Title:
Integrating Scents Simulation in Virtual Reality Multisensory Environment for Industrial Products Evaluation

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Introduction:
Virtual Reality (VR) is an integrated trio of immersion, interaction and imagination [5]. These characteristics are considered as more effective if multiple sensorial channels are involved in the VR experience. These sensory modalities include vision, audition, touch, smell and taste [5] Currently, most of the research works and devices in the area of Virtual Reality have focused on the visual, auditory, and tactile (haptic) simulation, while few of them have been carried out for what concerns smell and taste. Yet, also these senses are fundamental for human perception and indeed they could be helpful in order to reach a more effective level of immersiveness in VR experiences.

The sense of smell has a great importance in our daily life, even if today humans use more the senses of vision and hearing for interacting with the environment. The sense of smell is devoted to acquire and interpret chemical signals in the environment, and supports some basic biological and behavioural functions, as dangers recognition, identification of food, and social communication [11]. Nevertheless scents have other functions and impacts on humans. In particular, due to the structure of the olfaction process and the regions of the brain involved in it, scents work both at the conscious and unconscious levels in humans. Some studies [1, 2] have demonstrated that scents can impact on physiological parameters, such as heart rate and skin conductance, and, consequently, can induce activation or relaxation states in humans. For these reasons, scents can enhance learning activities, increase the level of attention, are deeply evocative [13] and can also influence moods [14].

On these bases, scents have been applied in the marketing research area, where several studies have been performed on the use of scents for eliciting positive moods in people, and for communicating information about products as perfumes, household cleaners and food. Some studies found out that congruent scents in the environment can be used for improving the time spent by customers in store [10], and for enhancing evaluations of products [4] and also of stores [15].

On the opposite side, few research works have been carried out in the field of industrial products not traditionally associated with scents, as household appliances, furniture, cars, and so on, but which can particularly benefit from their introduction. In fact, the use of pleasant scents for communicating product characteristics to users may represent a competitive advantage. Specifically, scents impact both on the conscious and unconscious levels of perception, and can evoke positive feelings and differentiate these products from others with very similar functionalities and appearance.

Obviously, the new olfactory characteristic of industrial products has to be evaluated in order to investigate its impact on user's evaluation of the product, and if the designed relation between the product and the scent is appropriate for communicating the product characteristics. As it already happens for other characteristics of industrial products, Virtual Prototyping could be an effective tool

for evaluating the new olfactory characteristic. Indeed, the use of Virtual Prototyping in the product development process is today a diffused practice [16] for evaluating and modifying design solutions, reducing the need to develop real prototypes. In addition, the use of multisensory approach, in which a combination of multiple sensory channels is used, allows the evaluation of multiple characteristics of the design solutions. For instance, Bordegoni et al. [3] demonstrated the effectiveness of using a multisensory approach based on the combination of vision, sound and touch in a design review activity. Consequently, in order to evaluate the new olfactory characteristic of industrial products, it is necessary to integrate also olfactory information in a VR multisensory environment by using devices capable of rendering scents.

In the area of Virtual Reality and simulation, several studies have focused on presenting scents in virtual environments, by developing both ubiquitous and personal olfactory displays. An olfactory display is a device controlled by a computer that generates scented air and that provides a user with scents [11]. Specifically, because humans sense scents through the air, the role of an olfactory display is to generate scented air from odorous materials in a stocked form (liquid, soaked in porous materials, gelled, ...) and to deliver the scented air to the human olfactory organ. The various technologies used to develop an olfactory display are categorized by scent generation methods and scent delivery methods [11]. These technologies have been used in several research projects [8, 9, 12, 17, 18, 19] that focused on the development of olfactory displays for specific purpose. For instance, Yanagida et al. [18] proposed an unencumbering olfactory display that conveys a clump of scented air from a remote place to the user's nose by using an air cannon. Narumi et al. [12] developed a "Pseudo-gustatory" display for creating a gustatory sensation. This display presents flavours by means of a cross-modal effect elicited by visual and olfactory Augmented Reality. Finally, some companies have developed and tried to sell virtual olfactory displays for personal computer use [7]. Unfortunately, due to the fact that the personal olfactory displays developed so far try to simulate a great number of scents, these are often cumbersome or very limited (in the number and quantity of scents that can be stored and generated, in the distance that the scented air can cover, and so on), and they have not found commercial success.

Nevertheless, the introduction of scents simulation in VR multisensory environment could represent an easy and flexible tool for increasing the realism of the experience in the evaluation of industrial products characteristics. Moreover, the scents simulation could impact on others field of research in which VR multisensory environments are used, such as marketing studies, medical rehabilitation, gaming and so on. In order to verify these hypotheses, the research presented in this paper aims at verifying if the introduction of scents simulation can influence and improve the level of presence perceived by the users. Moreover, the research aims at evaluating in what way scents can influence the users' evaluation of products, and if the influence of scents on the users' assessment of products in a VR multisensory environment and in a real environment can be comparable. Specifically, in [6] the testing sessions only concern the users' evaluation of product in a VR multisensory environment in which scents are added, while in this work the authors aim also at investigating if there is a correlation between the perceived level of presence, influenced by the introduction of scents, and the users' evaluation of products.

For this purpose, an experimental framework has been defined, a prototype of a wearable olfactory display has been developed, and some preliminary testing sessions have been performed. The collected data have been analysed for identifying any possible difference and correlation in the users' evaluation of the perceived level of presence and products with the used scent typology, and have been compared to results of testing sessions carried out in a real environment [4].

<u>Main Idea:</u>
In the research presented in this paper the authors make the hypothesis that the introduction of scents simulation in VR multisensory environments can contribute in increasing the users' sense of presence in the virtual environment and can allow evaluating the influence of scents on the users' assessment of products.

In particular, the research presented in this paper aims at evaluating:
- in which way scents can influence the level of presence in a VR multisensory environment,
- in what way scents can influence the users' assessment of products, and

- if the influence of scents on the users' assessment of products in a VR multisensory environment and in a real environment can be comparable.

For this purpose, a VR multisensory framework including a prototype of a Wearable Olfactory Display has been set up, and experimental testing sessions have been performed.

The experimental framework is a VR multisensory environment consisting of an Oculus Head Mounted Display (http://www.oculusvr.com/) used for displaying a digital scene in an immersive modality, and a prototype of a Wearable Olfactory Display capable of rendering one scent at a time. The authors decided to use a 2 (pleasant versus unpleasant) X 2 (congruent versus incongruent) between-subject method. This method, in which the only variable parameter is the scent, has been chosen in order to reduce the possible variables to take into account and that can impact on the experimental analysis. Moreover, the authors included a no-scent control condition for comparing users' evaluations in odour and odourless conditions. Consequently, five distinct groups of subjects were asked to perform the same testing session. For each group, made up of 15 subjects, one of the four selected scents (lavender-pleasant and congruent, orange-pleasant and incongruent, smoke-unpleasant and congruent, and anchovy-unpleasant and incongruent) rendered by the prototype of a Wearable Olfactory Display has been added to the virtual scene.

The virtual scene is made up of the digital models of three commercial washing machines, placed in a virtual room, the background of which is the picture of a household appliances store (Fig. 1). The shapes of the washing machines are different, while their colours have been made uniform.

In total, 75 subjects were asked to perform the experimental testing session. Subjects, not aware of the presence of smells in the environment, were asked to evaluate some characteristics of the virtual products (the pleasantness of the shape of the product and of the product components, the perceived level of usability, the perceived value of the product, the users' purchase intentions, etc.).

Fig. 1: The virtual environment with the 3D models and the background shown to the users.

The Wearable Olfactory Display (Fig.2) consists of air cannons for:
- the generation of scents, by using the ultrasonic atomization method (in which fine particles from a liquid are generated by using ultrasonic energy);
- the delivery of scents, by using a direct injection method.

In each air cannon, a small cylinder of porous cotton is placed and used as scented water cartridge. Commercial water-soluble flavours are used, diluted with water. The cylinder of porous cotton is drenched with the scented water and, under the effect of ultrasonic energy, a scented mist is generated and released in the air, which is eventually smelled by the user. For obtaining a non-cumbersome and comfortably Wearable Olfactory Display, the air cannons have been placed on the external part of commercial earphones (one air cannon in each side of the earphones). By using this solution the scented air can easily reach the user's noise and, in addition, the Wearable Olfactory Display is non-cumbersome and confortable for the user. These features of the Wearable Olfactory Display are quite innovative in comparison with the existing systems presented in section 2. Indeed, some of them [8, 18] are not wearable and have to be placed on a desk close to the user's nose, while the other prototypes [12, 17], also if presented as "wearable", are cumbersome and heavy.

The air cannons are controlled by means of a software application specifically developed. The architecture of the Wearable Olfactory Display is shown in Fig. 2. The software application, which runs on a tablet, sends the user's input via wireless to an Arduino board (http://arduino.cc), which processes the input and sends the command of generating and emitting the scent to the air cannons.
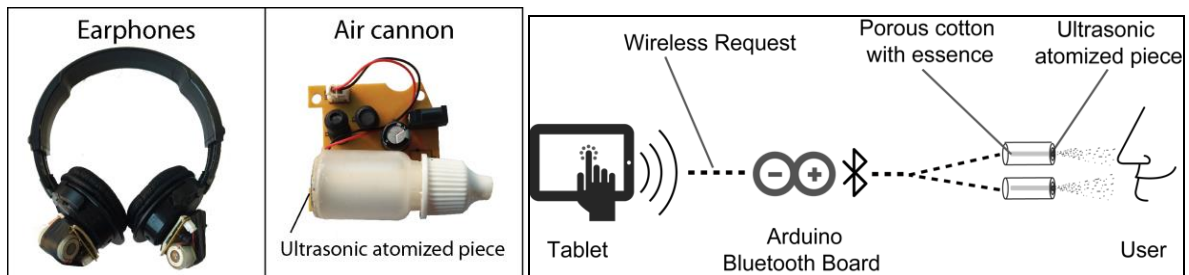

Fig. 2: The prototype and the architecture of the Wearable Olfactory Display.

Results analysis and conclusions:
After the tests, the collected data have been analysed for identifying any possible differences in users' assessments related to the used scent typology. Besides, it has been analysed if the obtained results can be comparable with those of Bosmans [4]. According to this study, scents congruent with the product category can have a strong influence on consumers' product evaluations. For this purpose, both the collected data of the first questionnaire (concerning the level of presence) and the other three questionnaires (concerning the washing machines) have been analysed.

The analysis of the data collected in the experimental tests demonstrates that the use of scents positively influences the user's experience of the VR environment and the perceived level of presence. Specifically, the medium values of the user's evaluation of characteristics as the responsiveness of the VR environment to the users' actions, the naturalness of the interaction with the VR environment, the perceived level of involvement in the VR experience and the consistency of the virtual and real-world experiences, are improved if scents are added to the VR environment.

Also, the analysis of the data related to the users' evaluations of the washing machines demonstrates that the use of congruent and pleasant scent positively influences the users' evaluations of the product shape, and the perceived level of usability and value. Indeed, even if there are important differences in the evaluation of the three washing machines (mainly for what concerns the washing machine number 1, considered by users as less satisfactory from an aesthetic point of view), the use of congruent and pleasant scent (lavender) positively influences the users' evaluation of some characteristics of the washing machines.

Moreover, the authors argue that there is not a direct correlation between the perceived level of presence in VR multisensory environment, influenced by the introduction of scents, and the users' evaluation of products. Indeed, in the case of the users' evaluations of the level of presence in the VR environment, both the use of the pleasant and incongruent scent (orange) and unpleasant and incongruent scent (anchovy) positively influence the evaluations. On the opposite side, in the case of the users' evaluations of some characteristics of the products, the highest medium value has been collected in test with the use of congruent and pleasant scent (lavender).

Eventually, the presented results match with those obtained in a real environment [4], and demonstrate that studies on the influence of scents on the users' evaluation of products in a VR environment and in a real environment are comparable.

Finally, since the introduction of scents in VR multisensory environments can improve the users' experience and the perceived level of presence, it can be also used in other applications in which VR multisensory environments are used, as for instance marketing studies, medical rehabilitation and gaming.

References:
[1]   Alaoui-Ismaili, O.; Vernet-Maury, E.; Dittmar, A.; Delhomme, G.; Chanel, J.: Odor hedonics: Connection with emotional response estimated by autonomic parameters, Chemical Senses, 223, 1997, 237–248. http://dx.doi.org/10.1093/chemse/22.3.237

[2]   Bensafi, M.; Rouby, C.; Farget, V.; Bertrand, B.; Holley, A.: Influence of affective and cognitive judgments on autonomic parameters during inhalation of pleasant and unpleasant odors in humans, Neuroscience Letters, 319, 2002, 162–166. http://dx.doi.org/10.1016/S0304-3940(01)02572-1

[3]   Bordegoni, M.; Ferrise, F.; Covarrubias, M.; Antolini, M.: Haptic and sound interface for shape rendering, Presence: Teleoperators and Virtual Environments, 19(4), 2010. http://dx.doi.org/10.1162/PRES_a_00010

[4]   Bosmans, A.: Scents and sensibility: When do (in)congruent ambient scents influence product evaluations, Journal of Marketing, 70(3), 2006, 32–43. http://dx.doi.org/10.1509/jmkg.70.3.32

[5]   Burdea G.C.; P. Coiffet: Virtual reality technology, Wiley-IEEE Press, 2003

[6]   Carulli, M., Bordegoni, M., Cugini, G., and Weibin, D., 2015. "A Methodology for the Analysis of the Influence of Odours on the Users' Evaluation of Industrial Products", ICoRD'15 – Research into Design Across Boundaries Volume 2, Smart Innovation, Systems and Technologies 35, http://dx.doi.org/10.1007/978-81-322-2229-3_34.

[7]   Davide, F.; Holmberg, M.; Lundström, I.: Virtual olfactory interfaces: electronic noses and olfactory displays, Communications Through Virtual Technology: Identity Community and Technology in the Internet Age, IOS Press: Amsterdam, 2001.

[8]   Kim, D.W.; Nishimoto, K.; Kunifuji, S.; Cho, Y.H.; Kawakami, Y.; Ando, H.: Development of Aroma-Card Based Soundless Olfactory Display, Electronics, Circuits, and Systems, ICECS 2009. http://dx.doi.org/10.1109/WHC.2013.6548416

[9]   Matsukura, H.; Yoneda, T.; Ishida, H.: Smelling Screen: Technique to Present a Virtual Odor Source at an Arbitrary Position on a Screen, IEEE Virtual Reality 2012.

[10] Mitchell, D.J.; Kahn, B.E.; Knasko, S.C.: There's something in the air: Effects of congruent or incongruent ambient odor on consumer decision making, The Journal of Consumer Research, 22(2), 1995, 229–238. http://dx.doi.org/10.1086/209447

[11] Nakamoto, T.: Human Olfactory Displays and Interfaces: Odor Sensing and Presentation, Information Science reference, 2013.

[12] Narumi, T.; Nishizaka, S.; Kajinami, T.; Tanikawa, T.; Hirose, M.: Meta Cookie+: An Illusion-Based Gustatory Display, Virtual and Mixed Reality, 2011, 260–269.

[13] Porcherot, C.; Delplanque, S.; Raviot-Derrien, S.; Le Calvé, B.; Chrea, C.; Gaudreau N.: How do you feel when you smell this? Optimization of a verbal measurement of odor-elicited emotions, Food Quality and Preference, 21, 2010, 938–947.

[14] Rétiveau, A.N.; Chambers, I.V.E.; Milliken, G.A.: Common and specific effects of fine fragrances on the mood of women, Journal of Sensory Studies, 19, 2004, 373–394. http://dx.doi.org/10.1111/j.1745-459x.2004.102803.x

[15] Spangenberg, E.R.; Crowley, A.E.: Improving the store environment: Do olfactory cues affect evaluations and behaviors?, The Journal of Marketing, 60(2), 1996, 67–80. http://dx.doi.org/10.2307/1251931

[16] Wang, G.: Definition and review of virtual prototyping, Journal of Computing and Information Science in Engineering, 2(3), 2002. http://dx.doi.org/10.1115/1.1526508

[17] Yamada, T.; Yokoyama, S.; Tanikawa, T.; Hirota, K.; Hirose, M.: Wearable Olfactory Display: Using Odor in Outdoor Environment, IEEE Virtual Reality 2006.

[18] Yanagida, Y.; Noma, H.; Tetsutani, N.; Tomono, A.: An Unencumbering, Localized Olfactory Display, CHI 2003. http://dx.doi.org/10.1145/765891.766109

[19] Yoshimura, T.; Sakashita, Y.: Development of a Perfume Emission System via Internet, J. Comput. Chem. Jpn., 5(4), 2006, 227–230. http://dx.doi.org/10.2477/jccj.5.227