Virtual Environment and Sensori-Motor Activities: Haptic, Audition and Olfaction

M. Mokhtari[†], F. Bernier[†], F. Lemieux[†],
H. Martel[‡], J.M. Schwartz[‡], D. Laurendeau[‡] and A. Branzan-Albu[‡]

[†] Distributed Synthetic Environment Group
Defence R&D Canada - Valcartier
Val-Belair, Qc, Canada, G3J 1X5
[marielle.mokhtari,francois.bernier,francois.lemieux]
@drdc-rddc.gc.ca

[‡] Computer Vision and Systems Lab.
Dept of Electrical and Computer Eng.
Laval Univ., Ste-Foy, Qc, Canada, G1K 7P4
[laurend,branzan]@gel.ulaval.ca

ABSTRACT

While the simplest Virtual Environment (VE) configuration considers only visual interfaces, the need for increased immersion drives the VE designers towards the integration of additional communication modalities. Sensori-motor systems are the components of a Virtual Reality (VR) system that contribute to generate the VEs and to create the feeling of immersion and presence, the feeling of *being there*. This paper quickly reviews the *(1)* olfactory, *(2)* auditory, *(3)* haptic sensori-motor activities and focuses on the hardware/software components that are currently available, either as commercial products or as academic prototypes.

Keywords

Virtual Environment – Virtual Reality – Haptic – Virtual Audition – Virtual Olfaction.

1. INTRODUCTION

Immersion is an essential feature of a Virtual Environment (VE) as it is central to the paradigm where the user becomes part of the simulated world, rather than the simulated world being a feature of the user's own world. The definition of the perfect immersion in a VE is analogous to Turing's definition of artificial intelligence: *if the user cannot tell which reality is real and which one is virtual then the computer generated one is immersive*.

However, immersion as the result of Virtual Reality (VR) technology can be achieved to various degrees. The degree of immersion in a VE depends on how much the virtual sensory data is integrated in the proprioceptive process. Each human being uses proprioceptive information to form a mental model describing the dynamic spatial and relational disposition of his body-parts. An efficient VR system is to provide consistency between proprioceptive information and sensory feedback.

The degree of immersion in a VE can be increased by using not only visual, but also olfactory, auditory and haptic user interfaces, by improving the body tracking process, by using high level body representations (avatars), by minimizing the lag between the real user movements and the resulting changes in sensory data, and so on [Laurendeau03].

This paper covers the different sensori-motor activities (others than visualization) that are encountered in VR and focuses on the hardware and software components that are currently available, either as commercial products or as academic prototypes, for building actual implementations.

WSCG POSTERS proceedings
WSCG'2004, February 2-6, 2004, Plzen, Czech Republic.

2. HAPTIC

The word haptic comes from the Greek word *haptesthai*, which means "to come in contact with". The scientific term haptic can be traced back to the German word *haptik*, meaning "the study of touch and tactile sensations, especially as a means of communication". Its modern extension has been expanded beyond touch to embrace contact forces in general. Haptic perceptions nowadays include *kinæstetic* (sense of limb motion), *proprioception* (sense of limb position relative to the body), *cutaneous perceptions* (contact of the skin with the outside world through vibro-tactile, temperature, and pain sensations), and *vestibular sense* (awareness of position and motion of the body relative to the rest of the world and to the gravity force) [Sheridan97] [ETSI02].

Early haptic research was motivated by the desire to substitute sensory information lacking to the visually or hearing impaired by touch information. Another source of motivation was the need for improving and developing telerobotic applications, where a slave device is attached, at first mechanically then electrically, to a master user-controlled device [Rodrigues02].

The increase of computer power has opened new applications for haptic research, including virtual prototyping, virtual exploration and observation, training, and, of course, recreational activities and entertainment.

2.1 Types of Haptic Interfaces

Haptic *displays* are devices conveying haptic information from the computer to the human user. By opposition, haptic *controllers* convey information from the user to the computer. A haptic *interface* is both a display and a controller. Displays can be either passive or active. A *passive display* always presents the same information to the user. The perception of the information solely depends on the user actions (active touch). On the other hand, *active displays* are able to transmit a variety of messages and require no activity from the user (passive touch).

Active haptic feedback can be achieved in two ways: by motion feedback, or by force feedback. Displays implementing motion feedback are usually devices with high inertia and are quite bulky, rigid, and heavy. They have mostly been developed in robotics. Contrarily to motion feedback devices, displays implementing force feedback are usually small, partially flexible, and light. Until now, they have been the most successful haptic devices on the market. Haptic devices implementing motion feedback respond to the force that the user is applying on them while force feedback devices respond to the motion the user imposes to them.

Anholonomic devices are purely passive devices. Instead of dictating the position of the display or applying a force against the user, anholonomic devices prevent motion in one or more directions and allow motion in at least one other direction [Colgate96]. *Tactile* devices were first developed for converting sensory information (noise, visual data, etc.) into haptic information. Pictorial devices reproduce spatial information directly on the user's skin (i.e. [Iwata01]) and frequency-to-place devices encode spatial/temporal information into vibrations, which are perceived at a specific spot on the user's skin (i.e. [Tan01]). Different solutions have been explored to provide *vestibular* information to users immersed in VEs. For instance, providing the user with information on his orientation in the environment can be achieved by lifting platforms, while the illusion of motion can be provided with treadmills, rolling spheres, force-feedback shoes, bearing floors, or tools such as bicycles or roller blades.

2.2 Issues with Haptic Devices

Stability is a major concern when working with haptic devices. Stability is affected by the reaction rate of the device, and by the quality of reaction. Unstable haptic feedback will most likely destroy the user sense of immersion and can also be potentially dangerous for the user.

Haptic systems can be stabilized by considering the haptic controller and the controller of the object modeled by the haptic device as a whole. The stability of the device will then depend on the design of the whole application. Alternatively, the haptic controller can be separated from the rest of the application and designed to guarantee stability when the application meets a given set of requirements. In this case the haptic controller is more generic and can be used in different applications without having to modify its design.

2.3 Design of Haptic Interfaces

The perceptual capabilities and limitations of human users impose requirements on the design of haptic interfaces. These requirements must cover a large number of topics such as: force sensing, pressure perception, position sensing resolution, stiffness, viscosity, and mass perception, human force and position control, temperature perception, texture perception, and finally, ergonomics and comfort requirements.

2.4 Commercial Haptic Controllers

[ReachinTechnologiesAB] is developing Reachin API, which is a C++ application creating an interface for developing "touch through tools" applications, where a stylus like device (Phantom haptic interface from [SensAbleTechnologies]) is manipulated as if it was an exploration stick.

[SensAbleTechnologies] distributes its GHOST SDK. It supports the entire line of Phantom haptic interfaces, and provides stable 3D force feedback. The force feedback can be associated with a static 3D geometric model, which allows a "touch through tools" perception of the geometry. It can also be used to interact with dynamic objects, having mass and behaviours. Force feedback can also be felt when rotating, scaling, and translating objects. Finally, the SDK can be used to generate "spatial effects" force feedback, which allows motion constraint, vibrations, and apparent inertia.

[NovintTechnologies] sells the e-Touch, which is a C++ framework providing an interface for a multi-modal (haptic, auditory, and visual) applications. It provides core classes and can be extended through modules. The modules are distributed under the Open Module system, which allows free usage of any module for research purposes, but requires a license for commercial applications. It is designed to be hardware independent; its porting to other operating system or hardware is supported. Modules for the Phantom haptic interface from [SensAbleTechnologies] and for the Delta haptic interface from [ForceDimension] are available.

2.5 Available Haptic Devices

2.5.1 Research Projects

A system called GSS (Ground Surface Simulator) has been developed by ATR Media Integration & Communication Research Laboratories [Noma00]. It is a locomotion interface, which allows free walking for the user and simulates natural terrain surfaces. The GSS could be used for rehabilitation purposes.

A locomotion device based on an array of small rollers has been developed by the Optical Design Laboratory [Hsu03]. It allows free walking using a "step-and-slide" walking pattern without wearing special shoes or using devices. Each roller is mounted on a switch, which is triggered by the pressure exerted by the user's feet. The user is maintained on the array by a hoop.

VR Systems UK has developed a fully immersive spherical projection system [Cybersphere]. It is a 3.5m of diameter translucent sphere in which the user is free to walk. The walking motion of the user causes the sphere to rotate, and computer-generated images are projected accordingly.

[VirtualSpaceDevicesInc.] has designed and developed an Omni-Directional Treadmill (ODT). The first generation model provides a walking speed of 3m/s, and has an active surface of 1.3m×1.3m. It is comprised of two belts, one for each axis; each belt is made from about 3400 rollers woven together. A second-generation model has also been developed, which offers a larger surface area comprised of flat belts instead of rollers. The main problem with the ODT is that it is very noisy and users cannot hear each other when using the device.

The University of Tsukuba (Japan) carried out a project to develop a new interactive technique that combines haptic sensation with computer graphics. The goal was to present visual and haptic sensation simultaneously, providing users with a surface on which they can touch an image using any part of their hand [Iwata01]. A device called FEELEX was designed, comprising a flexible screen, an actuator array and a projector. The actuator deforms the flexible screen onto which the image is projected, and the user can touch the image and feel its shape and rigidity. Possible applications include medical simulators featuring palpation, 3D shape modeling tools, and touch-screens.

The Haptic Interface Research Laboratory of Purdue University has developed a three-by-three tactor array designed to be worn on the back [Tan03]. This device can provide attentional and directional cueing. Attentional cueing has been found to improve the wearer's reaction time to detect a change in a visual scene. Directional cueing can provide spatial cue to the wearer, such as where to look, or provide a stable referential to users experiencing distorted spatial orientation such as pilots and divers.

2.5.2 Commercially Available Devices

[SensAbleTechnologies] offers different models of stylus-based haptic interfaces called Phantom. [ForceDimension] sells the DELTA haptic device. Three different models are available: one with three degrees of freedom, one with six, and the cardanic model, with a more robust design, for industrial applications. [ImmersionCorporation] produces the CyberGlove, a fully instrumented glove providing 18 or 22 joint-angle measurements. The CyberTouch adds vibro-tactile feedback to the CyberGlove. It features one stimulator on each finger and on the palm. Sensations such as pulses, sustained vibration or more complex tactile feedback patterns can be reproduced. The CyberGrasp system adds resistive force-feedback to the CyberGlove on each finger. The CyberForce finally attaches to the CyberGrasp to provide grounded-force feedback.

3. VIRTUAL AUDITION

Unlike visual information, the manipulation of sound in VE has only recently come to broad attention. The main reason is probably that sound does not appear absolutely necessary to most VE and users. But it has been widely recognized that virtual sound strongly contributes to the quality of immersion in a VE. Work in a VE is more efficient when actions are accompanied by appropriate sounds, seemingly emitted from their proper locations. It has been shown that response times to visual targets associated with localized auditory cues drop dramatically. Sound can also provide an important source of feedback for events occurring out of the field of view of the user. Virtual sound becomes even more important in a multi-source sound environment, because it is easier to discriminate and comprehend sounds when they are separated in space.

Virtual sound has been named by several equivalent designations, such as 3D-sound, virtual acoustics, spatialized sound... All of these refer to techniques allowing sound sources to be placed anywhere around the listener in the virtual space, either by hard sources or by filtered digitized sound signals rendered through headphones.

The ultimate goal of a 3D-sound system would involve the complete control and manipulation of somebody else's spatial auditory perception. Sound perception is not only characterized by a sound source's perceived direction and distance, but also by an apparent width or extent. The environmental context also plays a role on how a sound source is perceived, mostly because of reverberation, which acts as if a set of secondary sound sources were produced.

3.1 Acoustics Issues

Sound is a pressure wave produced when an object vibrates rapidly. It is characterized by *(i)* frequency related to the rapidity of oscillations, *(ii)* intensity related to the amplitude of the waveform, and *(iii)* complexity related to the spectral content along with the manner that the content changes over time. In the human auditory system, acoustic signals are broken down into constituent frequency components in a Fourier-like analysis. The standard range of audible frequencies is between 20Hz and 20kHz. Sensitivity to intensity is measured in decibels (dB) and follows a logarithmic scale. Doubling the level of a sound source causes roughly the same perceived change independently of the reference level. This gives the auditory system a large dynamic range. The auditory system is much more sensitive to temporal fluctuations than the visual system. The system is also sensitive to small fluctuations in the spectral content of the input signal for roughly the same modulation speeds [Shilling02].

3.2 Spatial Sound

The main problem with using loudspeakers for 3D sound is that control over perceived spatial imagery is reduced, since the sound is reproduced in an unknown environment. The room and loudspeakers will impose unknown transformations that usually cannot be compensated for by the designer of the 3D audio system. So it is difficult to harness 3D spatial imagery over loudspeakers in such a way that the imagery can be transported to a number of listeners in a predictable or even meaningful manner.

Different types of systems exist for adding virtual auditory into VR applications, depending on the level of sophistication that is expected. Basically two categories of products can be distinguished, *(i)* systems that are exclusively software-based (the Sound Lab [SLAB] system developed by NASA, the Mustajuuri software developed as part of the [EVE] project at Helsinki University of Technology, and the DieselPower software by [AM:3D]), and *(ii)* systems that include some sound-processing hardware ([AuSIM][LakeTechnologyLtd]).

4. VIRTUAL OLFACTION

Virtual olfaction is an emerging field and smell is generally forgotten in implementing current VR systems. However virtual olfaction could increase the level of immersion of people using virtual technologies and enrich the range of sensitivity. Smell and taste are the only senses that allow us to perceive information from the chemical domain, and the effect of smell on the human mind is strong, especially at the subliminal level. In comparison with the ear or the eye, the human nose is much more complicated. Hundreds of different classes of biological receptors are involved in olfaction, whereas in vision only three different classes are found. There are approximately ten million sensory receptor cells in the nose, each of them being sensitive to a large number of compounds. Therefore, human subjects are able to experience a wide range of different sensations from different odours. The response of a receptor is due to the activation of biochemical processes in the cell or of ion channels in the cell membrane. Furthermore a learning process is possible for smell, allowing a human subject to better recognize odours he is often exposed to [Davide01]. Two technologies open the way towards virtual olfactory: electronic noses and virtual olfactory displays.

4.1 Electronic Noses

An electronic nose is a system that aims at characterizing different gas mixtures. It uses a number of individual sensors (typically 5 to 100) whose respective selectivity towards different molecules overlap. The response from a chemical sensor is usually measured as the change of some physical parameter, e.g. conductivity or current. The response times for these devices range from seconds up to a few minutes. This is a significant drawback, and one of the main research topics in this field is to reduce response time. Electronic noses can be useful for a variety of applications such as product or process control (food, packages), medical diagnosis, and environmental monitoring to name only a few... However present electronic nose technology is a long way from assessing the level of complexity and sensitivity of the human olfactory system.

4.2 Virtual Olfactory Displays

A *virtual olfactory display* is a system composed of hardware, software and chemicals, able to provide olfactory information to the user of a VE. *Virtual olfaction* is defined as the act of smelling an odorant produced by a virtual olfactory display. *Teleolfaction* is a form of virtual olfaction defined as the act of smelling a mixture of odorants whose composition is related to a mixture present in a remote place. A virtual olfactory display should possess information about the type of smell, its concentration, its temporal dynamics, and its spatial localization. This information should be provided either by an electronic nose, in the case of teleolfaction, or by a computer simulator. This poses the problem of smell coding, and because of the complexity of the mechanisms involved in smell, no general way of representing odours has been found yet.

Only a few companies already sell virtual olfactory displays. They all use a number of chemicals stored in a type of cartridge, and when receiving a signal describing an odour, they release a mixture of these chemicals. Because no standardized way of describing odours has been created, different manufacturers may represent one smell in different ways: [TriSenx] with the Scent Dome, [ScentAir] with the ScentShow system and [AromaJet] with the Pinoke. It is difficult to evaluate the quality of these products and to estimate their potential for long-term development on the market. Rather than simulating a whole range of odours with a limited number of base components, future developments may rather attempt to focus on particular types of smells, for example fragrance or coffee.

5. CONCLUSION

This overview cannot offer a unique formula for creating a VE (in the case of haptic, auditory and olfactory devices) for a given application since this does not exist. VR is still an infant field, and fundamental issues about the best way to build systems, to integrate the interfaces, and to design graphics, interactions and behaviours for modeling specific phenomena remain a very open research topic. The evolution of VR is typical for new interdisciplinary fields. This evolution can be compared to the development of software engineering, which has evolved from a chaotic and unstructured activity to a formal process driven discipline of engineering.

Despite the enthusiasm surrounding VR, a substantial gap still exists between the technology available today and the technology needed to bring VEs closer to reality. The current state of specialized hardware necessary to support VE applications is not satisfactory in most of the cases, and true consumer-grade, high performance VR technology is not yet currently available. Haptic interfaces are still in a primitive phase of development, and progress in audition and olfaction technologies is much slower than that of displays and image generation.

6. REFERENCES

[AM:3D] http://www.am3d.com

[AromaJet] http://www.aromajet.com

[AuSIM] AuSIM Engineering Solutions http://www.ausim3d.com

[Colgate96] Colgate, J.E., Peshkin, M.A. and Wannasuphoprasit, W., "Nonholonomic Haptic Display", *Proceedings of the IEEE International Conference on Robotics and Automation*, Minneapolis, MN, USA, April 22-28, pp.539-544, 1996.

[Cybersphere] http://www.vr-systems.ndtilda.co.uk/sphere1.htm

[Davide01] Davide, F., Holmberg, M. and Lundström, I., "Virtual Olfactory Interfaces: Electronic Noses and Olfactory Displays", *Communication through Virtual Technology, IOS Press*, pp.193-220, 2001.

[ETSI02] ETSI EG 202 048 v1.1.1, "Human Factors (HF) – Guidelines on the Multimodality of Icons, Symbols and Pictograms", August 2002.

[EVE] The Experimental Virtual Environment - http://eve.hut.fi/

[ForceDimension] www.forcedimension.com

[Hsu03] Hsu, Y.L., Wang, C.F., Lien, C.M. and Kao, C.Y., "Design and Comfort Evaluation of a Novel Locomotion Device for Training Overhead Traveling Crane Operators in a VE", *Journal of the Chinese Institute of the Industrial Engineers*, Vol. 20, No. 1, pp. 62-90, 2003.

[ImmersionCorporation] http://www.immersion.com

[Iwata01] Iwata, H., Yano, H., Nakaizumi, F. and Kawamura, R., "Project FEELEX: Adding Haptic Surface to Graphics", *Proc. of SIGGRAPH*, Los Angeles, CA, USA, pp. 469-475, 2001.

[LakeTechnologyLtd] http://www.laketechnology.com

[Laurendeau03] Laurendeau, D., Branzan-Albu, A., Boivin, E., Drouin, R., Martel, H., Ouellet, D. and Schwartz, J.M., "Survey of the State-of-the-Art on Synthetic Environments, Sensori-Motor Activities in Synthetic Environments, Simulation Frameworks and Real-World Abstraction Models", *Technical report*, contract between DRDC-Valcartier and Laval University, Canada, 2003.

[Noma00] Noma, H., Sughihara, T. and Miyasato, T., "Development of Ground Surface Simulator for Tel-E-Merge System", *Proc. of IEEE Virtual Reality*, pp. 217-224, 2000.

[NovintTechnologies] www.novint.com

[ReachinTechnologiesAB] www.reachin.se

[Rodrigues02] Rodrigues, D.L., Campos, M.F..M. and Kumar, V., "Design, Implementation and Evaluation of Haptic Interfaces ", VI SPG, Sept. 4-6, 2002.

[ScentAir] http://www.scentair.com

[SensAbleTechnologies] http://www.sensable.com

[Sheridan97] Sheridan, T.B., "Human and Machine Haptics in Historical Perspective", *Workshop on Human and Machine Haptics*, Monterey Peninsula, CA, USA, December 7-9, 1997.

[Shilling02] Shilling, R.D., Shinn Cunningham, B., "Virtual Auditory Displays", in *Handbook of Virtual Environments*, Lawrence Erlbaum Assoc., 2002.

[SLAB] http://human-factors.arc.nasa.gov/SLAB/

[Tan01] Tan, H.Z. and Pentland, A., "Tactual Displays for Sensory Substitution and Wearable Computers", in *Fundamentals of Wearable Computers and Augmented Reality*, Laurence Erlbaum Associates, Mahwah, NJ, USA, pp. 579-598, 2001.

[Tan03] Tan, H.Z., Gray, R., Young, J.J. and Traylor, R., "A Haptic Back Display for Attentional and Directional Cueing", *Haptics-e The Electronic Journal of Haptic Research*, 3(1), 2003.

[TriSenx] http://www.trisenx.com

[VirtualSpaceDevicesInc.] http://www.vsdevices.com/