences in users' perception of different scent types as being pleasant or unpleasant, and the ability to detect scents based on culture are well documented in [Ayabe-Kanamura et al. 1998]. In this study involving 84 females (40 Japanese and 44 German), each assessor reported the perception of 18 stimuli in terms of intensity, scent being pleasant versus unpleasant, familiarity, edibility and identification. The results indicated that the different groups were better able to provide appropriate information on the scents that were well known to them, with little differences between the groups for odors that were less familiar to either of the groups. Also, for certain scents, the German group reported a number of odors as being of higher intensity than the Japanese group. A number of the Japanese odors were described as unpleasant by the German group. Seok et al.'s study investigated regional influences on olfaction perception [2010]. They reported the results of an extensive study of over 1000 assessors between ages of 21 and 50 years from Mexico, Korea, Czech Republic and Germany. The Mexican group reported statistically significant differences from the other groups in their attitude towards olfaction and interestingly the female groups from each of the countries reported greater interest in olfaction than their respective male cohorts. It has also been shown that one person's perception may change from day to day [Kaye 2001]. Yazdani et al. reported that different parts of the brain were activated during the perception of pleasant and unpleasant odor stimuli via electroencephalograms (EEG) of five subjects [2012]. Yeshurun and Sobel noted that humans found more difficult to name odors perceived than to detect them [2010] . For this reason, more often than not, people will identify an odor by naming it after something it reminded them of. They also reviewed literature and proposed that an association between odor definition and user emotion exists e.g. a user's perception of an odor is affected if they are hungry or angry etc. In addition to this, Sela and Sobel discussed literature on human olfactory detection [2010]. They reported a paradox in that, while humans have excellent olfactory capability, a person's awareness of the presence of olfaction in an environment is quite limited. This point is supported by works on synchronization with audio and video media [Ademoye and Ghinea 2009; Ghinea and Ademoye 2010; Murray et al. 2013a; Murray et al. 2013b; Murray et al. 2014a]. This is discussed further in section 5.

2.2 Olfactory Phenomena

Since scent is a chemical media, a number of phenomena which are not common with audiovisual media are associated with olfaction. Olfactory *adaptation* arises due to a person's continued olfactory stimulation, and results in a reduction, to varying degrees, in the user's ability to detect scents. Essentially, the sensory nerve becomes fatigued and the user is unable to detect the presence of scents. Works have investigated and demonstrated the effects of adaptation, and in particular the relevance of concentration of odor and duration of exposure [Berglund et al. 1971; Dalton 1996]. Berglund et al. [1971] required assessors to rate one of two odors (one test stimulus and the other an adaptation stimulus), with the latter varying in concentration. For each of these adaptation stimuli, two assessors were required to indicate if they could detect the presence of the test stimulus. At higher concentrations of the adaptation stimulus, assessors were less well able to identify the presence of scents. Generally the approach to reverse olfactory adaptation is the removal of scents from the environment. Another olfactory phenomenon is *anosmia* where persons have an inability to detect the presence of olfactory stimuli. Anosmia can be total or partial, permanent or temporary. In [ISO 5492 2008] a number of sensory thresholds were presented, as well as terms and explanations for sensory analysis vocabulary. Such thresholds define the amount of stimulus needed to result in an olfactory sensation. These thresholds have gained traction as they link between physical concentrations and user perception of olfactory sensations. The *detection threshold* indicated the minimum amount of a stimulus needed to provide a sensory sensation, without the sensation needing to be defined. This has gained traction as it facilitates an objective mapping in terms of concentration of olfactory stimuli to users' perception [Lawless 1997]. Another threshold termed *recognition threshold* is the minimum physical intensity of a stimulus required for an assessor to assign the same descriptor each time it is presented [ISO 5492 2008]. The *difference threshold* is the minimum difference in the physical intensity of a stimulus needed to be perceived by a user [ISO 5492 2008]. *Terminal threshold* is the "minimum value of an intense sensory stimulus above which no difference in intensity can be perceived" [ISO 5492 2008].

Synesthesia is another phenomenon which exists whereby the stimulation of one sensory modality results in experiences in another modality [Cytowic 2002]. This phenomenon is not unique to olfaction, but the remainder of this section presents and discusses works that have investigated the impact of synesthesia specific to olfaction. The existence of a relationship between the sense of smell and taste is well known and documented, and indeed people often discuss a lack of tasting ability when suffering from colds or flus (nose blocked). Spence et al. [2013][Synesthesia 2012] analyzed the cross modal relationship between audio and smell. Their experiment involved a sample size of 30 assessors, who were asked to associate different scents with different sound pitches. The results indicated that high pitched sounds were associated with sweet and sour scents, whereas lower pitched sounds were associated with woody or smoky scent types. Gilbert et al. [1996] looked at the relationship between color and odors. In a study involving 94 subjects (38 men and 56 women aged between 18-40), assessors were presented with an odor and were requested to describe the scent via a scale that had 11 color names. Interestingly the tests were conducted in a neutral colored room. The results reported that statistically significant associations between odor and color existed for 20 of the odors. The work of Morrot et al. also looked at the relationship between odor and colors and demonstrated the unreliable nature of scent perception. They reported that the absence of a visual queue highlighted the limitations of users in discriminating between different scent types [2001], even among expert assessors; hence the visual modality was dominant. Assessors were also found to be willing to change the name of an odor with auditory or visual cues, which supports the findings of Tanikawa et al. [2008]. Dematte et al. looked at the relationship between olfaction and tactile in a study where 17 assessors rated the roughness of fabric materials considering two odors (lemon and animal) [2006]. The results of statistical significance showed that assessors rated fabrics softer when the pleasant lemon scent was presented as opposed to the unpleasant scent type. Hence, it could be concluded that the olfactory cues can alter tactile perception.

This section has reported olfactory psychophysics and phenomena which can affect user perception of olfaction. For researchers working with olfaction, a sound understanding and consideration of these aspects is required to ensure unbiased results are presented in olfactory related research works.

3. A TAXONOMY OF OLFACTORY DISPLAY RESEARCH AND DEVELOPMENT

Olfactory displays (OD) are computer controlled devices which present scented air. Key requirements of ODs are to present scent at an acceptable quality level in terms of intensity, realism and for the correct duration. These requirements have proven challenging for OD developers. ODs should aim to deliver smell in a non- invasive manner. Although Kortum [2008] mentioned that the development of olfactory displays are in their infancy when compared to the other sensory interfaces (i.e. visual, auditory, and haptic), an olfaction enhanced cinema theater existed in 1906 [Gilbert 2008]. The widely reported "Sensorama" system developed by Heilig [1992] in the 1960s incorporated scent as part of an immersive 3D bike ride through New York city.

In this work, ODs are classified based on their location and how they deliver scents to users. Within this classification, there are various technologies for scent storage and generation. The literature reports ODs based on natural diffusion, air-flow based diffusion, vortex rings, head mounted and on-body displays. Each of the different approaches has their advantages and disadvantages. A challenge unique to olfaction is its lingering nature. Two main approaches have been used to address this issue; (a) presentation of minimum amounts of scent to the users' olfactory field (b) usage of ventilation systems to remove lingering scent. Another unique facet to olfaction as a media is its slow movement, unlike the more instantaneous nature of audiovisual media. Once again, the presentation of minimum amounts of scent and use of fans/pressurized presentation have been the principal approaches employed in addressing this issue. Ideally, ODs should be able to support multiple scents and display same to varying degrees of concentration and intensity in line with stimuli from other media. They should have an ability to control the speed at which scent is delivered as well as be able to accurately specify where the scent is presented.

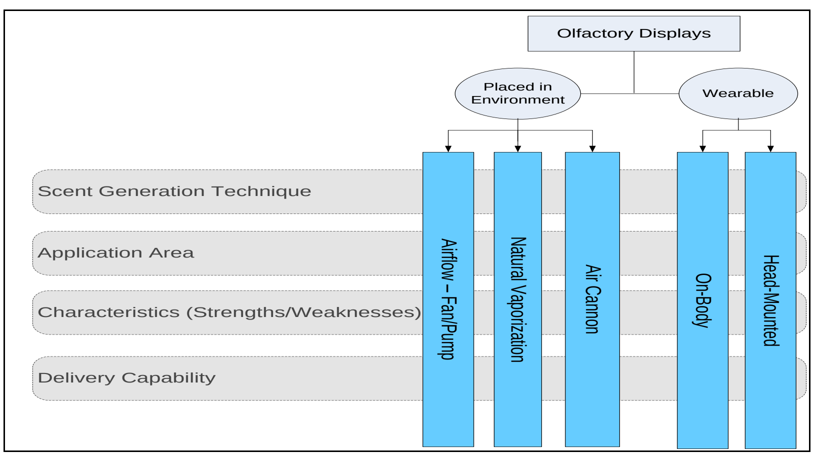

Fig. 1. Classification of Olfactory Displays.

3.1 ODs placed in the Environment

The key advantage of a display placed in environment is its non-intrusiveness: the user may not even be aware of the presence of the OD. The principal disadvantage is also related to this point: scent presentation is susceptible to air movement in the environment. This can result in variable times for the scent to reach the assessor's olfactory field, or the scent may not reach its intended destination at all. In the *Natural* scent delivery class, ODs present scents to the user via natural dispersion. *Air*

Flow based ODs deliver scent to the user based on fans, air pumps, compressed aerosols or blowers. Finally, *Air Cannon* ODs, while also based primarily on fans, are designed to achieve accurate delivery of scent via vortex ring presentation.

3.1.1 Natural

Kaye reported a number of different OD prototypes [2001]. His aim was to evaluate if, and how, scent could be used to convey information across different application areas. He introduced the terms of *olfactory icons* and *smicons*. The use of a scent that is directly related to other information which is also being presented is termed *olfactory icon*. The use of a scent that is not directly related with the information it expresses is reflected by the term olfactory *smicon*.

The OD prototypes were all developed to convey different types of information using scent. The *inStink* system analyzed the use of scent in providing sense of presence in a remote location. Once a jar of spice was moved at a remote location, a scent corresponding to that spice was presented locally; hence assessors were aware of what was happening in the remote location (i.e. olfactory icons). The *Dollars & Scents* system presented information on the American stock market. Different scents were emitted depending on whether the market value rose or fell (i.e. olfactory smicons). The olfactory display employed was based on solenoids and perfume bottles. The *Scent Reminder* system used scents as part of a reminder application where scents were released to signify particular appointment times. The *Honey I'm Home* system looked at the use of digital scent to support relationships.

Atomization by sprayers [Yanagida 2012] was the scent generation mechanism employed in these works. This technique involves emitting the scented liquid through a fine nozzle. The result is that the odor liquid is presented as small scented droplets, which can be delivered through the air, and can be perceived as odors. The work of Kaye [2001] highlighted issues and limitations on the use of olfactory data and has been the basis for much work in olfactory related research since. Two such issues were slow movement and lingering of scent. As such Kaye proposed that the use of single scent stream presentation as an ambient media. As discussed later 3.2, these two issues have been a major focus of the research community. Works like the one of Noguchi et al. [2011] also address another issue raised by Kaye, i.e. intensity and accurate presentation of odors. He also discussed limitations in terms of understanding the constituents of scents and the lack of primary scents as exist for color. As was reported in section 2, in terms of olfactory psychophysics, he discussed differences in human perception and how presentation of olfactory media needs to be based on the context of the user, considering the culture and previous emotional experiences.

The emitter used by Brkic et al. [2009] was an off-the-shelf perfume atomizer which released a small puff of scent automatically at a user defined time interval as part of work that looks at multimodal experiences including olfaction. They reported that when olfaction enhanced a video clip, it was possible to reduce the quality of video without the user being aware of the quality reduction i.e. due to the presence of the olfactory component; the users' sensitivity to video quality was reduced. Kim et al. [2009] reported an OD which used thermalization to generate and emit scents, and was controlled via a peltier module. Temperature responsive hydrogels were positioned on copper sheets termed *aroma-chips*. These are inserted in a card-like transparent acrylic board [Kim et al. 2009] and as such are named *aroma-cards*. Once heated, the scent is naturally diffused. The key claim in this work was a noiseless OD. The authors also reported that it took approximately 7 seconds for assessors to detect the emission of scents. Tan et al. [1998] described an electromechanical OD which used a linear solenoid positioned on top of perfume bottles which was used to depress the atomizer of the perfume bottle. Different scents could be selected to be emitted via a PC interface and as such this set-up is somewhat reflective of an everyday kiosk with the added dimension of olfaction. The authors' focus was on the design of the OD. Although it was mentioned in their paper that application areas included multimedia applications and educational training, no evaluation of the system was presented. Brewster et al. [2006] designed the "*olfoto*" system which used smell in aiding photo recall. The use of scent and text as tagging mechanisms were compared. The scent was delivered using a Dale Air scent cube [Dale Air] The study involved a training phase where users correlated certain scents and text tags with specific images. After a period of two weeks, a comparison between the use of text and scent tagging to retrieve images was compared. The results indicated that although users rated higher using text tagging, tagging using scents resulted in above chance recall.

The primary issues with this type of display are the very slow-moving nature of scent and the fact that the presentation of scent is entirely dependent on the direction of natural air movement. This 'Natural' classification is most suitable for ambient scent presentation and not for applications that have strict timing requirements.

3.1.2 Air-Flow – Fan/Blower/Air-pump

Air flow-based ODs deliver scent based on the support of fans, blowers or air pumps. Once again, numerous scent generation mechanisms are included within this classification. Davis et al. [2007] reported interesting findings specific to olfactory interactive design. In particular, they focused on identifying the problems which OD designers are required to address - such as specifying and controlling odor, as well as addressing differences in perception of olfaction from different persons i.e. user preferences. In terms of specifying odor, they discussed the lack of a classification mechanism as exists for colors (primary colors). With regards to controlling odor, the issues of synchronized presentation times (delivery on time and lingering problems), and accuracy of intensity whilst supporting non-intrusive feeling for users are key. Finally in terms of human perception, the authors discussed works which have highlighted differences in human perception considering age, gender, human experiences as well as the issue of adaptation due to continued olfactory stimulation. Their OD delivered scents by applying pressure on the button of an aerosol can, supported by low power fans. Interestingly, given the issues they encountered during their study, they proposed the use of direction stimulation of the brain (once this is possible) as a more convenient approach to creating user experiences with olfaction. Haque [2004a; 2004b] introduced an interactive smell system that created dynamic olfactory zones. Scents were emitted based on a person's movement, with air flow generated through an array of fans. A similar model was also reported by Emsenhuber and Ferscha [2009]. Nambu et al. [2010] presented a visual-olfactory system. The scent generation was based on air pumps. Each of the air pumps had a direct connection to scented filters. The air-pumps directed odor air towards the assessors' olfactory field as part of a work that analyzed the relationship between scent and position of the scent's source. They discussed the influence which the visual stream had on the assessors' ability to identify the type of scent being presented. As such, they concluded that systems which include an olfactory component can exist with just a few scent types, as assessors associated the scent presented based on the visual content.

Matsukura et al. [2011] described an OD which used the collisions of air flow from different ODs to accurately deliver scent. The advantage of this approach is that the OD does not have to be placed in front of the user. Odor vapor generation is achieved by pumping air through liquid perfume. It is then delivered to the fans via tubes. Matsukura et al. [2010] reported on a work that analyzed the relationship between the location of the odor sources and associated air flow. In an evaluation involving 14 assessors, they found that airflow had an effect on what assessors believed was the source of the scent. The OD used was the scent dome system from Trisenx discussed later on. Tanikawa et al. [2008] reported on two olfactory/visual displays: the "*nioi café*" and "*flavor of color*" systems. Each used an OD that contained 3 independent components: a controller, a scent generation mechanism and scent presentation mechanism. The aim was to provide an olfactory illusion as part of a multimodal communication system The researchers tricked audiences by presenting scents conflicting with what they saw and studied the results. They evaluated the system via a subjective questionnaire and objective EMG data. The results highlighted the influence of the visual over the olfactory. The generator had 8 DC motor air pumps, each with a scented filter. The scent presenter had a nozzle connected to the filters. Odored air was generated by blowing non odor air through the scent cartridges to the user. Matsukura et al. [2012; 2013] presented an OD that emits scent from different parts of the LCD screen; hence the scent source reflects the object associated with the scent in the video. The scents were generated by pumping air through liquid perfume.

Okada and his team [Noguchi et al. 2011; Noguchi et al. 2008; Kadowaki et al. 2008; Sato et al. 2009; Kadowaki et al. 2010; Ohtsu et al. A 2009; Sato et al. 2008;Noguchi et al. 2010; Ohtsu et al. 2009b; Sugimoto et al. 2011] have developed a scent emitter based on inkjet technology. Scented oil is stored in scent chamber. Tiny amounts of scent can be placed on a heated plate for vaporization and are presented via miniature fans in the device. Okada's team have investigated scent presentation techniques to avoid olfactory adaptation [Kadowaki et al. 2008], expressing two smells in a single breath [Kadowaki et al. 2010], instantaneous switching of scents [Noguchi et al. 2010] and measuring time characteristics of olfaction in a single inhalation [Noguchi et al. 2011]. Ohtsu et al. [2009b] reported the same device which controls emission to be synchronized with the assessor's breathing pattern. The challenges addressed by these works are olfactory adaptation and scent lingering. Another key aspect of this work is in relation to emitting more than one scent in a short space of time. This is in contrast to conventional beliefs reported by Washburn et al. [2003], whereby it was generally accepted that scents should not be emitted close together, with a recommended separation of scent presentation of between 20-60 seconds.

Another device based on inkjet technology, but involving piezoelectric scent generation and fans to present the scent, is that of Wallace et al. [2007; 2009; 2006]. Applications of these devices exist in the health industry (for diagnosis of neurodegenerative diseases). The authors evaluated the device and akin to other works, found that a significant elevation in olfactory thresholds exists for patients with neurodegenerative diseases, and as such testing of the olfactory capability can be employed as an approach for early detection. Ariyakul et al. [2011; 2013] proposed an OD based on miniaturized Electro Osmotic (EO) pumps and a Surface Acoustic Wave (SAW) device. Minute amounts of liquid perfume are emitted from the EO pumps, vaporized and are then presented using fans. As part of a virtual reality (VR) theatre Park et al. [2002] used five containers containing liquid oils for aroma generation. Vaporization of the liquid was achieved using heated plates and the scent being delivered via the ventilation system. In recent times, we have seen such theaters become available to the consumer market [CJ 4DPLEX; RGB Screen Networks], highlighting the traction that that multi-sensorial multimodal media experiences are gaining.

Kim and Ando reported an OD that was based on micro air flow [2010] . The device provided directional display of scent with an average of 0.2m/s air speed. The key accomplishment of this work was the small size of the display (20 mm^3). They evaluated the device with 200 users to evaluate the length of time it could continue to present scent whereby the odors were still detectable after one month. They also evaluated the odors which could support directional airflow of 0.20m/s. *Ad-smell* and *SubSmell* described in [Pornpanomchai et al. 2009; Pornpanomchai and Benjathanachat 2009] outlined a system that enhances the movie watching experience with olfactory data. The olfaction enhanced multimedia system consisted of a webcam, motion detection mechanism, movie player, scent reader, olfactory display and olfactory display monitor. The olfactory display consisted of a scent storage mechanism containing scent cartridges with fans used to present the scent. This is similar to the commercially available device, the *Vortex Active* from Dale Air [Dale Air]. In terms of integration with audiovisual media, SubSmell incorporated color coding symbols which were related to a particular scent. These were akin to subtitles for when to present a particular odor. Based on the presence of the subsmell color logos, the subsmell management software executed the presentation of the scent. In both *SubSmell* and *Vortex Active*, interchangeable cotton pads are soaked in scented oils. Fans blow air through the pads and the scent is presented. Another device based on the same principle but with a different scent cartridge is the *SBiX V2* from Exhalia [Exhalia], the device used by Murray et al. in [2013a; 2013b; 2014a; 2014b]. As per the previous two devices, the SBiX V2 fans blow air through scent cartridges, but unlike previous works, cartridges are made from scented polymer balls.

Tominaga et al. addedscent to a VR project using a scent generation device from Fukurara Co. Ltd [2001]. This device was based on an air compression system and a tank storing scent liquid. Air was pumped through the scented liquid and then presented to assessors. They evaluated the system with 20 assessors in terms of sense of presence, sense of realty and enthusiasm, by comparing user ratings with/without olfaction. Statistically significant differences were reported in 80% of the assessor's responses. The *ScentScape* [Scent Sciences] from Scentsciences Corp. is a scent dispenser currently being trialed. It can store up to 20 scents in a cartridge and can be controlled via an USB interface. At the time of writing, it was not commercially available. *GameSkunk* from SensoryAcumen [Sensory Acumen] is another new device which is currently only commercially available to the medical market. This device emits scent by blowing air around scented substrates (solid). Their device can store up to 12 cartridges, each containing one scent. It is controlled through USB interface with plans to develop Bluetooth compatibility.

Scent Communication [Scent Communication] provided a number of commercial ODs which fit into various classification areas. The Ambient Air suite supports a *ScentCube*, *Scense*, *ScentDiffuser.aircon* and *ScentDiffuser.wave* displays. The *ScentCube* is based on dry storage, and diffusing technology is targeted at ambient scent presentation. The *Scense* device generates odor by using air flow through replaceable scent gel cartridges. The *ScentDiffuser.aircon* device is a scented oils-based OD. It presents scent through micro-nebulization. Scent Communication also provides a *ScentStick.car* and *PromoScent* for automobile and handheld scent delivery. ScentAir [ScentAir] provided three scent delivery systems, *ScentWave*, *ScentDirect* and *ScentStream*, which are based on dry-air cartridge or a diffusion technology to convert scented oils into vapor for emission.

DigiScents developed the *iSmell* device which consisted of scented oils being used to present fragrances to the user. The iSmell device was never commercially available. Osmooze provided numerous ODs that were based on gel and piezoelectric technology. Richard et al. described an augmented reality application which included olfaction (as well as visual, and audio) [2007]. Its aim was to assist cognitively-disabled children in decision making processes. It used the Osmooze SyP@dTM display discussed earlier. Trisenx released the scent dome system in 2003. It allowed users to mix scents to create different odors. It also provided exchangeable cartridges to all users to customize aromas. Digiscent, Trisenx and Osmooze are no longer commercially active.

MicroFab Technologies [MicroFab Technologies] developed a number of devices specific to the gaming and medical industries. The medical device is a digital Olfactometer which utilizes "microjetting technology". The micro dispenser can produce minute amounts of scent e.g.200 Pico-Liters. The device for gaming is wearable and as such, is discussed in section 3.2. Olfacom have a number of commercially available devices, the *OlfacTest*, the *OlfaCom* and *OlfaMag* [OlfaCom]. These systems are based on a fan blowing air through a scent cartridge made from scented polymer material. Hirota et al. in [2011] as part of their work towards a multi-sensory theatre, developed a prototype equipped with olfactory sensations as well as haptic, wind, and audiovisual media. Fans and air nozzles connected to a source of compressed air presented odorants into the air. Sakari et al. [2009] described a system which could alter the concentration of scent based on the position of an associated visual object on the screen. The scents were stored in a scent cartridge with scent generation resulting from a combination of valves and heat.

3.1.3 Air-Cannon

The use of the air cannon concept is an attempt to accurately present scent towards the assessors' olfactory field. The principle involves launching vortex rings of scent that maintain their shape until they reach their desired location.

Yanagida et al. [2003] focused on specific delivery to the assessor's nose through the use of air cannon. The air cannon creates vortices of odor air [Yanagida et al. 2003]. These hold their shape until presentation to the assessor's olfactory field. Yanagida et al. [2013] also presented a pilot study based on the use of scent projectors and vortex rings, with two assessors seated at distances of 50cm and 120cm from the ODs. They reported accuracy levels of 72% in terms of smell detection. Tomono et al. [2012; 2010; 2011] reported a proposal for the presentation of scent through a display screen in the direction of the viewer. The scent was presented as vortex rings, with the display itself residing behind the screen. The scent was stored in an air box and fans generated pressure until the air duct was opened to present the scent. Scent Projection based on nose tracking in [Sakari et al. 2009] focused on spatio-temporal control of odors. The scent generator, based on valve switching, was the *Aromaguer* from Mirapro Inc. In this system, it was possible to create multiple odor components at various concentrations, and as such addressed the intensity problem highlighted by Davis et al. [2007]. Yanagida et al. [2004] described another device based on the vortex ring that achieves scent generation via the commercially available *Hippocampe* of Jacques

G. Paltz. The scented air is delivered in the direction of the device using air cannon. The *Hippocampe* scent diffuser generates scent by vaporizing scented oils.

This survey has presented a broad classification only. As a result of the differences in scent generation methods, there are significant differences between the performances of these displays. The ODs based on inkjet and other micro diffusion technologies can accurately control the actual amount of scent presented (to Pico liter level). This somewhat addresses the challenging issue of scent lingering. The use of fans/blowers/air pumps aims to address the issue of the slow moving nature of scent. The disadvantage of these types of devices is in terms of where the scent is presented (relative to the assessors' olfactory field). The air-cannon approach has attempted to address this issue, yet reportedly, unless the target is within a short distance (< 2 meters), issues can arise. With this said, with miniaturization of inkjet, piezoelectric micro-dispensers or other micro-diffusion technology, ODs based on these principles appear a viable option. In the next section, wearable ODs are introduced to the reader.

3.2 Wearable ODs

Wearable ODs are an approach that have great potential. They are by their nature, close to the user's olfactory field. It is also a particularly interesting approach considering humans willingness to use perfumes and odored anti-perspirants. We review wearable ODs, and classify them as either being "On-Body" or "Head-Mounted".

3.2.1 On-Body

An early example of an on-body OD is from Cater [1994]. A backpack-mounted fire fighter training device called AVERT (Advanced Virtual Environment Real-Time Fire Trainer) delivered scents to the user through the oxygen mask. The system produced up to 10 odors by crushing microencapsulated odorants. No results on the evaluation of this system were provided. Yamada et al [2006] reported on a work that focused on the spatiality of odor, a key characteristic as mentioned earlier. The display contained an odor generation unit composed of air pumps and scent filters (cotton infiltrated with perfume material) as well as a controlling unit which dictated the strength of, and the timing of odor presentation (both based on assessor position in the virtual environment). A tube ran from the backpack with scent pumped to nose-interface-equipped headsets which acted as the presentation unit. The *Scent necklace or scent collar,* as discussed by Washburn and Jones [2004] and [Anthrotronix], was placed around a user's neck and scent presentation was controlled using a wireless interface. This device can support up to four scent cartridges. Another OD placed around the user's neck is the *Pinoke* from Aromajet [MicroFab Technologies] and was designed for gaming. The device itself can also be placed in the environment standalone.

The embedding of ODs into different materials to facilitate multiple sensorial experiences was discussed in [Ferraro and Ugur 2011]. The work of Tilletson as part of the Scentsory Design research initiative [2008] was also based on wearable ODs. [Jenkins et al. reported a number of prototype devices; e.g. broches inspired by insects [2006]. The *eScent* product range includes jewelry, clothing and handbags. It utilizes Microfluidics, a technology that facilitates the creation of devices to support minute amounts of fluids. Such devices use combinations of electrical/mechanical "components to scale of 1 micron" [EScent]. In addition, bio-sensors are used to provide biofeedback.

The key application area of this work is health and wellbeing. This work has the potential to serve all of the above industry areas seamlessly.

3.2.2 Head-Mounted

The key advantage of the head-mounted display is that, by its nature, it is very close to the user's olfactory field. The challenge that arises is the degree of intrusiveness experienced for the user. Nakamoto et al. in [2008] described an interactive OD used as part of a cooking game. The OD itself, described by Nakamoto et al. in [2007] used solenoid valves with high speed switching to emit scents. 32 component odors could be blended, by pumping air through scented liquid. The odor scent was then pumped via a tube to nose-interface-equipped headsets, which the user wore. Matsukura et al. in [2010a][2010b][2009a][2009b] reported an interesting OD approach that considered environment fluid dynamics in the consideration of scent presentation. The odor concentration was generated using an odor blender which could change concentration by adding unscented air. The odor vapor was then delivered to the assessor's nose through the nose-interface-equipped headsets. The aim was to be able to reflect intensities based on the position of the scent emitting sources in an environment. The device could blend up to 32 odor components. In this work, the concept that the source of the odor has a particular reference point was analyzed. They evaluated the system with 94 assessors. The concentration of the odor was altered based on impact of air movement (calculated via a computation fluid dynamics simulation). In their evaluation, over 50% were unable to correctly identify the source of the scent based on the concentration levels. The authors reported that this was due to high odor concentrations. In a further study involving 123 participants, and with reduced concentrations, 65% were correctly able to identify location of scent.

Narumi et al. reported a multi-sensory device that integrates vision, olfaction and gestures [2011b]. The aim of this work was to determine the influence of the different modalities on taste. The OD component of this system could present up to six scents, with air blown through scent cartridges (filters) via an air pump, with the presentation close to the user's nose. Considering all scents, up to 127 different concentration levels could be presented. This device could present scent retronasally and orthonasally via direct injection [Yanagida 2012] i.e. fine droplets of liquids were generated and injected directly into the human nostrils. In terms of evaluation, they introduced conflicts between the odor and visual presentation of a cookie and asked assessors to compare their experiences with simply eating a plain cookie without the system. In doing this, 79% of assessors reporting a change in taste. Nakamoto and Yoshikawa developed an OD that used solenoid valves to mix multiple odors at varying concentrations and compositions [2006]. They also attempted to analyse the impact of adding olfactory information to a movie. They reported that the movies which were enhanced with scent engaged users more than those without, and this was exaggerated when scents were changed during the clip. The scent was presented via a tube to nose-interface-equipped headsets.

3.3 Olfactory Display Discussion

In this section, the authors present a comprehensive review of research and commercial approaches to achieving viable ODs by considering: scent delivery mechanism, scent generation technology employed, and application area. A key impedance to the realization of olfaction-enhanced multimedia has been the unavailability of commercial ODs which can accurately recreate a scent in terms of intensity, quality, quantity and accurate presentation. What this section shows, is that a fragmented approach exists to realizing ODs, with a variety of scent generation mechanisms, scent presentation approaches and positioning of ODs. These have been driven by the requirements from different application domains. To support the aforementioned requirements in a non-intrusive manner, has proven to be challenging. Each of the various classifications has been shown to have its advantages and disadvantages. The ODs placed in the environment have the distinct advantage of non-intrusiveness – users may not even be aware of their existence. With this advantage comes the challenge of dependency on environmental? air movement and the slow moving nature of olfaction. For wearable ODs (particularly head mounted), this is less of an issue as the scent is presented very close to the assessor's olfactory field; however the issue of non-intrusiveness exists. Realization of a viable olfactory display requires a multi-disciplinary approach. Contributions are required from chemical and biotechnology fields amongst others. It is clear that a lack of a general classification scheme, such as that which exists for color, is a key impediment. It seems likely that until such a classification exists, the storage and presentation capabilities of ODs will be limited (i.e. 20 or less). . Considering the likelihood that, in the near future, ODs will be required to switch between scents, it would seem that ODs which fall within the wearable domain have the greatest potential. . The head mounted approach must address the issue of intrusiveness and awkwardness, hence the wearable on-body display appears to have the greatest potential. With the expected continued miniaturization of the technology, it seems plausible that commercial ODs could indeed be placed around the neck as a non-intrusive collar or be embedded into clothes.

4. OLFACTION IN HEALTH, TOURISM, EDUCATION AND TRAINING

This section complements the work of Ghinea and Ademoye [2011] and Nakamoto [2013], which reviewed the use of olfactory data in entertainment, gaming and film industries, multimodal displays, Virtual Reality (VR) systems and alerting systems. Here the use of olfaction in less apparent industries such as health, tourism, education and training is reported, thus highlighting the significant potential of olfaction as a media component.

4.1 Olfaction in Health

Multiple works highlight the importance of olfaction in the field of medicine, such as those reviewed by Spenser [2006]. He highlighted the potential for olfaction both in the diagnosis of disorders and training with virtual patient simulators. Links between an ability to detect olfactory stimuli and a number of neurodegenerative diseases exist in the literature: e.g. Alzheimer [Alberts et al. 2006], Huntington [Alberts et al. 2006] and Parkinson [Haehner et al. 2009]. As part of medical training, doctors are trained to use their sense of smell in the recognition and diagnosis of disorders. A number of works have also shown the use of smell in recognizing disorders even before a patient begins exhibiting symptoms [Bohner et al. 2010]. In terms of presentation of sensorial media, communication of information using senses other than sight and sound will be especially relevant to delivering high quality experiences to those with sight and hearing related disabilities [Pereira and Burnett 2003].

The results of a comprehensive study into requirements for multimodal reminders for assisted living were reported by McGee-Lennon et al. [2011]. Data from 379 assessors was captured to determine (a) the types of events for which users wanted to be reminded (b) why reminders were necessary (c) how users would prefer to receive reminders i.e. modality preferences (d) techniques currently used by assessors as reminders. Here we focus on reporting their findings with respect to (c) i.e. how users would prefer to receive reminders. 66% of assessors reported that their preference was for visual reminders , primarily via mobile phone, with just 3% preferring the use of olfaction. However, based on an ageing population and the number of people presenting with both significant vision and hearing impairments, the modalities of touch and smell are avenues that can be exploited. Also with respect to home care technology, Warnock investigated the cognitive workload of responding to multi-sensory notifications (tactile, olfactory, visual and audio) whilst carrying out a memory game [2011]. 47 participants took part in two experiments which evaluated the distraction associated with multimodal notifications and its effect on the users' ability to undertake a task. The OD used in the experiments was the *Vortex Active* from Dale Air, already introduced. Interestingly, the assessors reported a level of fear associated with the olfactory notification but the results for all modalities indicate that multimodal reminders did not have a negative effect (statistically speaking) on a users' ability to carry out a task. Assessors were tolerant of employing multimodal reminders but user preferences on such modalities was a key factor.

Depledge et al. used olfaction as part of their work in analyzing the various sensual aspects that influence a persons' wellbeing [2011]. They highlighted the requirements for studies into the various aspects of nature e.g. colors, sounds, odors, lighting effects, wind etc. These effects can accurately (to different degrees) be simulated in virtual environments to enhance a person's wellbeing and health i.e. as part of Virtual Restorative Environment Therapy (VRET). Redd and Manne the use of vanilla fragrances was shown to reduce anxiety and distress [1995]. In a study that involved 57 assessors, split into two groups (control and experimental), over 60% of the experimental group reported a reduction in anxiety when compared with the control group. Baus and Bourchard [2010] reviewed the literature on olfaction and outlined potential applications in VR environments from a healthcare perspective such as pain management, information recall and calming patients. They also stated that VR environments have failed thus far to successfully integrate the olfactory modality. Chen highlighted the potential of olfaction in VR therapy [2006]. Specifically he discussed how olfaction as a source of ambient information could create a greater sense of presence in VR therapy applications. They highlighted its positive impact on emotional state and pain, in particular the scents of lavender, rosemary and peppermint.

Gerardi et al. used olfactory data delivered with a scent palette in conjunction with audio and visual stimuli to treat a soldier with Post Traumatic Stress Disorder (PTSD) [2008]. Their evaluation involved a 29 year old veteran of the Iraq war. During the procedure, the participant was presented with a virtual Iraq using eMagin head mounted display, stereo headphones, a hand controller for movement in the environment, tactile via subwoofer floor platform and a scent palette as the olfactory display which included scents such as burning, rubber, diesel and spices. Their findings (via CAPS (Clinician Administered PTSD Scale) and PSS-SR (PTSD Symptom Scale-Self Report)) indicated that following brief VR treatment (4 sessions in 4 weeks), the veteran demonstrated statistically significant improvements. Rizzo et al. [2009; 2007] also used olfaction in addition to tactile, audio and visual with the aim of increasing the sense of presence as part of VR exposure treatment to treat PTSD patients. In the two case studies reported, both patients noted significant improvements in PTSDwhen comparing pre and post administration ratings across a variety of psychological assessment methods. Other examples also document the use of VR to treat PTSD in troops [Brewin et al. 2007; Pair et al. 2006]. Rizzo et al. provide a detailed review of how VR applications were being used in military behavioral healthcare was provided [2011]. The use of sight, sound, touch and smell were used to accurately recreate a sense of presence and as such, the feelings associated with the traumatic experience so that rehabilitation was possible. A virtual reality PTSD application called Virtual Iraq was introduced and discussed by Shih-Cinget et al. [2009]. They also reported particularly positive results with 20 persons completing 11 VRET sessions with 80% of those who completed the treatment reporting improvements in PTSD and the other symptoms. Richard et al. reported the design of an augmented reality application that used olfactory as one of a number of media components to assist children with cognitive disabilities [2007]. The experiments aimed to evaluate how children found the experience of working with AR technology. Furthermore, this work aimed to determine how cognitively disabled children reacted and could gain from such technology. The results indicated that children with disabilities reported significant motivation and emotional attachment with these types of applications. Hence, it highlighted the requirement for further research and development of such approaches.

Hayes et al. used an inkjet based micro-dispenser for quantitative determination of olfactory thresholds for neurodegenerative disease diagnosis [Wallace et al. 2009][Wallace et al. 2006]. Their findings reported statistically significant differences between healthy persons/ control group, and persons suffering from Parkinsons, with the difference reducing for older people (>50yrs in the control group). Keller et al. reported the transmission of olfactory metadata as part of an application in telemedicine [1995]. The proposed system included a sensor based on vapor sensors and an artificial neural network which identified the odors. The potential application of this system was for the transmission of odor information, as part of an overall aim of medical telepresence system for patient diagnosis. Kawai and Noro discussed the use of olfaction with 3D images and analyzed if scents and images could have induced psychological effects based on odor type [1996]. Buckle et al. discussed the role of aromatherapy in paraesthesia pain management [1999]. They presented a sample protocol on how to employ aromatherapy with the aim of reducing patient anxiety. No experimental evaluation was reported. Anderson et al. included olfactory data in addition to audiovisual, vestibular and wind effects in a virtual Equine Assisted Therapy (EAT) project which was part of an immersive horse riding experience [2010]. They used an electro-myogram (EMG) to capture any associated user movements but no findings on the success of the prototype were reported. Krueger highlighted the requirement for the inclusion of olfaction in surgical simulations to enhance realism of the experience [1995]. He also highlighted the challenges associated with olfaction such as synchronization with the correct time in the procedures, and also the requirement to address lingering of scents after the appropriate period had passed.

4.2 Olfaction in Tourism

Hoven highlighted the requirement for tourism experiences to move beyond the audiovisual domain and reviewed works that facilitated multi-sensory tourism experiences [2011]. He discussed in detail how each of the senses of sight, sound, taste, touch and smell contributed to the tourist experience of the Great Bear Rainforest in Canada. Similarly D'Arcens noted the importance of smell in tourism, to heighten the sense of realism and presence [2011]. The experience of the Jorvik Viking Centre [JORVIK Viking Centre] and the "works of God and Man" located at the Rievaulx Abbey in North Yorkshire were outlined and the role of scent in the tour was discussed. The authors mentioned how the use of olfaction could encourage children to explore different career options but also to appreciate the lifestyles of a bygone race in a different manner. Tuan discussed the relationship between odors and places, and the manner inhow people associate these two factors when recalling tourism experiences [2001]. In a related concept, Porteous defined the term "smellscape", again suggesting that the association between a place and a smell have a powerful connection [1995]. Guttentag provided a review of the current and potential uses of olfaction for VR in tourism [2010]. They highlighted the potential of including olfaction in VR in terms of marketing, entertainment, education and accessibility and heritage preservation.

With the motivation for visitors to move beyond the traditional browse-mode to that of a greater learning experience, museums are searching for avenues which include multisensory experiences, to further engage their consumers [Schauble et al. 2002]. Hall and Bannon outlined a learning environment based in a museum in [2005] and found that the addition of olfaction added to the authenticity of the user's experience. Their aim was to evaluate how interactive systems could enhance engagement and participation. Based on a sample size of 326 children, they defined a set of guidelines (both experiential and design) of interactive systems for enhancing children's learning in museums. Fernstrom and Bannon mentioned the concept of "hybrids" between museums and arcades [1997]. They discussed the use of interactive multimedia within museums with the aim of ensuring that technology improved / heightened the visitor experience. Ryan and Pan discussed the importance of olfaction as part of tourism experience to facilitate the consumer's link with the past. [2009]. They also specified the requirement to address tourism as a corporeal experience. The work of Ballantyne et al. aimed to determine effective methods of educating visitors about wildlife threats [2011]. In their work the authors also highlighted sensory impressions (which included olfactory) in relation to one of four levels of visitor response. Cheong stated that future VR systems which incorporate olfactory and taste senses in conjunction with other senses, may be a "threat" to the traditional model of tourism [1995].

Numerous works report the use of scents to influence customer behavior [Emsenhuber 2011]. One such example is reported in [2003] where Chebat and Michon investigated the impact of odors on the behavior of customers. They tested a number of hypotheses in relation to customer mood, behavior (making purchases) and presence of ambient scent. They reported that the presence of odor had a strong effect on shopper's perceptions of the products and the mall environment. Blackwell looked at the influence of olfactory cues on food choice, consumption and acceptability in a restaurant environment [1997]. He reported statistically significant differences when odors with high hedonic ratings were presented. Guéguen and Petr also concluded that the scent of lavender positively impacted upon restaurant customers' behavior in terms of time and money spent [2006]. Hirsch investigated the influence of odors on slot machine usage [1995]. He reported statistically significant increases in the use of slot machines when an odor was presented. and also found that the concentration of the odor had an effect on slot machine usage.

Zemke and Shoemaker examined how physical environments affected interactions between people. They found that the existence of ambient odor [2007] increased the number of social interactions in the environment. In their study, the environment for the test group was enhanced with a pleasant scent, and in the case of the control group, the environment was void of scent. 77 university students took part, 40 in the test group and 37 in the control group. Statistically significant differences existed between the number of interactions in the test group when compared with the control group, p=0.028. Mitchell et al. analyzed the effect of congruent and incongruent ambient scents on customer choices between candy and flowers [1995]. Two aspects were examined: firstly the time consumers spent analyzing product information, and secondly, whether or not customers sought extra information via an information display. The results showed that marginal statistically significant differences were found, i.e. the congruency of the odor affected the decisions made by customers where they spent more time examining the products and sought extra information. Dann and Jacobsen discussed the use of 5 senses at Walt Disney World with a focus on olfactory [2009]. The use of olfactory data in other tourist sites such as the Guinness Storehouse and the Bow Street Old Whiskey Distillery in Dublin was discussed in [Ghinea and Ademoye 2011]. Jacobsen [Dann and Jacobsen 2003; Jacobsen 1996] discussed the use of senses in the tourism industry. Despite an emphasis placed on the visual in tourism, they argued that sight alone provides a “superficial” experience and stated that a tourist experience involves stimulation of all of the senses (tastes, smells, sights and sounds).

4.3 Olfaction in Education & Training

Gardner’s multiple intelligence theory proposes that a person’s learning is reinforced by stimulating multiple sensory channels [1996]. In this context, this section reports works on the use of olfaction in training and education across a variety of disciplines. Shams and Seitz discussed the advantages of training and education involving multiple senses over a uni-sensory paradigm [2008]. They argued that we learn most naturally through all of our senses, and that this mimics how the brain has evolved to learn in nature. However, the authors state that the extent of this benefit is based on the **congruency** of the stimuli i.e. the learning environment must closely map what users have experienced in nature. This supports the findings of Haverkamp et al. in [2010]. However, the researchers also noted that inducing perceptual conflicts can be beneficial in certain applications where it is necessary to attract users’ attention e.g. alerting systems or in advertizing.

The connection between smell and memory has been an active research topic. Issanchou et al. analyzed memory performance, and the effect of odor on different types of memory i.e. implicit or explicit memory [2002]. They reported that olfaction is more suited to implicit memory. This is plausible due the ambient nature of olfaction as a media component. Hyacinthe proposed an apparatus for printed aromatic information, with the purpose of conveying information in the form of scented text [2006]. In a review of virtual environment interface technologies Youngblut et al. highlighted many potential applications for the use of olfaction such as altering mood, increasing awareness, reducing stress and the ability to improve retention and recall of learned materials [1996]. They also provided a brief critique of olfactory display design approaches under the auspices of storage and presentation technologies. For olfaction in VR, they listed the key challenges as including: storage, selection, regeneration and breathing space control. Ghinea and Ademoye examined the effect of olfaction-enhanced multimedia on information recall in [2009], where contrary to other reports, the authors noted that olfaction had a negative impact on information recall. In [Ademoye and Ghinea 2013], the same authors also reported that the presence of an information recall task did not adversely affect the user QoE of olfaction enhanced multimedia. This suggests that multisensory learning as an approach can lead to high levels of user QoE. Tortell et al. determined that scent had a positive effect on users' ability to recall the details of an environment [2007]. In the experiment reported, as part of a game playing application, the scent provided contextual information which was consistent with the other aspects of the VR system. The olfactory display was the wearable scent collar reported and discussed earlier in [Washburn and Jones 2004]. The results from 16 assessors was analyzed based on the supported hypothesis that those whose experience was enhanced with scent would recall information better that those whose experience did not involve scent with p=0.02. Interestingly, when scent was presented as assessors completed the questionnaires, it had a negative and distractive effect. Herz et al. looked at the influence of odors on mood and further discussed odor-assisted learning [2002]. Mikropoulos and Natsiset [2011] reviewed the use of education in virtual environments but made reference to two works only with respect to olfaction [Tijou et al 2006; Richard et al 2006]. In [Tijou et al 2006; Richard et al 2006a; Richard et al. 2006b] the authors described a VR application which included an olfactory component and evaluated its usefulness on learning and information retention. The OD used was the Mad *P@d*TM from Osmooze, and the scent cartridges were odored gels. The odor was released by blowing air through the scent cartridges.

The "Nice- Smelling Interactive Multimedia Alphabet" project used the modalities of vision, sound and olfaction to assist with learning the letters of the alphabet [NICE]. Unfortunately no data is available on the analysis. Speech and Language Therapists use scent as part of the Picture Exchange Communication System (PECS) for reinforcement i.e. accompanying the visual card with the reinforcing olfactory cue [PECS]. Dinh et al. reported the results of a comprehensive study involving 322 assessors to evaluate users' sense of presence as well as their ability to recall information on the environment [1999]. As discussed by Brkic et al., they also reported that adding the senses of olfaction and tactile meant that reductions in the visual quality went unnoticed [2009]. In terms of the information recall task, assessors were queried on the location of objects in the environment. When queried on the location of one particular object (coffee pot), over 95% of assessors whose experience included olfaction were correctly able to recall it. In contrast, only 59.4% were able to recall its location when olfaction was n not present. Hughes et al. included the olfactory modality within their mixed reality training environments and applications [2005]. The system included audio, visual, haptic and olfaction as part of the Orlando Science Center's DinoDigs exhibition hall. In responding to a questionnaire, more than 80% of respondents felt that they learned more about the exhibition due to its multisensory nature, but results are not reported on a per modality basis. Ludvigson and Bottman described and demonstrated how the use of lavender and clove improved cognitive processing [1989]. Mustonen et al. studied the effect of sensory education on food perception [2009]. A sample size of 211 children aged between 7-11 years were split into control and evaluation groups. The results reported improvements in participant's ability, in terms of taste and odor awareness. In measureable terms, the results showed an improvement in the children's ability to describe the sensory properties of food. Chi-Wai Kwok et al. described their "Smart Ambience for Affected Learning" (SAMAL) system which used olfactory data with a number of modalities to provide an effective evocative learning environment [2011]. The preliminary results suggested that the SAMAL system positively influenced learning effectiveness. Childers and Coleman discussed the role of olfactory data in serious gaming, mental training and therapy [2010]. The authors highlighted its advantages which included : reinforcement, real life authentic learning, retention of information, improvement of concentration levels, promotion of independent thinking and familiarity.

Miyaura et al. reported a system that combined objective feedback in the form of electrocardiogram data as a reading of users' concentration levels when performing basic tasks such as addition [2011]. They reported that the presentation of odor at the point when a user has a lapse in concentration is an effective method of decreasing errors in addition tasks. The aim of the system was to present an odor to re-engage users once a lapse in concentration was detected. The olfactory display device was based on inject technology with the scents of peppermint and ylang-ylang used. Garcia-Ruiz et al. reviewed works that integrated scent into VR applications during the task of learning a new language [2008]. They also reported on an initial study that looked at the effect of mint odor on listening comprehension for English. Mint has been reported to assist with memorization [Holloway 1998]. The results of a small study (12 assessors all from computer science with an average age of 24 years) indicated that the addition of odor assisted with student anxiety during the information retention Further work was identified in the paper to support more concrete results and conclusions. For many years the US military has been developing and using multi-sensory simulations, with the aim of recreating authentic real world experiences during training simulations. Fletcher reviewed a number of multisensory VR training and treatment projects which aimed to emotionally engage users (Sensory Environments Evaluation project) and PTSD treatment (The Full Spectrum Warrior Post Traumatic Stress Disorder Therapeutic Virtual Environment) [2009].

Reflecting on the works discussed in section 4, olfaction has a significant position to fill in the health, education and tourism industries as well as the more salient industries of gaming, television, notifications and entertainment. The potential in each of these areas will drive the demand for enabling technologies in the form of sensors and ODs and this will potentially fuel the development of new applications across each of these disciplines as well as in areas such as film, alerting systems and entertainment.

5. QUALITY OF MULTIMEDIA EXPERIENCE AND FUTURE RESEARCH DIRECTIONS INVOLVING OLFACTION

A key challenge for olfaction as a media component, and indeed other sensorial media components, is a lack of understanding of the human perception in terms of user experience. Hence this section provides a state of the art review of olfaction enhanced-multimedia research works, with a focus on its effect on user QoE. It also includes a discussion of a number of potential future research directions for olfaction-enhanced multimedia.

5.1 User-Perceived Quality of Olfaction- Enhanced Multimedia

In terms of the perceived quality of a multimedia experience, the Qualinet definition of QoE refers to the "user degree of delight or annoyance in relation to an application or service. It is determined by the level of fulfillment of user expectations and is dependent on user personality and current state. In the context of communication services, QoE is influenced by service, content, network, device, application, context of use, users' personality and current contextual state" [Le Challet et al. 2012]. ITU-T defined QoE in terms of "overall acceptability of an application or service, as perceived subjectively by the end-user" [ITU-T Study Group 12][ITU-T P. 10/G. 100 Amendment

12 2007]. Numerous other definitions are available in the literature, and in general, have proposed a similar description [Stankiewicz et al. 2011; ITU-T Study Group 12; Ebrahimi 2009]. The ultimate aim of QoE researchers is to model human perception of multimedia experiences, beyond traditional Quality of Service (QoS) approaches. QoS based research to date has focused on network and multimedia system characteristics such as delay, loss, jitter, codecs, display capability etc., however to capture user QoE involves subjective ratings, user behavior and past experience, appropriateness, context, usability and human factors as discussed by Le Challet et al. [2012]. Although the key focus in multimedia networking research has been maintaining network QoS control, an improvement in QoS does not necessarily translate to proportionate QoE increases [Kilkki 2008].

Perception was traditionally regarded as a modular function. It has long been thought that each of the sensory modalities operated independently. However, recent studies are changing this view. They suggest that interactions between different modalities have an significant effect on our perception [Calvert et al. 2004; Shimojo and Shams 2001]. In this context, the multimedia community has in recent times begun to consider olfaction in terms of its perceived temporal, spatial and contextual relationship with other media as a step towards enhancing the user QoE through mulsemedia.

The study by Ishibashi et al. analysed the impact of the length of time it takes for an odor to be detected on fairness as part of networked games [2012]. The authors reported that with a skew of less than approximately 500ms, the fairness is not significantly impacted. Artificial skews were introduced between players of the 3D virtual fruit picking game with the analysis reported in terms of mean opinion score for 30 assessors Huang et al. assessed user perception of time in a multimodal system involving haptic, olfaction and visual presentations [2012]. Assessors were required to provide information on their perception of skew whilst moving a flower towards them. The researchers discussed the existence of what they defined as a "smell space". "Smell space" was defined as the area around the source of the scent where users could perceive the scent. They also reported that the speed at which the flower moved had an effect on assessors' perceptions of the scent presentation time. Hoshino et al. [2011] looked at defining the temporal boundary between haptic and olfactory streams. The authors introduced skews between the media streams and assessors were required to qualify their experience of the streams as being synchronized or not synchronized. In addition, if the streams were not in sync, the authors aimed to identify whether or not the level of skew was acceptable. The results illustrated that with the existence of skew levels of between 500ms to 1000ms, assessors did not perceive the presence of intermedia skew, and more specifically assessors were tolerable of skew levels up to 1400ms i.e. the skew level did not have an adverse effect on QoE.

Nakamoto and Yoshikawa also carried out some analysis between olfaction and audiovisual media as part of evaluating an OD [2006]. The author presented a guideline which stated that the time between consecutive emissions of scents should be between 5-8 seconds when experiencing olfaction enhanced audiovisual media in order to ensure enhanced user QoE. Unfortunately, the length of the scent presentation time in the tests was not reported. Considering the results presented in [Murray et al. 2014b], this raises an interesting question as to whether or not, the length of presentation time for scents affects the time needed between consecutive presentations of scents to ensure enhanced QoE levels for the user. Narumi et al. [2011a; 2011b] investigated the cross-modal effect between visual, gustatory and olfactory via a pseudo-gustatory display outlined above in section 3.2. The researchers evaluated the effectiveness of their system for inducing/encouraging people to experience various flavours. Assessors were presented with flavour of a cookie. They were then queried in terms of their perception and ability to identify the flavour of a plain cookie when its appearance and scent were changed. The evaluation involved 44 participants with 6 cookie appearances/scent combinations. Firstly assessors experienced a plain cookie enhanced with olfaction and visual overlay. Following this, they experienced only a plain cookie without any augmentation. In over 79% of the trials, a change in taste was reported. [Bodnar 2004] reported works that investigated the use of olfaction, visual and audio as notification tools in a messaging system. Their system was evaluated in terms of the usefulness of olfaction as a notification method, compared with audio/visual notifications considering effectiveness, errors, engagement and disruption. In the results, olfaction proved less capable than audio/visual notifications for each of these scenarios. However the authors reported that based on these findings, olfaction as a notification tool has potential in tasks where minimal disruption is required. The Fragwrap prototype by Kyono et al. was an initial prototype used to evaluate the concept of scent mapping between visual to real objects [2013]. In this system, the olfactory streams enhanced 3D projected images. No evaluation of the system was reported. Arroyo et al. compared scent with four other modalities (heat, sound, vibration and light) to evaluate modality interruption and disruptiveness [2002]. The evaluation system compared the users' performance during a reading and counting exercise while being interrupted by the different modalities. Their ability to recall information related to the reading exercise was also assessed. Considering the fact that scent has often been described as non-intrusive, it was reported to be the most disruptive of all the notifications. [Ramic et al. 2007; Brkic et al. 2009] found that with the presence of smell, the visual quality could be reduced significantly without a viewer being aware of quality differences or reduced QoE. Such findings support the concept that spreading contextual information across the senses is a viable approach. In this context, a key focus of multimodal presentation systems is to improve the link between the various media in order to reduce the load on the visual sense [Brickman and Hettinger 2000]. Rainer et al. reported that the use of sensory media is a key tool for enhancing user QoE, and in addition demonstrated that sensory effects can be used to compensate for degradation of audio/visual quality [2012]. This is consistent with the findings of Brkic et al. who demonstrated that adding olfactory data could disguise the lowering of video quality when viewing video of cutting grass [2009]. Huang et al. proposed the use of scent to enhanced QoE in virtual environments [2012b]. The key aim to was to evaluate changes in output timing of the scent based on the movement, speed and direction of the scent source. Their results reported that the movement or speed of the object did not have a significant impact on the user QoE (captured in terms of MOS degradation Likert scale). The experimental research in the area of augmented and virtual multi-modal environments as reported by Jones et al. has tested the impact of olfaction on a human operator's sense of immersion into the virtual environment [2004]. Following detailed subjective tests, it has been concluded that beyond the audio-visual innovations of the VR, the olfactory component did not significantly enhance immersion into the simulated environment and further studies are required to fully understand same.

Ghinea et al. has published numerous works investigating the relationship between olfaction and audiovisual media, as a step towards enhancing the user perceived experience. They reported findings on the relationship between olfaction and audiovisual media in terms of temporal relations [Ademoye and Ghinea 2009; Ghinea and Ademoye 2010], odor profiles and enjoyment [Ghinea and Ademoye, 2012], content association [Ghinea and Ademoye 2012b], and use of scent in information recall [Ghinea and Ademoye 2009; Ademoye and Ghinea 2013]. In this latter work, the olfaction, audio and visual media components provided contextual information i.e. they were all semantically related. Gulliver and Ghinea examined the relationship between different modalities in what the authors defined as the "content" and "media" levels, a model initially defined in [2007]. The content level was concerned with how information is perceived and understood by the user. The media level was concerned with the impact of network transmission effects on users' perception of the quality. In [Ademoye and Ghinea 2009; Ghinea and Ademoye 2010] the same authors asked the participants to consider how "timely" they viewed olfaction data in relation to audio and video when in the presence of various levels of inter-media skew. They concluded that an in-synchronization boundaryof 30 seconds when olfaction was ahead of the audiovisual content, and a maximum skew of 20 seconds when the olfaction was after the audiovisual content. In terms of the effect of olfaction on information recall [Ghinea and Ademoye 2009; Ademoye and Ghinea 2013], the aim was to evaluate whether or not olfaction can be used to enhanced information recall. The OD used was the vortex active from Dale Air as discussed above. The results of Ghinea and Ademoye indicated that users were less well able to recall information when scent was presented which contradicts the results reported above [2009]. This led the authors to conclude that the use of ambient scents was more appropriate for information assimilation, as opposed direct scent presentation provided by the vortex active. In a follow-on study by the same authors [2013], the experiment had two key goals: (1) to analyze the impact of olfaction on information assimilation and (2) to analyze the impact of information recall activity on user QoE. The results indicated that olfaction didn't have a significant effect on the user ability to recall information. However, the authors did report, that, with the addition of scent, the QoE of the user was not adversely affected by the impact of the information recall task and in fact, the results indicated that the users' sense of reality increased with the inclusion of a recall task, thus highlighting its potential in the education/training.

The authors of this work have also reported a number of findings in terms of user perception of olfaction enhanced multimedia, outlined in detail in [Murray et al. 2013a; Murray et al. 2014a]. As part of defining user based olfaction-enhanced multimedia synchronization profiles, the authors performed subjective testing using the same videos as were used in Ademoye and Ghinea [2009], and were based on age and gender [Murray et al. 2013b], and assessor culture [Murray et al. 2014a]. The contextual audio was replaced with audio which was unrelated to the content i.e. a blowing fan, hence the temporal relationship between olfaction and visual was analyzed. There were significant differences in the temporal relations between olfaction with audiovisual media (where the audio provided contextual information) as opposed to olfaction enhanced visual media only. The authors concluded that the removal of contextual audio significantly altered the perception of the experience. Murray et al. also defined user profile-based olfaction-enhanced multimedia synchronization [2014a]. Significant differences existed in user perception when considering age, sex and culture of assessors. An in-synch region existed between a maximum skew of 10/15 seconds when olfaction was after visual media and a maximum skew of 5/10s seconds when the olfaction was before the audiovisual content, dependent on age, sex and culture [Murray et al. 2014a]. In general, females were more sensitive to the presence of skew than males, younger assessors were more sensitive to skew and indeed olfaction presented before video, than older assessors. Young female assessors were the most sensitive to skew with the older males group the least sensitive. In our analysis of culture, comparing European, African and Asian assessors, the European group were the most sensitive to skew, with the African group being the least sensitive. The African group reported the most enjoyment and relevance of the olfaction enhanced multimedia clips across a wide range of skews and synchronized presentations. From a QoE perspective, inter-media skew between olfaction and video has a negative effect on QoE. It was concluded that olfaction presented in advance of video resulted in a more negative experience for assessors than olfaction presented after video. Results supported this when considering sense of reality, sense of relevance and sense of enjoyment. For the interested reader, detailed information can be obtained in [Murray et al. 2013a; Murray et al. 2013b; Murray et al. 2014a]. In [Murray et al. 2014b], the authors reported the results of a study whereby two olfactory streams enhanced multimedia content. The aims of the study were to determine the impact of conceptual delay and jitter between the scent streams when they enhanced audiovisual content. In addition, the effect of enhancing multimedia with two olfactory streams on user QoE was analyzed and discussed. A number of findings were presented: (1) The assessors' ability to identify skew levels for the second scent was affected by the skew level for the first scent (2) With a predefined gap of 6s, users reported low levels of enjoyment and QoE, (3) A minimum of 21s was required to enhance users QoE (4) Users did not enjoy mixing of scents.

In the next section, the authors identify and classify research challenges for multimedia research involving olfaction as a media component.

5.2 Challenges and Future Works

Considering the works discussed in the previous sections, there is only a basic understanding of if, when and how olfaction enhances user perceived QoE levels. The integration of olfaction with other modalities to recreate and maintain multimedia experiences such that they accurately reflect real world scenarios is very much a work in progress. To achieve optimum interaction, the various media sensory channels must be coordinated in a clear and informative way [MacLaverty and Defee 1997]. Synchronization of olfaction-enhanced multimedia is non-trivial. All the previously discussed issues i.e. slow moving nature of scent, lingering of scent and variable perception are unique to olfaction. It has been shown that the semantic of a particular media presented with olfaction greatly affects perceived synchronicity between the media [Murray et al. 2013a]. Further studies involving olfaction in terms of the impact of loss, multiple scents presentation, odor profiles, and frequency of presentation are required. It also remains to be investigated if disparity between scent presentation and relevant objects has any significant effect on user experience. Although previous findings on this are mentioned, the visual aspect tends to dominate. The impact of the position of the associated object (close up versus distant position, etc.) with a scent in the scene also warrants study. It was shown by Steinmetz to have an impact on the user perceived temporal boundaries for audiovisual lip synch [1996]. Research is also required to facilitate the transmission of olfactory metadata over constrained communication networks. Yuan et al. proposed the ADAMS framework which considered the truple of video quality, sensory effects and network quality on the delivery of multisensory multimedia that included olfaction, hatpic and wind effects and audiovisual content [2015]. In evaluating what aspects of the mulsemedia content contributed to enhanced QoE, tactile was the highest, with olfaction lowest: tactile

(62.5%), wind effect (31.25%) and olfaction (6.25%). The ISO/IEC 23005 standard that provides a Sensory Effects Metadata (SEM) that describes multisensory effects [ISO/IEC 23005-1 2011]. Some works have evolved from this standard [Waltl et al. 2012; Waltl et al. 2013; Yoon 2013; Yoon et al. 2011; Yoon et al. 2009] which investigated the user QoE of a number of sensory effects (wind, lighting etc.). However results with respect to an olfactory component were not reported. Harel et al. described an end to end solution for odor communication involving a scent sensor (sniffer), a mixing algorithm (describing odor constituents) and an OD (whiffer) [2003]. Byun et al. presented a reference model and metadata model for control of digital olfactory presentation were proposed [2012]. Nakamoto et al. reported on a system that identified, transmitted and could reproduce scent at a remote site [2008b]. The odor recording system "involved four QCMs (Quartz Crystal Microbalance, 20 MHz AT_CUT) coated with different sensing films, with the pattern recognized by LVQ (Learning Vector Quantization)" [2008b]. The odor display system was already discussed above in [Nakamoto et al. 2007]. The classification used was based on LVQ neural network. However as mentioned above, an open question the multimedia community must address is how we can model the perceived relationship between a limited set of well known odors and associated other media such as video, audio, haptic and gustatory. A requirement still exists for a metadata and a reference model for mulsemedia i.e. a specific model on a per modality basis e.g. relationship between olfaction and visual, relationship between olfaction and audiovisual, olfaction and wind, heat, gestation, tactile and synchronization of combinations therein. Such a component will then facilitate the study of transmission of olfactory streams of media across constrained networks. Such a metadata language needs to describe the temporal, spatial and content relationship for mulsemedia. Biofeedback is another avenue currently being pursued to obtain objective data on multisensory experiences, including olfaction and is likely to be required to facilitate an objective understanding of multisensory integration. Such work would facilitate triangulation verification between subjective, objective and necessary utility models required to estimate user QoE of olfaction enhanced multimedia. Some initial works exist in this space such as reported in [Donley et al. 2014], where artificial skews between sensory effects and video content resulted in differences (via raw EEG data) in temporal lobe and occipital activity as opposed to synchronous presentation with just 500ms skew levels.

Over the last few years, the European Union Framework programmes (FP) and their successor Horizon 2020 have supported a number of projects in the media and multimodal space which have relevance here. However, to the best of the author's knowledge, no project exits which focuses specifically on olfaction as a media component in the context of a truly immersive multimedia experience. A number of the publications discussed above based on sensory experiences (wind, lighting effects etc.) [Waltl et al. 2012; Waltl et al. 2013; Rainer et al. 2012; Waltl et al. 2010] recognized the support of the ICT Alicante project [ICT Alicante]. This project supports "a media ecosystem deployment through Ubiquitous Content-Aware network Environments" [ICT Alicante]. One particularly interesting work that has emerged from this project was the development of a utility model for mulsemedia QoE. Timmerer et al. [2013; 2014] modeled the impact of some individual sensory media (i.e. lighting, wind and vibration) and combinations of same on user QoE. They reported a linear utility function based on subjective data tests. Although the potential for olfaction is mentioned in a number of their works, their experiment results do not report the use of olfaction. The REVERIE project [REVERIE] aims to support immersive collaborative environments as the next step in the evolution of social networks. One particular case specifies multi-sensory multimedia museum experiences. While it explicitly mentions audio, visual, tactile – the use of olfaction is a noticeable absentee. In the authors' view, potential for more than one EU projects exists with respect to olfaction as a media component considering users perception, OD and associated sensor development across numerous application areas.

6. SUMMARY AND OUTLOOK

This paper provided a comprehensive insight into olfaction or the sense of smell as a media component. It introduced the reader to a number of olfactory phenomena, the knowledge of which is required in order to perform olfaction-enhanced multimedia testing. It contained the most in depth listing and review of olfactory displays available in the literature. Additionally, a classification was provided that considered the location of the olfactory display, the scent generation method employed, suitable applications, and strengths and weaknesses of each approach. The paper surveyed the use of olfaction across a number of industries, with focus on education and training, tourism and health. In this context it noted the significant potential and current use of olfaction outside more apparent application areas such as in gaming, television, notifications and entertainment. Works which integrated olfaction in order to enhance user quality of experience were discussed. It is clear considering these works that only a **limited understanding of olfaction enhanced multimedia** exists and significant research efforts are required in this domain. A number of research challenges were introduced and discussed which highlighted the steps required for future work involving olfaction as a media component.

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