Use of specially designed Haptic Devices in a Virtual Reality environment for Educational Purposes: Requirements, Specifications, and hands-on experience derived from an IST project

S. P. Christodoulou[1], D. M. Garyfallidou[2], G. S. Ioannidis[2], E. A. Stathi[1]

[1] HPCLab, Computer Engineering & Informatics Department,
[2] The Science Laboratory, School of Education,
University of Patras,
26500 Rion, Patras, Greece
spc@hpclab.ceid.upatras.gr, D.M.Garyfallidou@upatras.gr,
gsioanni@upatras.gr, stathie@hpclab.ceid.upatras.gr

Abstract. *In this paper the use of haptic interfaces and applications for educational purposes is discussed. The question whether Haptics technology (virtually touching objects and feeling forces), could be implemented fruitfully in the teaching procedure is studied as well as if it helps the understanding of certain scientific concepts.*

The hardware haptics components was designed after careful consideration of the educational needs: the most important parameters of the end user requirements were drawn up, and the functionality of the end product was discussed with selected educational experts (mostly teachers).

These requirements were transformed into specifications for a large scale system, called the Interactive Kiosk Demonstrator (IKD) in the framework of an IST project entitled "Multi-User Virtual Interactive Interface (MUVII)". For the application software design (thinking especially in the context of science education) the educational needs of the end users were painstakingly analyzed and evaluated and, subsequently, some applications were designed and developed. These applications have been used and tested by students of different ages, and their teachers, for more than three months in order to reveal the benefits and the drawbacks of the haptic device as well as the applications.

Some interesting results were derived from the users' feedback, and these support the view that haptic interfaces can be used in education for the benefit of the students.

Keywords. Haptic Interfaces, Science Educational Applications, User requirements, Virtual Reality.

1. Introduction to Haptics, 3D Graphics and 3D Sound

It is useful, to define some terms of *Haptics*, *3D Graphics* and *3D Sound*, since all haptic devices use this kind of technology.

The term *haptics* was popularized in the United States by the philosopher Gilles Deleuze and comes from the Greek verb "haptesthai", which means to touch and to handle. The technology refers to the ability of touching and handling virtual objects. In a more general sense, it is an interface that enables users to understand the weight, the shape, the volume of an object and the forces acting on it. By using *special input/output devices* (joysticks, data gloves, or other devices), users can receive feedback from computer applications in the form of sensations felt on the fingers, the hand, or other parts of the body. The term *"tactile feedback"* refers only to the sensory input on the fingertips of the user.

With *3D (three-dimensional) graphics* we refer to a space where objects (polygons) are made up by a series of dots which are referred to as corners. The coordinates of these corners are specified by three values: x, y and z. The representation of the 3D space on each of user's eyes is always a 2D image obtained through the rendering process. The impression of 3D is created in the human mind after some (quite elaborate) computation, albeit without conscious effort from the part of the user. Many parameters are used as input to this computation, like the different 2D image in each eye, different colouring (hue) of objects as distance increases, common assumptions as to the size and speed of various objects etc.

As far as *3D sound* is concerned, true 3D sound has genuine depth and width to it. Just like

3D graphics, 3D sound can also be recreated by just two speakers and some very advanced mathematics! The use of 3D graphics and 3D sound combined with haptic feedback create a multi-sensory immersion for the users.

2. MUVII project description

The key objective of MUVII project [8] was to develop on the one hand two new Man-Machine-Interface Devices featuring haptic feedback, called Haptic-3D-Interface (H3DI), and on the other hand a prototype of an innovative integrated platform using the device: the Interactive Kiosk Demonstrator (IKD). University of Patras (HPCLab - High Performance Information Systems Laboratory) was responsible for the design and integration of the IKD platform as well as the development of the 3D haptic applications. In cooperation with The Science Laboratory of the School of Education of University of Patras, provided the specifications of the device and carried out the testing of the whole platform with pupils and teachers. The other partners of the project were: Laval Mayenne Technopole (France), CEA - Commissariat a l'Energie Atomique (France), SINTEF - The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (Norway), De Pinxi (Belgium), Institut für Kommunikationsakustik – Ruhr University of Bochum (Germany), ONDIM (France), CompuTouch (Norway), Centre PIC (Russia).

The opportunity of having a natural "look and feel" environment for teaching purposes is very promising indeed. The purpose of MUVII IKD was to demonstrate new interactive paradigms in a novel integration of the following modalities as these interfaced interactively with the user: *3D-vision, 3D-audio and haptic (force and tactile) feedback*. The process followed in order to design, implement and test the IKD was:

1. *User requirements and constraints* for the IKD device and applications were gathered and analyzed.
2. *Technically feasible specifications* of the IKD device, applications and platform were defined in detail.
3. Design and development of the *IKD device*
4. Design of the modular architecture of *IKD supporting platform.*
5. Design and development of *IKD Applications.*
6. *Integration of the hardware and software modules.*
7. *Educational Testing of the IKD*, for more than three months, with an adequate sample of more than 300 pupils, and some teachers.

In the present paper the first two steps of this process are described, and some conclusions regarding the issues raised in them are drawn, which can be used as a useful guide for those interested in developing haptic interfaces and applications for educational purposes.

3. User Requirements Gathering

In order to collect the most important user requirements, several discussions with potential users (mostly with teachers and to a lesser extent with students) were held. It is interesting to note that although students normally have a better knowledge of computers than their teachers, they are also "dreamers" and ask for features that are not feasible yet.

During these discussions the concepts behind the current haptic technologies (force and tactile feedback) as well as our ideas were explained. In order to judge the pupils' reaction towards virtual reality environments involving haptic feedback interfaces, some trials were run using both children (of various ages) as well as adults, and utilizing a setup involving commercial haptic interface devices (i.e. Phantom by SensAble Technologies, I-Feel-Mouse by Logitech). The results of those trials were most encouraging, especially considering that these devices have a "feel" which is a lot less natural than the one expected from the H3DI of the MUVII IKD.

Moreover, regarding the tactile feedback, it was demonstrated that the tactile motors of CompuTouch (one of the partners in MUVII project) gave the sensory input expected when they were integrated in a common mouse. The users got feedback on their index while interacting with a windows application and the capabilities and limitations of such tactile motors were studied in detail.

The teachers were fascinated with the idea of using haptics in their classes since this technology gives the opportunity to observe, test and simulate phenomena that could not be performed in a class or in a school laboratory [2]. This is due to several reasons such as safety problems (e.g. it is too risky to use explosives or certain chemicals in an ordinary lab) or too difficult and perhaps impossible experiments ("switch off" friction for instance, driving any type of vehicle and feel the forces of a collision, construct a certain machine etc.).

One of the primary interests during this phase was to specify the best shape and functionalities of the IKD device. The main requirements for the IKD device was the movement independence, the feeling of force feedback independently on each finger, the precision of the movement so that the haptic device could function "transparently" as an extension of the user's hand. Apart from that, users expressed their interest for the use of two devices, one for each hand. Moreover, users wanted a large workspace (i.e. actual space where the device would be active).

As far as the applications were concerned, the potential users wanted to use applications that couldn't be easily performed in a class, but with a high educational value and, of course, to be exciting enough for the students. Many different ideas for applications were offered and discussed, and finally two applications were selected and implemented for the IKD, as specified in a following section.

4. User Requirements Analysis

In the ensuing analysis it was revealed that, as far as the device was concerned, users wanted to use advanced *wearable (not ground-based) haptic interfaces* instead of joysticks. The characteristics most users required involved *grasping, manipulating and throwing objects* in the virtual space, while feeling forces and tactile feedback on as many fingers as possible (but at least on the 2 essential ones: thumb and index). The users required to be able to *investigate and explore* various 3D objects and *feel* their material, surface, size, shape, etc. Another very important characteristic, for the educational use of the IKD was deemed to be its *realism*, (something that is normally ignored by game developers). Special emphasis was paid in support of *accurate hand and finger movement*.

More specifically, users wanted an *"easy-to-use" device* that doesn't require in depth knowledge of computers, robotics or physics in order to use it. Another important factor for them is the *weight* of the device – they want it to be as light as possible so that young children can handle it – and the *freedom of movements*. The users want the device to be a "natural" continuation of their hand which they can freely move and act in the application's environment.

Regarding *3D sound features*, users found very interesting the idea of hearing the various sound cues of the application and being able to easily perceive their direction, distance and volume, while at the same time they can communicate with the other users by using open air headphones. Furthermore, *Haptic related sounds* (i.e. sounds that are produced directly from the interaction of the user's virtual hand with the objects) should also be supported by the sound subsystem of the IKD.

One of the most innovative and challenging requirements was to support two users interacting simultaneously in the context of the same application. The users should be able to jointly manage the common viewpoint, but each user be able to independently move inside the 3D world of the application. The two users should be able to act at the same time either at the same or on different object.

The IKD applications to be developed were selected after the analysis of the requirements and these were: (A) Newtonian Physics, Trajectories and the Solar System (with learning mode, recapitulation mode and edutainment mode) and (B) Virtual Model Assembly – Gears (with learning, training mode and game mode).

5. IKD Specifications

The analysis of the user requirements led to the specifications of the IKD haptic device, the IKD platform and the IKD applications, as described in the next sections and in [3].

5.1 IKD Device Specifications

The MUVII IKD Haptic 3D Interface (H3DI), as the human-interface part of the IKD platform and applications, plays an extremely important part in the final functionality of the applications. Furthermore, the IKD H3DI should respect some specific constraints, regarding the varied ages of the final users (children as well as adults) and some requirements of the specific IKD applications. More specifically, the requirements are the following:

Size of H3DI: How small should the body of the 3DHI be? The main concern is the use of the device by young children (primary school age). As the size of the hand is smaller, we cannot expect young children to be able to handle with ease (or if at all) a device created with a fully-grown male in mind. Therefore, the best possible solution is to create a device that is *adjustable in* *size*, so it can be used by adults and children as well. This could be achieved by having detachable pads attached to the main body.

Weight: Should be as light as possible approximately 100 - 150 grams. The balance of this weight is of considerable importance, as it should not be very top – heavy, or in anyway out of balance. A top-heavy 3DHI would feel unnatural to use and, therefore, it would present an obstacle to the user to associate with it, and “immerse” in the use of it.

Priorities to be kept in the design: The *balance and fit* are (probably) more important parameters than size and weight. Any inevitable compromises made should keep this in mind.

Type of movements: The users should have the capacity to move their hand (with the device worn) freely in space without strict movement restrictions. Also, the users should be able to use at least two of their fingers (thumb and index) independently. This way, it was observed that they could easily manipulate virtual objects (albeit in a rather unnatural fashion). Taking into consideration that in this trial a new haptic interface was evolved, this is acceptable. It also turned out that the user could easily adapt him/herself to this situation, e.g. the use of only 2 fingers to manipulate objects). Furthermore, the precision of the movement is an important factor, because this allows the user to perceive the haptic device as an extension of his hand.

Type of actions: By exploiting the force-feedback of the H3DI, users should be able to select, pick-up, hold, move, orient, release/place, pull/push and throw objects, while they feel forces acting on their fingers (weight, torque, collisions, etc.). By exploiting the tactile feedback (provided by the tactile motors integrated on the H3DI) users can investigate and explore various 3D objects and feel their surface material, shape, etc.

Force feedback: Users manipulate objects using their two fingers and feel forces acting on them, independently on each finger.

Tactile feedback: Users are able to get tactile feedback on their two fingertips.

Workspace: This is the actual physical space where the device would be operational (its position can be tracked). Minimum requirements are 600 mm (width), 600 mm (length), and 400 mm (height). Obviously, the greater the final workspace is the better it is.

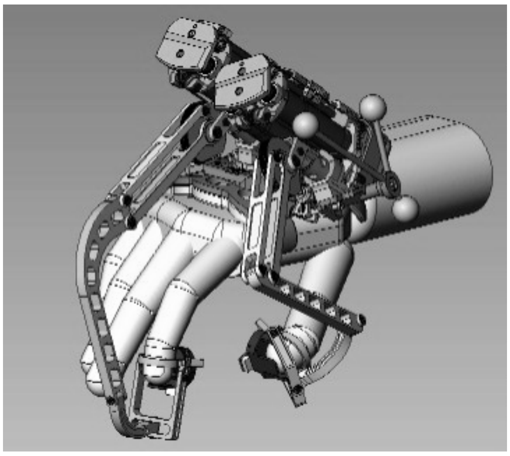
Robustness: A certain amount of robustness is required especially as we envisage children using it. Ideally, it should be able to withstand a drop from 80 – 100 cm height onto a hard floor without breaking or needing adjustment or realignment.

5.2 IKD Platform Specifications

To achieve the best virtual reality immersion for a multi-modal interactive environment like the MUVII IKD Platform the best solutions for each one of the three modalities involved in MUVII (visual, haptic and sound) were integrated. MUVII IKD demonstrates new interaction paradigms in a novel integration of these three interaction modalities: 3D-vision, 3D-audio and haptic (force and tactile) feedback. Innovations of IKD include:

- The multimodality of haptics, 3D-audio and 3D-graphics, to provide an integrated, natural “look and feel” immersion environment for edutainment purposes.
- Integration of two haptic feedback devices (see Figure 1) that support tactile & 3DOF force feedback, thus providing multi-user ability (either teacher-pupil or pupil-pupil) to enhance the teaching procedure and the collaboration among pupils.
- Motion capture / tracking for hand and head of two users.
- Sophisticated 3D-sound: use of open headphones, head-tracking and real-time reproduction of individual 3D sound for each user.
- Innovative Haptic Interaction Metaphors, like visual-haptic and audio-haptic (see next section).
- Rapid application development support, through the customized Virtools authoring environment, the MUVII IKD library of predefined generic objects & behaviours and the MUVII IKD audio authoring toolkit.
- Innovative Demonstration Haptic Applications: They introduce several innovative features and their primary purpose is to demonstrate the capabilities of the H3DI and to build on its functionality.

The really hard but technically challenging part in IKD is to keep the latency time between visual, haptic, tactile and audio feedback as small as possible in order to achieve a great degree of realism. Very short time latency is also required for the hand tracker that is used for the accurate positioning of the real human hand and the real-time rendering of the virtual hand inside the 3D world of the application. The problem is getting harder, if you consider that these subsystems of the IKD platform are implemented by different pieces of software which they are being executed in different computers and in some cases under different operating systems all connected to form a single system.



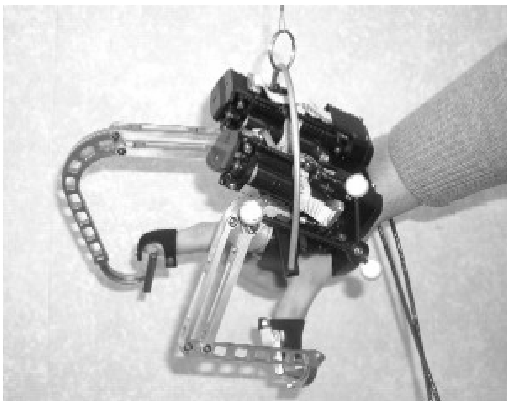


Figure 1: IKD H3DI concept and realization respectively (Courtesy of CEA [1])

5.2.1 Innovative Haptic Interaction Metaphors

To enhance the haptic experience of IKD applications, special visual, audio and haptic interaction metaphors have been specified in order to give emphasis on events that give haptic and tactile feedback to the users. These metaphors include Avatars, Haptic, Visual and Audio metaphors [4, 5]. Moreover, we provided specifications on enhancing haptic metaphors through "real-world" and "non-real-world" audio cues and sound effects, with emphasis on near real-time performance, without loss of user's perception of immersion in the virtual world.

These metaphors help the users to better immerse in the virtual world and perceive the concepts of the Educational Applications. Moreover, it is possible to turn on/off these metaphors so that we can observe the user's reactions and verify the metaphors' effectiveness

6. IKD Applications

Many different applications were proposed and were exhaustibly discussed and evaluated so that finally two applications were selected and implemented for the IKD [6, 9]: (A) *Newtonian Physics, Trajectories and the Solar System*, and (B) *Virtual Model Assembly – Gears* (each one with learning mode, recapitulation mode and edutainment mode).

From the educational point of view, the applications were based on the **constructivist** theory, according to which students are responsible for their own learning. Meaningful learning demands that pupils construct their own knowledge. Some emphasis was also paid in self-directed learning techniques, in that students are left free to decide which part of the knowledge offered interests them most and how much time they spent on it.

As supported by the constructivist learning approach, it is much more fruitful for the students to consciously choose to investigate something (e.g. properties of an object) as opposed to passively watch a science video.

Computer aided learning and virtual reality environments allow students to learn by following his/her own pace, or even according to his/her interest. In MUVII IKD applications, in "active manipulation" mode, the student can manipulate objects after some conscious decisions to do so. Thus, users interact with the objects they choose in the way they choose, and feel the feedback from their actions. This stimulates their interest, and increases their attention. We have reasons to believe that the knowledge remaining to the student after such a learning activity is higher than what is left after teaching the same subject using traditional methods of teaching, where the student passively hears the teacher teach. The control on the objects that the software gives to the user, is recognised as a very important and interesting feature [10].

Within the application of *Newtonian Physics and the solar system*, the user interactively (and virtually) navigates through the solar system, while collecting information about anything that interests him/her. Various elements that our solar system consists of, such as the planets, the satellites, the comets and the asteroids offer tactile, auditory and written information about themselves. The user experiences the effect of the forces when accelerating objects (e.g. tries to throw them off their course) as well as the strength of the gravitational forces applied to objects at different distances from the sun or from a certain planet. Obviously, for the purpose of such an interaction the user is endowed with "super-powers". With the use of haptics the pupils are able to experience, feel and gradually learn the way the laws of simple mechanics are applied at the scale of our solar system. Figure 2 shows a screenshot of the application.

Figure 2: Feeling the gravity (Planet: Hermes Diameter: 4.878 km)

Figure 3: Assembling a windmill

Regarding the *Virtual Model Assembly - Gears*, the users are offered a lesson in the history of cogs, gears and their applications through the ages. They can also try to assemble some selected applications by combining gears. The users experience the effect of forces like weight, friction, motion, rotation etc. This application can be used to enhance students' understanding of phenomena like the transmission of motion from one part of a machine to another. Figure 3 shows a screenshot of the application.

7. IKD Experimental Validation

IKD H3DI, software infrastructure and applications were tested, against functional and performance issues, in a real-time educational setup situation, during a three-month continuous operation. Moreover, IKD was demonstrated in Laval Virtual 2004 (see Figure 4) exhibition event.

Students responded quite well to the use of this haptic prototype. Students were also pleased and seemed to be amused by their experience. They would wish to repeat their experience and to see the haptic device extend its abilities as well as to see it used in other applications too (more varied applications). For more information see [7].

Figure 4: Laval Virtual demonstration, a young user

8. Conclusions

The multi-sensory environment of a haptic device can offer great improvements to the existing teaching methods, by offering tools of enhanced quality suitable for deeper understanding of the entities taught. Students seem to have adjusted well to the new system and to have liked the experience of using it. Currently there are no other applications with capabilities similar to the ones specified in MUVII project, incorporating characteristics like multi-user collaboration among pupils and teachers, efficient 3D-sound sub-system, targeting children of varied school age, efficient haptic interaction metaphors etc.

This paper outlines some important requirements and specifications for haptic devices, especially for applications that will be used in education. The specifications presented should prove useful as a guide for those that aim to develop haptic interfaces as well as application software for education. On the other hand, the present paper will also help potential users (teachers, pupils) to become better acquainted with the idea of using haptic interfaces in education, to understand the power (and the limitations) of haptically-enhanced virtual reality educational systems, and to start generating some useful feedback in terms of their potential implementation in everyday school practice.

References

[1] Commisariat a l'energie atomique ,CEA www.drt.cea.fr/fr/prog/list/list_syst_int.htm

[2] Ioannidis G. S. and Garyfallidou D. M., Education using information and communication technology (ICT), and ICT education: categories methods and trends, In: Auer M. and Auer U. (Eds.) Proc. ICL2001 workshop: "Interactive Computer aided Learning, Experiences and visions", Villach, Austria, Kassel University Press, (2001) ISBN 3-933146-67-4

[3] MUVII Deliverable D1: MUVII ITD and IKD Functional Specifications

[4] MUVII Deliverable D14: Supporting Software Infrastructure sub-systems specifications document

[5] MUVII Deliverable D16: Interactive Kiosk Demonstrator Supporting Hardware / Software Infrastructure modules

[6] MUVII Deliverable D22: Definition and Specifications of the Interactive Kiosk Demonstrator Applications

[7] MUVII Deliverable D24: IKD Applications Evaluation Report

[8] MUVII - Multi User Virtual Interactive Interface (IST Project): Web Site http://muvii.hpclab.ceid.upatras.gr

[9] Pantelios M., Tsiknas L, Christodoulou S. and Papatheodorou T. "Haptics technology in Educational Applications, a Case Study". Journal of Digital Information Management 2004; 2(4): pp. 171-179.

[10] The University Of North Carolina At Chapel Hill – Department Of Computer Science – "Nanoscale Science Education" Web Site: http://www.cs.unc.edu/Research/nano/ed/haptic.html