Design, Evaluation and Impact of Educational Olfactory Interfaces

Research-in-Progress

Miguel Angel Garcia-Ruiz
Department of Computer Science and Mathematics
Algoma University
miguel.garcia@algomau.ca

Pedro C. Santana
School of Telematics
University of Colima
psantana@ucol.mx

ABSTRACT

Olfactory interfaces (digital systems that generate and diffuse smells to a human user with a purpose) have been proposed and developed to support learning in a number of educational settings. This emerging type of human-computer interfaces has great potential for stimulating information recall, helping immerse learners into educational simulations, and supporting other human senses for learning. However, little is known on the proper design and evaluation of olfactory interfaces for learning. This paper discusses research in progress on the design and evaluation of an educational olfactory interfaces, including prototyping development methods based on user-centered design (UCD) and usability methods. An electronic prototype is to be used as a testbed. Prototyping+UCD approach indicates potential for developing practical, efficient and effective olfactory interfaces for learning. Future usability tests with our olfactory interface will confirm the design and testing methodologies used in our project.

Keywords

Design, usability, testing, olfactory Interfaces, education, learning.

INTRODUCTION

Olfactory interfaces (digital systems that generate and diffuse one or more odors to a human user with a purpose) have been proposed and used for learning and training, stimulating information recall and helping immerse learners into 3D educational environments, supporting other senses. Smell can convey meaningful and useful information at the computer/digital product interface. Other applications of olfactory display include smell as warning signals, and "mood enhancer" using aromatherapy techniques, since smell stimulates emotional responses. In addition, olfaction is a powerful recall stimulant that may support learning of complex information (Chu & Downes, 2000). Odors have a number of technical properties that can be successfully exploited in human-computer interaction (HCI), such as directional properties (Wook, Kim & Ando, 2010), intensity, the chemical nature of the odor, and hierarchical properties, among others. The digital interface is the part of a computer or digital product where the user and the digital product meet and interact; it is the place where human-product or human-computer interaction takes place using one or more sensory channels (Rogers et al., 2011). Thus, an olfactory interface provides users with smells that convey meaningful information. This paper will focus on the design and testing of olfactory interfaces for education. It will not touch upon "artificial noses" that detect particular molecules of odors, which are beyond the scope of our research. Despite significant advantages of olfactory interfaces, the sense of smell is one of the least used and researched senses in HCI, including its educational applications. One possible reason is because olfactory interfaces have important challenges regarding smell generation, diffusion, and removal. Another reason is that the number of design and evaluation methods on smell interfaces is still very limited.

A Brief History of Olfactory Interfaces

The use of smell in media with a purpose goes back several decades ago. Fragrances delivered to cinema audiences have been sporadically applied since the first movies were projected at the beginning of Twentieth century (Drobnick, 2006). For example, scent of roses was dispersed with a fan to an audience during the projection of a newsreel on the Pasadena Rose Bowl game in 1906 (Ijsselsteijn, 2003). At the end of the fifties and beginning of sixties, Morton Heilig, an American cinematographer, designed and constructed Sensorama, an electro-mechanical one-person movie system that included auditory, visual, tactile and olfactory displays (Heilig, 1962), with the objective of immersing the user in a multimodal movie. For example, while watching a movie in stereo about riding a motorcycle on the streets of Brooklyn in New York, the user could smell baking pizza as the bike passed by a restaurant, as well as smell car exhaust fumes coming from the street.

The odors were generated from spray cans and the odor was transmitted to the user using fans. Interestingly, one of the applications of Sensorama that Heilig proposed in his patent was that it could be used as a tool to support teaching and learning. Heilig stated in his patent that the Sensorama simulator could relieve teachers the burden of teaching complex materials, and to use Sensorama to train soldiers, to avoid exposing them to "potentially dangerous equipment" (Heilig, 1962). Unfortunately, Heilig could not make Sensorama a commercially-available system due to the lack of financial funding.

The use of smell at the computer interface was initially proposed and researched during the eighties and nineties as an important component in virtual reality/virtual environment applications (Reinghold, 1991), since olfaction can be a powerful sensory channel to enhance presence in 3D virtual environments and improve the perception of spatial cues, which are key characteristics of virtual reality (Cater, 1994; Barfield and Danas, 1996). It seems that previous literature on olfactory interfaces do not describe formal design and testing methodologies.

Up until recently, smell-generation technology for virtual reality/virtual environments and other general applications has being successfully developed, most of them are described in next section.

Available Techniques for Generating and Diffusing Odors

Artificially-created smells can be stored, generated and diffused at the digital interface using mechanical, chemical, or electro-chemical methods, or by using a combination of them. Kaye (2004) describes the main technologies used for storing and generating odors in HCI:

- Keeping a scent compressed in a bottle and spray it over the air by means of a computer-controlled solenoid or motor.
- Storing a smell in a cartridge and dispersing it using inkjet technology, which diffuses very small drops of a scent to the air or sprayed on a particular surface (e.g. paper).
- Heating a scented liquid, oil or wax can evaporate a scent and release its smell. Some scented waxes evaporate by themselves releasing an odor.
- Using scratch-and-sniff stickers and other materials.

Nakamoto and Yoshikawa (2006) devised a system to generate up to eight odors that were presented along with movie scenes. Their system contained solenoid valves that released an odor that was synchronized with a particular movie scene. The odor was sent through a tube to a specially-made interface placed close the spectator's nose and mounted in a microphone headset with the objective of keeping the distance between the olfactory interface and the nose constant.

Surprisingly, techniques, guidelines or methods on the removal of used odors in olfactory interfaces either from the user's personal or ambient space have been very scarcely reported or addressed. Of course, odor removal must be an important part of olfactory interface applications due to the odors' intrinsic characteristic of persistence, and its multiplier (an odor may enhance another one) and masking (an odor may suppress another one) effects (Yanagida, 2008). Computer-generated odors may "escape" personal or ambient spaces that were using them and thus distract or even annoy other people nearby. In addition, sometimes it is necessary to quickly remove a generated odor at the interface to generate and diffuse another one, otherwise smell masking or multiplication will occur. This may be overcome using efficient air filters installed in educational settings. Olfactory adaptation (this happens when a person gets used to the odor after some time) may occur if the odor is presented for long periods of time at the computer interface. Kadowaki et al. (2007) and Sugimoto et al. (2010) have overcome this problem by devising an odor pulse ejection technique that applies a smell for very short periods of time to minimize the time the odor remains in the air. This technique may be very useful in a computer lab or a classroom.

Semantic Classification of Olfactory Presentation in HCI

Computer-generated smell can be classified into smicons or olfactory icons, according to their semantic meaning and its relationship with its context of use. An olfactory icon has been defined by Kaye (2004) as a computer-generated scent that conveys meaningful information to its user(s), which is semantically and environmentally related to the information to be conveyed. For instance, a computer monitor can show a 3D virtual environment of a forest, and the computer immediately release a scent of pine trees, this to enhance the immersion experience of its user in that virtual forest.

A smicon is a computer-generated smell that has only an abstract relationship with the information that it represents (Kaye, 2004). For example, a Japanese firm developed a prototype of an olfactory alarm that uses a very distinctive wasabi (Japanese horseradish) smell working as an olfactory fire alarm to alert hotel guests, to substitute auditory and visual alarms in case some of those guests are deaf or profoundly asleep (Buerk, 2010), although the idea of using olfactory alarms is not new (Schiffman, 1995).

Past Literature on Olfactory Interfaces for Learning

Olfactory information displayed in a computer interface (including virtual environments) can be a powerful support for learning, since it could be useful for reducing stress in learners, as well as "enhance memory performance through better problem solving, reduce response times, produce fewer errors, increase recall, recognition, and retention, and enhance productivity, alertness, and physical performance" (Washburn et al., 2003). What follows describes recent research on olfactory interfaces for learning.

Tijou et al. (2006) described technical aspects on the implementation of a desktop (using a computer monitor) and fully-immersive (using a head mounted display) virtual reality (VR) system to be used to investigate the effect of olfaction on learning, retention, and recall of 3D structures of organic molecules. With this system, students could watch 3D graphical molecular models either in the monitor or the head mounted display configuration, and interact with the molecular models using a special mouse or with their tracked head movements. What is particularly intriguing in this VR system is that some molecular models were associated to particular odors, according to molecules' names, to be smelled by the students. For example, the molecule vanillin was associated with vanilla odor. Odors were automatically generated (according to the molecule being watched) through two commercially-available smell spreaders, both working with fans to send the odors to the student. However, Tijou et al. Did not mention in their paper any test done with students. We consider that the association between learning materials' names and odors (as Tijou et al. did in their configuration) can be potentially used in other learning domains, such as Physics.

Richard et al. (2006) mentioned the ‘‘Nice-smelling Interactive Multimedia Alphabet’’ project, where a multimodal educational application was developed that included visual, auditory and olfactory information. The main objective of this multimodal application was to support learning of of letters of the alphabet. However, Richard et al. do not give further details on the project.

Garcia-Ruiz et al. (2008) described an usability study that tested the integration of an odor in an educational 3D virtual environment (a virtual town) developed for second language learning. Twelve computer science graduate students tested the multimodal virtual environment where their main task was to follow oral instructions in English (their non-native language) for going from point A to B in the virtual town, using the mouse. At the time of carrying out the task, the participants smelled fresh leaves of mint (Mentha Spicata). Each student had to take three mint leaves, rub them with their fingers to release their odor, and smell them while navigating through the virtual environment. A System Usability Scale (SUS) questionnaire was administered as post-test to each participant. Preliminary results shown overall good usability of the multimodal virtual environment. Garcia Ruiz et al.'s main finding was that mint odor helped students minimize their anxiety when listened to the oral instructions and performed the virtual town walk-trough.

Kwok et al. (2009) carried out a research project called SAMAL (Smart AMbience for Affective Learning), where developed and tested a multimodal ambient room with visual, auditory and olfactory stimuli. One of the objectives of SAMAL was to integrate cognitive and affective issues with the purpose of enhancing learning, and studying emotional and affective experience of students while receiving multimodal stimuli, and thus find out its learning effectiveness. The ambient room included 3D stereo projection, 3D interaction using a Wii-mote, high-fidelity audio, and olfactory display in the form of spray dispensers, among other features. SAMAL provided students with a number of different ambient "scenarios" to evoke different cognitive and affective states of mind and feelings. For example, a scenario called "Blue Hat Smart Ambient" provided students with a 3D projection of a quiet road displayed along with a sound of heavy rain, and students perceived in the ambient a smell of violets. According to Kwok et al., all these stimuli were designed with the objective of promoting "feeling of calm and wakening needed for better control and direction" in students while solving a problem. In another scenario, a smell of green apples were dispersed to "stimulate a fresh, liberated and free thinking feelings needed for triggering new or wild ideas." Preliminary statistical findings of post-tests showed that the SAMAL multimodal system as a whole did influence affective experiences of students and it improved their learning effectiveness. However, Kwok et al. did not describe in their paper the particular effects of smell on students' cognitive processes and affective issues, nor the odor generation mechanism.

OUR DESIGN AND EVALUATION APPROACH ON EDUCATIONAL OLFACTORY INTERFACES

Designing an olfactory interface should require the development of a number of prototypes, since we would like to test out different intensities and types of smells, and different versions of smell diffusion. They should be tested under special conditions, e.g. in a well-ventilated area or in a place with an efficient odor removal system, due to the volatility and persistence of smells, and they must be tested in educational settings, such as in the classroom and the computer laboratory. In addition, we must be careful to provide the right intensity and exposure of smell to the user, otherwise habituation and odor masking may occur. Before started our project, we conducted a literature review on systems development life cycle (SDLC) methods for designing and developing digital olfactory interfaces using prototypes, but most of the literature on that topic is very scarce. For example, Rizzo et al. (2010) reported that they used a "design-collect feedback-redesign" cycle during their project for the design and development of an exposure therapy virtual reality system. This immersive system (it included an olfactory interface) was used to treat post-traumatic stress disorders in American military personnel from Iraq and Afghanistan wars.

In order to design and develop our olfactory interface, we decided to use a system lifecycle development method based on prototype creation because of the following reasons:

- We want to create and improve an olfactory prototype in a short period of time.
- We want to improve the system concept as we move through the project.
- We would like to have visible signs of progress during the project.
- We would like to test out a number of versions with our olfactory prototype in different educational settings.
- We would like to conduct usability tests of our olfactory prototypes with different groups of students.

Figure 1 shows a diagram of the evolutionary prototyping method, which we adapted from McConnell (1996). It is important to note that we are incorporating the user centered design (UCD) paradigm (Lowdermilk, 2012; Rogers et al., 2011) in our lifecycle method, since we will test out the initial concept and successive prototype versions. We also plan to get users' feedback in all the main phases. Our method takes into account the importance of prototype usability evaluation, as Hix and Hartson (1993) established in their Star lifecycle method.

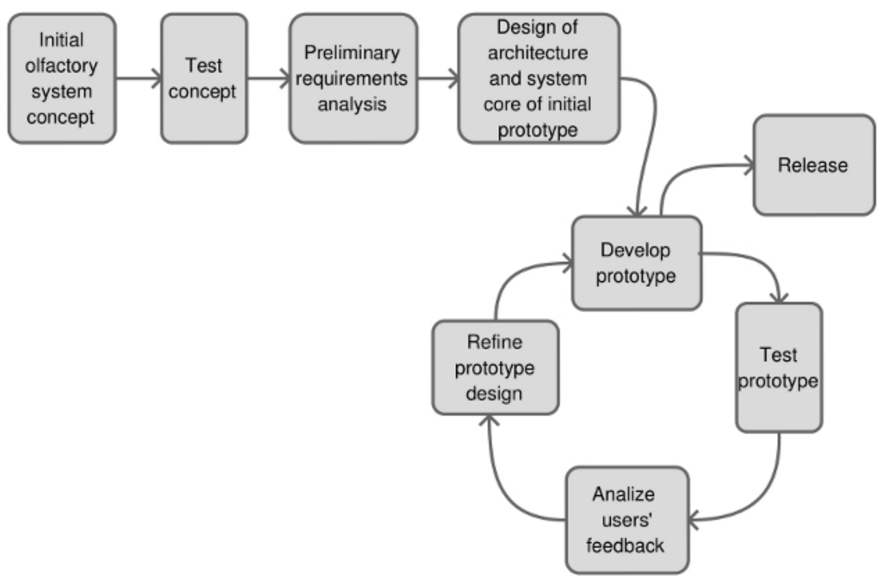

Figure 1. Our evolutionary prototyping method, adapted from McConnell (1996).

We decided not to use an agile development methodology such as Scrum, since our development team is composed of only two people and we wanted to develop a working (high-fidelity) prototype in a short period of time, as well as developing substantial documentation about it.

The usability methods that we will be using to evaluate the concept and the prototype versions are the following:

- The Concurrent Think Aloud Protocol is simple usability method where each participant is asked to do some tasks on the proposed system and he/she is asked to say out loud his/her thoughts about each task while performed it (e.g.

comments about task difficulty, how the task relates to the context of use, etc.) (Someren et al., 1994)

- The System Usability Scale (SUS) questionnaire is a 10-Likert scale instrument to be applied as a post-test that will give us insight about technical issues on the smell interface, general usability issues such as efficiency an efficacy, as well as a usability score with a value from 0 (very poor usability) to 100 (excellent usability).

The design objectives for our olfactory interface are the following:

- To develop an effective, efficient and pleasant to use olfactory interface (ISO 9241-11, 1998)
- To facilitate learning by supporting and complementing other senses of students and contributing to an effective multimedia learning environment (Mayer and Moreno, 1998).

OUR OLFACTORY INTERFACE TESTBED

At the beginning of our project, our initial concept defined our olfactory interface to be easy to use, simple, low cost, and easily adaptable to a number of learning situations. Figure 2 depicts a schematic diagram of our proposed olfactory interface.

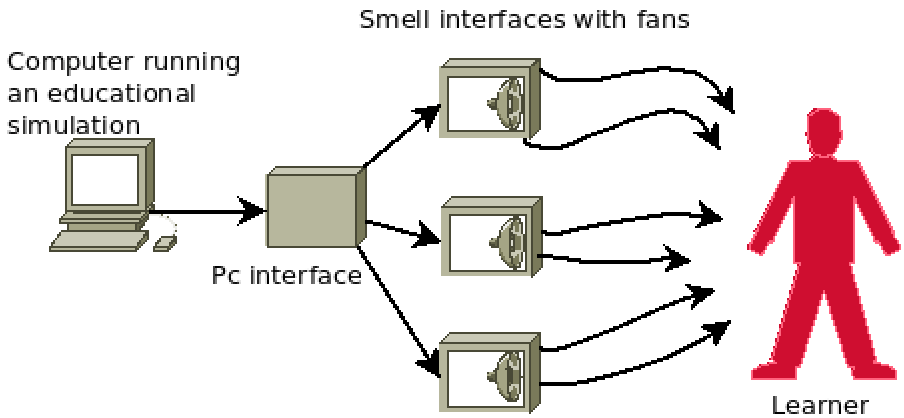

Figure 2. schematic diagram of our initially proposed olfactory interface.

Figure 3 shows an initial electronic prototype of our smell interface. We are using the Arduino Uno (TM) microcontroller working as the PC interface. Our testbed prototype will originally generate and diffuse one smell at a time. Once we complete and refine it we will duplicate the circuit to generate more odors. The smell interface will be activated by the multimedia/multimodal educational simulation shown on the computer. Then, the PC interface will activate both an electronic circuit to heat a scented liquid and a fan who will release and diffuse the odor from the liquid. The circuit from figure 3 does not include the scented liquid and the heating sub-system yet.

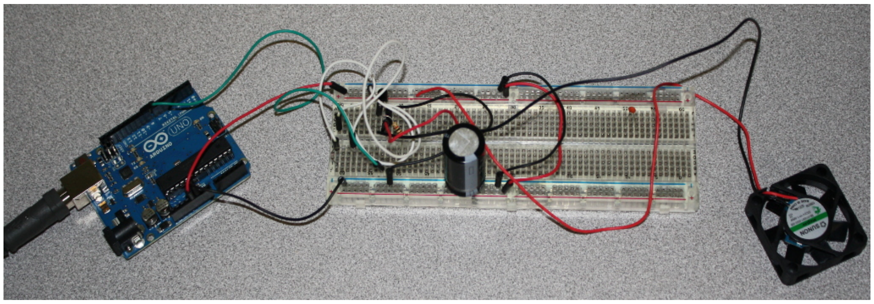

Figure 3. Electronic prototype.

CONCLUSION

According to recent research, olfactory interfaces have great potential for stimulating information recall, helping immerse learners into educational simulations, and supporting other human senses for learning. However, little is known on the proper design and evaluation of olfactory interfaces for learning. This paper discusses research in progress on the design and evaluation issues on educational olfactory interfaces. A Prototype-based development method is being used to develop an olfactory interface to be used as a test bed. The development method is taking into account the user-centered design (UCD) paradigm. Usability methods such as the System Usability Scale (SUS) questionnaire and the Think Aloud Protocol will be used to evaluate the usability of the prototype versions. This indicates potential for developing practical, efficient and effective olfactory interfaces for learning. This olfactory interface might be helpful in the educational context because it may support, complement, or reinforce audiovisual and tactile information for learning topics and concepts from science, technology, engineering and mathematics (STEM) courses. For example, a stinky odor in a multimodal simulator for monitoring computer network traffic may indicate engineering students that a hacker perpetration is in progress. Another example can be to apply real odors (e.g. smell of blood) in a medical simulator for training to enhance its immersion. Future usability tests with our olfactory prototype should confirm the design and testing methodologies proposed in our project. We will also evaluate students learning outcomes when using the olfactory interface by applying knowledge pre-tests and post-tests.

REFERENCES

1. Baines, L. (2008) A teacher's guide to multisensory learning. Alexandria, VA: Association for Supervision of and Curriculum Development (ASCD).
2. Barfield, W., and Danas, E. (1996) Comments on the use of olfactory displays for virtual environments. *Presence*, 5(1), 109–121.
3. Brooke, J. (1996) SUS: a "quick and dirty" usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & A. L. McClelland. Usability Evaluation in Industry. London: Taylor and Francis.
4. Buerk, R. (2010) How the stimulant smell of wasabi can save lilves. BBC one-minute world news. Retrieved from http://news.bbc.co.uk/2/hi/asia-pacific/8592180.stm
5. Cater, J. P. (1994) Approximating the senses. Smell/Taste: Odors in virtual reality. *In Proceedings of IEEE International Conference on Systems, Man and Cybernetics*, San Antonio, TX.
6. Kwok, R.C., Cheng, S.H., Ip, H.H., and Kong, J.S. (2009) Design of affectively evocative smart ambient media for learning. *In Proceedings of the 2009 workshop on Ambient media computing (AMC '09)*. ACM, New York, NY, USA, 65-76.
7. Chu, S., & Downes, J. J. (2000) Odor-evoked autobiographical memories: Psychological investigations of Proustian phenomena. *Chemical Sensors*, 25, 111–116.
8. Drobnick, J. (2006) The smell culture reader. Oxford, UK: Berg.
9. Emsenhuber, B. (2011) The olfactory medium – smell in human-computer interaction. *Science, Technology & Innovation Studies*, 7(1).
10. Garcia-Ruiz, M.A., Edwards, A., Aquino-Santos, Alvarez-Cardenas, O. Mayoral Baldivia, G.M. (2008) Integrating the Sense of Smell in Virtual Reality for Second Language Learning. *In Proceedings of Elearn 2008*, Las Vegas, NV. Association for the Advancement of Computing in Education (AACE).
11. Heilig, M.L. (1962) Sensorama simulator. United States patent no. 3,050,870.
12. Hix, D. and Hartson, H.R. (1993) Developing User Interfaces: Ensuring Usability through Product and Process. New York: John Wiley & Sons, Inc.
13. Holloway, M. (1998) Seeking "smart drugs". *Scientific American*, 9(4), Pp 39-51.
14. Ijsselsteijn, W.A. (2003) Presence in the past. In Riva, G. Davide, F. and Ijsselsteijn, W.A. (eds) Being There. Amsterdam, The Netherlands: IOS Press.
15. Kadowaki, A., Sato, J., Bannai, Y., and Okada, K. (2007) Presentation technique of scent to avoid olfactory adaptation. In Proceedings of ICAT '07, pp 97-104.

16. Kaye, J. (2004) Making scents: Aromatic output for HCI. *Interactions*, 11(1), Pp 48-61.
17. Lowdermilk, T. (2012) User-centered design. Sebastopol, CA: O'reilly.
18. Mayer, R.E. & Moreno, R. (1998) A cognitive theory of multimedia learning: Implications for design principles. *Paper presented at the annual meeting of the ACM SIGCHI Conference on Human Factors in Computing Systems*, Los Angeles, CA.
19. McConnell, S. (1996) Rapid development: Taming wild software schedules. Redmond, Wa.: Microsoft Press.
20. Nakamoto, T. & Yoshikawa, K. (2006) Movie with scents generated by olfactory display using solenoid valves. *In Proceedings of IEICE,* Vol.E89-A No.11 pp.3327-3332
21. Rheingold, H. (1992). Virtual reality: The revolutionary technology of computer-generated artificial worlds - and how it promises to transform society. New York, NY: Simon & Schuster.
22. Richard, E., Tijou, A., Richard, P., Ferrier, J.L. (2006) Multi-modal virtual environments for education with haptic and olfactory feedback. *Virtual Reality*, 10:207–225.
23. Rizzo, A.S., Difede, J., Rothbaum, B.O., Reger, G., Spitalnick, J., et al. (2010) Development and early evaluation of the Virtual Iraq/Afghanistan exposure therapy system for combat related PTSD. Annals of New York Academy of Sciences, 1208: 114–125.
24. Rogers, Y., Sharp, H., and Preece, J. (2011) Interaction design – beyond human-computer interaction. 3rd edition. Chichester, UK: John Wiley & Sons.
25. Maarten W. van Someren, M.W., Barnard, Y.F., Sandberg, J.A.C. (1994) The think aloud method. London: Academic Press.
26. Schiffman S. S. (1995) Use of olfaction as an alarm mechanism to arouse and alert sleeping individuals, *Aroma-Chology Review*, 4(1), 2-5.
27. Spencer, B.S. (2006) Incorporating the Sense of Smell Into Patient and Haptic Surgical Simulators. *IEEE Transactions on Information Technology in Biomedicine*, 10(1).
28. Sugimoto, S., Noguchi, D., Bannai, Y., and Okada, K. (2010) Ink jet olfactory display enabling instantaneous switches of scents. *In Proceedings of ACM Multimedia*, Firenze, Italy, 301-310.
29. Tijou, A., Richard, E., Richard, P. (2006) Using olfactive virtual environments for learning organic molecules. *In Technologies for E-learning and Digital Entertainment,* LNCS 3942, 1223-1233.
30. Vlahos, J. (2006) The smell of war. *Popular Science*, 8.
31. Washburn, D.A. et al. (2003) Olfactory use in virtual environment training. *Modeling & Simulation*, 2(3), pp. 19–25.
32. Wook Kim, D. & Ando, H (2010) Development of directional olfactory display. *In Proceedings of the 9th ACM SIGGRAPH Conference on Virtual-Reality Continuum and its Applications in Industry (VRCAI '10).* ACM, New York, NY, USA, 143-144.
33. Yanagida, Y. (2008) Olfactory interfaces. In Kortum, P. (ed.). HCI Beyond the GUI: The Human Factors of Non-traditional Interfaces. San Francisco, CA: Morgan Kaufmann.