8. OLFACTORY INTERFACES

The olfactory interface is one of the least developed areas within the field of human-computer interaction. There are a number of reasons why this has been so, the main reasons being the lack of useful applications and the current societal mores associated with olfaction. However, with the advent of new VE technology, olfactory interfaces are now seen as a valuable sensory cue for applications such as fire-fighting and surgical training.

While the input or sensing device for an olfactory interface is not solely within the domain of VE technologies, it is a necessary component for the development of VE olfactory systems. These devices are commonly referred to as artificial or electronic noses and are used to collect and interpret odors. There are three basic approaches to sensing technology: gas chromatography, mass spectrometry, and the use of chemical sensor arrays. These are used in a range of applications, such as chemical and biological warfare detectors (used in the Gulf War), and product quality control. It is likely that the same types of technology are suitable for use in acquiring data on odors to be used in a VE. The focus of this section, however, is on systems that can deliver olfactory cues in a VE.

Odorant storage is, perhaps, the most mature of the various technologies required for an olfactory delivery system. Odorants can be stored in a number of ways, including as liquids, gels, or waxy solids. The most popular storage method for previous and current VE-related work seems to be to microencapsulate odorants. This method is the basis of scratch-and-sniff patches. Droplets of liquid (ranging in size from 10-1,000 μm) are encapsulated in a wall of gelatin. They can be printed using silk screen techniques, allowing multiple odors to be printed onto a flat surface. Typically, the odorant is released by subjecting the particle to mechanical shear, or melting the gelatin wall. Microencapsulation offers the advantages of discrete metering of odorant dosage, stability at room temperatures, and the unlikelihood of messy spills. Released odors must then be presented to the user. At present, the major methods include air dilution olfactometry, breathable membranes coated with a liquid odor, and a system of liquid injection into an electrostatic field with air flow control. A summary of the strengths and weaknesses of the various delivery technologies is given in Table 20.

Olfactory delivery systems for VEs, however, require more than odor storage and display. They also need to clean the air input, select odorants for display, and evacuate and clean exhaled air. The greatest obstacle to this is in controlling the breathing space for the individual; for example, it is necessary to accurately control odor intensities, quickly flush

Table 20. Olfactory Delivery Technologies[a]

Storage Technologies	Presentation Technologies	Advantages	Disadvantages
Liquid	- Unpowered evaporation: Saturated cotton balls Breathable membranes Permeation tubes Bubble chambers	- No power - Inexpensive	- Bulky - Odorants clumsy to handle
	- Heat induced evaporation	- Inexpensive	- Power hungry
Gels	- Electrostatic evaporation	- Good for large spaces - Materials easier to handle	- Never miniaturized - Requires higher voltages
Microencapsulation	- Mechanical release	- Could be valveless - Materials easy to handle	- Mass production technology - Impractical for small lots
	- Heat release	- Could be valveless - Materials easy to handle	- Mass production technology - Impractical for small lots
	- Valve design options: No valves	- Smaller, cheaper	- Intercontamination of odors
	Off-the-shelf valves	- Mass produced	- Bulky, power hungry - Fast or precise, not both
	Ink jet printer nozzles	- Precise control	- Single units large because of packaging
	Microvalves	- Potentially fast & small	- Must make custom minifolds to get greatest miniaturization

a. Based on Krueger (1995, 1996).

an odor from the breathing space when a particular odor cue is no longer required, and prevent any contamination by persistent odors. Krueger (1995) identifies several ways of presenting odors that attack this problem with varying degrees of encumbrance to the user:

1. A sealed room with a precise air filtration system.
2. An unsealed cubicle that directs treated air toward the user's face and that provides a collection vent behind his head to evacuate the odorized air he exhales. This still requires some general air filtration system for the room housing these cubicles.
3. A completely sealed pod in which only treated air is breathed and exhaled air is continually evacuated.
4. A tethered mask that can be used in a general purpose room by either a seated or stationary standing user.
5. An untethered system that would consist of a belt pack and tubes running to and from a mask in a HMD.
6. An untethered system that is completely incorporated into the HMD itself.

In addition to differing in the degree in which they encumber the user, these alternative ways of presenting odors differ greatly in such factors as cost, space, and support requirements.

Why odors? There is evidence that odors can be used to manipulate mood, increase vigilance, decrease stress, and improve retention and recall of learned material. One recent experiment demonstrated that a peppermint odor gave superior performance to a lavender odor or no odor at all in spatial visualization and perception tasks (Krueger, 1995). Knasko and Gilbert (1990) found that even the suggestion of odors described as pleasant, unpleasant, or neutral can lead subjects to give self-reports of pleasure and induce a more positive mood. In this experiment, the number of reported physical health symptoms differed as a function of the hedonic quality of the feigned odor; the condition with the feigned pleasant odor reported the fewest number of physical symptoms. Although subjects in the unpleasant odor condition predicted higher task performance, actual performance did not differ across the conditions. Also, as with auditory cues, it is possible that odors can be used for sensory substitution, representing phenomena that have no smell or purely abstract information.

This section starts with a brief overview of the human olfactory sense, followed by descriptions of two commercial products. The discussion then moves on to review research efforts in this area. As usual, the section closes with a summation of likely developments in the near future.

8.1 The Human Olfactory Sense

When a human sniffs an odor, molecules carrying the scent are captured by the receptor neurons in the nasal passages. The cells that become excited fire pulses that travel through axons to a part of the cortex known as the olfactory bulb. The number of activated receptors indicates the intensity of the stimulus and their location in the nasal passage conveys the nature of the scent. Each scent is identified by a pattern of receptor activity, which in turn is transmitted to the bulb.

The bulb analyzes each of the input patterns and then synthesizes its own message, which it transmits to the olfactory cortex. These new signals are sent to many parts of the brain where they are combined with signals from other sensory systems. The result is a contextual perception of the odor that is unique to each individual. This is, however, an incomplete account of olfaction. There are a number of questions that remain unanswered. For example, how does the brain distinguish one scent from all the others that accompany it and how does the brain generate a pattern when some receptor signals are missing? The University of California at Berkeley, Harvard University, and Yale University are all researching the underlying basic science issues in mapping out the human olfactory system. The University of California is focusing on mapping the spatial patterns that the brain recognizes as smell, while the Harvard and Yale research has centered on mapping the DNA of the receptor sites.

As reported by Krueger (1995), there are two senses that are closely related, but distinct, from olfaction. One is taste. The second relates to the tactile sensors in the nose (and also in the mouth and throat) that detect hot and cold, irritation and pain sensations. The sharp smell of ammonia, for example, is actually a tactile sensation that is reported to the brain through the trigeminal nerve (the fifth cranial nerve) rather than through the olfactory nerve (the first cranial nerve). In general, the greater the trigeminal component in an odor, the faster it is recognized, although the perception of oral heat does have a long lag.

Other sensory systems play an important role in human olfaction. As reported by Zellner, Bartoli, and Eckard (1991), for example, humans may correctly identify only one third of odors in the absence of input from other sensory systems, such as vision. These researchers review their own and others' work in assessing the role that color cues have on odor identification. Overall, the findings show that when the appropriate color cue is presented with an odor, both the accuracy and speed of identification improve. Conversely, an inappropriate match of color cue can lead to reduced accuracy and longer response time.

The human capability to detect odors is quite sensitive, capable of detecting odorants in concentrations of one part per million, or even one part per billion, depending on the odor in question. Data on identification thresholds and reaction times for a range of different odors is given in several sources, for example (Overbosch et al, 1989), (Naus, 1985), and (Laing, 1986). Increases in concentration are far more likely to be detected than decreases. Krueger (1995) reports that the smallest detectable change is a 15% to 30% increase in concentration; perceived magnitude is not linear with changes in concentration, but closer to a logarithmic relationship. Further, Krueger makes the point that many studies have shown that humans can only reliably identify such gross measures as: barely detectable but not identifiable, barely identifiable, clearly present, strong, and very strong. It is known that response of smell receptors is time, temperature, and humidity dependent. But many other factors play a role. Segal et al (1995) report that there appears to be a genetic influence on odor identification for males, but not for females. These researchers also found that there is a curvilinear age trend for males, but, again, not for females. Also, the acuity of the sense of smell is subject to change. This change can arise due to physiologic or pathologic reasons. In most cases, however, prolonged or repeated exposure to an odor can result in adaptation that reduces detection.

8.2 Commercial Products

In addition to an entertainment-oriented motion chair that releases odors into an uncontrolled air space (see Section 7.3.1.4), only two commercial olfactory delivery systems intended for use in VEs have been identified.

8.2.1 BOC Group Olfactory Delivery System

The BOC Group plc, in the UK, market an olfactory delivery system to organizations such as VE entertainment and video game producers. Their patented approach is based on dissolving odorants in an environmentally friendly, high pressure solvent, such as carbon dioxide, and then delivering the resultant gas via an air stream blown at the user. The actual delivery system is computer-controlled and delivers dose levels down to the parts per billion level. It can be attached to a HMD. BOC Group plc works with various fragrance houses to enable them to deliver a very wide range of odors.

8.2.2 Smell-Enhanced Experience System

Ferris Productions, Inc. developed the first commercial VE-related olfactory delivery system, integrated in an entertainment-based system called the Experience System. The Experience System includes a NASA-developed zero gravity position chair, 3-D spatial sound, 3-D visuals delivered by a HMD, and the olfactory capability.

The olfactory system stores up to seven odors in liquid form in separate canisters. Odors are generated by releasing controlled amounts of an odor into an air stream produced by a 20 psi air compressor. The scented air stream then is delivered to the user via a small hose pointed towards his nose. The system can be used with an uncontrolled air space, or the user can wear a mask that can be integrated into any HMD. The odors introduced into the air space are expected to clear within about one quarter of a second. In addition to its use with the Experience System, the olfactory delivery system is available as an independent unit. It is controlled by a stand-alone, microchip-based system that not only turns a selected odor on or off, but controls the strength of a generated odor. The price of the complete Experience System is $11,999. The price for the stand-alone olfactory delivery system starts at $4,000.

8.3 Current Research and Development in Olfactory Interfaces

The earliest known work in providing olfactory input for VEs was an internal research study performed at the Southwest Research Institute in 1993. This work led to the development of a prototype odor producing hardware system called DIVEpak. Controlled by a microcomputer, this system could deliver eight different odors. The (essential) oil-based odors were encapsulated and contained in a cartridge. When released, the capsules were ruptured using heated motors and then air was blown across the liquid odorant to let the odors evaporate into the air stream. Trials with the prototype were partially successful and design modifications were defined to resolved problems found with the DIVEpak. At the completion of the study, further work in the area was placed on hold pending active market interest.

Four groups have been identified as currently pursuing research in the area of olfactory delivery systems. The E. Piaggo Bio-Robotic Laboratory at the University of Pisa is developing a VE with integrated olfaction for telemedicine applications. This work includes the development of an odorant capture device (called a smell camera) to record odor patterns for regeneration and an olfactory delivery system for the odor regeneration. Dr. Clifford Bragdon at the National Aviation and Transportation Center, Dowling College, is developing a so-called multimodal simulation system that will support a variety of transportation modalities, olfactory stimuli, and 3-D sight and sound. Further details on these three efforts are not available. The remainder of this subsection discusses the work of the remaining two groups of researchers, those at Artificial Reality Corporation and at Marketing Aromatics, Ltd.

8.3.1 Artificial Reality Corporation

Sponsored by ARPA, the Artificial Reality Corporation (ARC) is conducting a feasibility study for the inclusion of olfactory interfaces in VEs. Part of the plan for this work is to review the state-of-the-art in olfactory sensing and odor delivery to individuals, and to assess the basic science, technology, techniques, and products that are available on the market. This part of the work has been completed, see (Krueger, 1995). Additional work includes a series of studies aimed at ascertaining the effects of odors on the acquisition of skills related to surgery and addressing such questions as: Do appropriate olfactory stimuli add to a sense of presence in a VE? and, Do appropriate odors improve efficacy of VE training? Experiments are now looking at the impact of olfactory stimulation on the acquisition of fine motor skills. Additionally, the researchers are negotiating with the developers of some surgical simulators to the possibility of developing an integrated system to support further experimentation.

Integration of an olfactory capability with a surgical simulator requires a number of specialized odorants that have not previously been available. Here ARC is working with two other companies, Monell Chemical Senses Center, and International Flavors and Fragrances, to develop the necessary odorants in liquid form. Odorants for human body, blood, and liver odors have already been developed, but five or six more odors are deemed necessary to represent the common odors experienced in surgery. A prototype of this first olfactory system using only commercially available clean odors and the three current special odorants could be ready by Fall ‘96. This prototype is expected to be an environmental unit such as a pod or booth where odors are introduced through the floor and vented through the ceiling using a closed air system. This type of controlled breathing space was chosen because it is known to work, although it can be very expensive. Subsequently, the researchers will investigate the capabilities of odor delivery systems that are less intrusive on the instructional environment. The researchers also are considering modifying a CAVE system to include an olfactory system.

ARC has identified a design option that may allow miniaturizing a delivery system, enough that it may fit inside an HMD. Such a portable olfactory system requires miniaturized and lightweight components with low power requirements, and ARC is currently examining candidate technologies. For example, ink-jet printer nozzles are being considered for odorant delivery since these will allow precise control of some odorants. Memory metal valves and electrostatic diffusion delivery technology also are under consideration. When a prototype has been developed, probably by mid 1997, it will be used to study olfactory perception in the context of physical behavior and to develop a testbed for medic training.

Potential future work will address the use of olfactory stimulation for telepresence medical applications. Here odors will be measured at one site and electronically transmitted for reproduction at the surgeon’s remote site. Chemical sensors are not yet fast enough to detect rapid changes in odors and the researchers plan to look at the use of a mass spectrometer that operates continuously for the measurement element of this work. The effort will include identifying which odors are relevant to medical applications and pick a set of these for demonstration. In addition, odors at surgical procedures will be recorded for use with video tape presentations.

8.3.2 Marketing Aromatics, Ltd.

Marketing Aromatics, Ltd. is working on a technology for olfactory delivery systems that is intended to meet three critical physical criteria: a rapid rise/decay of olfactory stimuli, provision of a wide palette of odors, and microprocessor control of the delivery process. The technology itself is a spin-off from other company work and employs aromatic oils that are effectively vaporized to an almost molecular level, thus allowing precise control of minute amounts of vapor. The conversion is very rapid, with vapor generation occurring in the order of milliseconds. The vapor can be delivered, via an air stream, to the user in a number of ways, for example, by applying an electric charge and then directing the vapor using an ionic wind. The user’s air space is controlled, using a mask that can be rapidly evacuated.

Little information is currently available about the actual technology. The key part of the technology, however, is the patented vaporization procedure. The initial delivery system is expected to include around twenty odors, provided by nozzles mounted inside the mask close to the user's nose. The actual choice of delivery and evacuation systems has yet to be made, but the researchers anticipate an odor decay time of less than 1 second. The technology is expected to become commercially available within the next two to three years. Marketing Aromatics, Ltd. see their major consumers being organizations that develop VE entertainment applications and fragrance houses.

In other work, Marketing Aromatics, Ltd. are looking at the use of their olfactory generation technology for large air spaces, such as shops, offices, and airports.

8.4 Summary and Expectations

It seems likely that some olfactory delivery systems for VEs will be developed in the next few years, but these are expected to be largely prototype systems intended for research and experimental purposes. Problems to be solved include the mechanical ones associated with odor storage, selection, regeneration, and breathing space control. Early devices are likely to be too large and heavy for prolonged use, especially if air tanks are required to provide a fresh air supply. Another impediment is the scarcity of suitable odorants: the types of odors likely to be required for use with VEs are unlikely to exist in the standard repertoires of fragrance companies and will take time, and funding, to develop. For these reasons, and others, it is doubtful that a practical olfactory delivery system will be derived from existing technology with the next five years.