Empty Museum. An Immersive, Walkable VR Framework for Multiuser Interaction and Telepresence.

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ABSTRACT
This paper describes a new system for experimentation with three-dimensional, multiuser, virtual reality (VR) environments, based on the creation of an immersive and walkable space we have named Empty Museum. We have worked on the design of the hardware and controlling software for this immersive space, and also on the creation of an application that allows the users to visualize any type of multimedia content in this VR hall, enabling us to create various animated and interactive worlds. These experimental worlds have served, on one hand, to analyze the response of the users to new forms of interaction in a virtual, walkable space, and on the other, to discern new forms of creating contents that can derive from the use of real space as part of the actual interface.

Categories and Subject Descriptors
I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism – *Virtual Reality*; H.5.1; [**Information Interfaces and Presentation**]: Multimedia Information Systems – *Artificial, augmented and virtual realities*.

General Terms
Design, Experimentation, Human Factors, Theory.

Keywords
Multiuser Virtual Worlds, Wireless, Wearable Computing, Immersive Environments, Telepresence.

1. INTRODUCTION
The natural way a person experiences space, i.e. observing while moving in any direction, made it necessary for simulations to use hardly believable metaphors in VR environments [1]. Through a joystick, mouse or other similar type of direction controlling interface, the user is expected to imagine he or she is moving around a virtual setting in a car or by means of other external forms of propulsion.

The necessary use of the imagination to perceive the metaphor of the vehicle as something real takes away naturalness and, consequently, much of the sense of presence to the experience of the exploration. When moving through a space in the real world, the sense of movement a person experiences is not only the motion in itself, but also the kinaesthetic sensation of perceiving his or her own body in movement. The interpretation of our own movement helps us understand the scale of what surrounds us.

The fact that the user actually walks around the VR setting increases the sense of presence of the experience because he or she moves naturally through a real space, without the aid of artificial devices to simulate the movement. This user does not need to practise in order to gain skill in moving around and the sense of motion is real. The absence of wires is also an important factor to facilitate free movement around the virtual/real space.

This paper describes the architecture and design issues we worked on to implement a wireless, multiuser, networked VR system that allow the users to view and interact with multimedia contents, while walking around three-dimensional environments. This system is equipped with high-resolution graphics and is compliant with authoring tools and a data format for the creation of the multimedia contents.

There are already several wireless systems, i.e. MARS [3][4], Archeoguide [2], that allow the user to walk freely without connection to a workstation, while displaying the 3D contents. But they are mainly applied to outdoor Augmented Reality environments. Our work was instead focused on the application of a wireless system to improve the sense of presence in VR environments and on multiuser and telepresence features.

The idea is to use real space as one of the elements in the motion interface and as part of the actual virtual space. This facilitates experimentation with synthetic architectonic type spaces. The contribution of our work is based on the use of a new form of contents, where the experience of the visit goes further than simple contemplation. Although there is still much to do, we have started to study the parameters associated to the perception of

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one's own movement and worked on new forms of interaction with the virtual contents and other users, based on the location of the observers.

2. SYSTEM DESIGN

The system here described was planned as an extension to HMD based systems we had previously developed for different purposes. During the handling of these systems, two significant attitudes were repeatedly observed in the users.

In the first place, there was a tendency of starting to walk with the HMD on, while observing the environments. However, movement was limited by the short cable that connected the user to the station that generated the VR images.

Secondly, we noticed the difficulty of the users to learn to skillfully handle "artificial" systems that simulate movement (i.e. mouse-based) even when very elementary. Certain movements were very complicated; for example, stepping back two paces, ducking, turning around, moving sidewards in a circle or just varying the speed. The simple fact of being able to look in one direction while moving in another was confusing. The alternative of not regarding this possibility, so movement could only take place in the direction looked at, though less confusing, set such limitations to freedom of movement that made the system less natural and quite awkward.

With the objective of avoiding these limitations, we decided to work on the hardware of a wireless VR multiuser system. It was also desirable for the devices carried by the user to be comfortable, light-weighted and manageable. As HMD we chose Sony's Glasstron, because it is much lighter than other HMD while offering a good image quality. The main disadvantage is its reduced field of view.

The display information is sent to the HMD from a portable computer the user carries in a backpack. The portable computer integrates an nVidia GeForce chip that provides quite powerful graphic performance.

The tracking system needs 6 DOF to detect the position and orientation of the users at all times. The technology commercially available at the beginning of the project led us to use the Intersense InertiaCube2 as orientation tracker and IS-600 as position tracking system. The latter is attached to a workstation that communicates with the users' laptops through a wireless network. With this tracking system, a millimetric resolution for the position can be reached, not possible with other wireless systems (as those based on GPS).

This hardware configuration allowed the system to be wireless, while keeping the user as light and comfortable as possible. The overall design of the system is depicted in figure 1.

The system's software architecture is composed of two applications, corresponding to the fixed-mobile units division shown in figure 1: a controlling application that is run on the workstation that manages the wireless tracking system (*base*), and a visualization application that is run on the laptop carried by the user (*satellite*).

The base application monitors the connections of the satellites present in the system and allows the operator to view the condition of these satellites, disconnect them, calibrate their tracking devices, assign virtual worlds to them, etc.

The satellite application continuously receives data of its position from the base through the wireless network and of its orientation from the InertiaCube2. From this data, it generates the images and sounds the user should perceive in each instant, corresponding to the position of his or her head. It also processes the interaction with other users and elements in the virtual world.

Communication between base and satellites are managed by a custom-made highly efficient protocol using TCP and UDP.

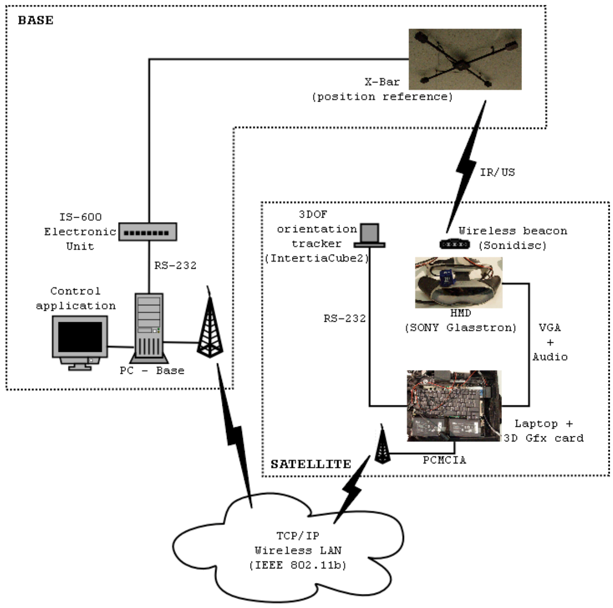

Figure 1. Diagram of the system blocks.

For the construction of the virtual worlds we used the VRML 2.0 format, for its versatility. Apart from defining the scenegraph with geometry, materials, textures, lighting, etc., it enables the incorporation of spatialized 3D sound, animations, video and behaviours controlled by sensors of proximity, touch, visibility, etc. In general, it provides a great potential for interaction and combination of multimedia elements.

This system also allows multiple users to visit the same or different virtual worlds at the same time, in the same real/virtual space. Since this is a VR HMD based system, the user can only see what is displayed by the system. So it is necessary to show the location of the other users to avoid collision and allow for interaction.

The users can see each other as an avatar, a 3D model (including all the VRML2 dynamic multimedia and interaction posibilities) which moves associated to the corresponding user's position. Also the avatar can be composed of different blocks which move/rotate and behave differently. We usually manage the head and the body of the avatar independently from each other, so the head can tilt in every direction, but the body only changes its heading. Also, we attach the feet of the avatar to the ground level to avoid it flying or sinking through the floor.

This avatar management allows interaction between users and with the elements of the world. It is also possible to interact with users that are in a different physical space (logically mapped to the same virtual space) using a similar facility in distant geographical locations, i.e. for applications involving telepresence.

The empty museum is an environment designed to show virtual contents. Thus, avatars must be designed, if possible to be part of the experience of visiting those virtual worlds. The system can assign the behaviour of the avatar to any model chosen by the designer of the scenery, so every virtual set can have its own avatars with an appearance according with the content of the world being shown.

3. HYBRID SPACE

The users of the Empty Museum experience space in a double manner. On one hand, the space as what he or she knows as such, with known dimensions, a real area the person is conscious of being in (figure 2). On the other hand, in that same space there are virtual objects. Not only does the user see and accept these as inserted in the space, but is also able to identify their size and position in relation to him or herself through parallax when moving around, nearer and further from them. The virtual space (not the objects inserted in it) is, therefore, as genuine as the real space, inasmuch as it has its same properties. As a user, you see yourself immerse in a hybrid space in which it is easy to move around and observe the objects. The real space thus becomes part of the interface.

As a multiuser system, there can be various users at the same time in the same hybrid space. However, the system also enables various users to share the same virtual space without being in the same physical space or be in the same physical space, but in different virtual worlds.

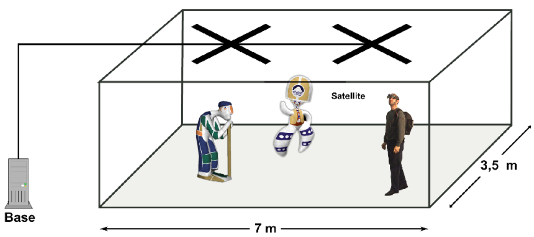

Figure 2. Empty Museum for three users. Every user sees the others as avatars.

The dimensions of virtual and real spaces can, however, be different in size, and this difference can be manipulated by introducing a scale factor in the movement. This way, we can fit a large virtual space into a much smaller dimensioned physical space. The user moves around, taking steps that can cover various metres of the virtual space, giving a sensation of very fast movement that is surprisingly not unpleasant. On the contrary, the testers described it as natural and flowing. This allows us to display great virtual spaces in a small room. When experimenting with an example of architectonic space, we displayed the inside of a more than 30m long building in an Empty Museum of only 8m long.

For worlds that are much larger or complex, we have also experimented with the "teleport chamber", a metaphor well accepted by the users. This metaphor consists on placing a special element in the virtual world, such a bright cylinder, that, once the user steps into it, switch to another virtual world, behaving as a transfer system that will take him or her to other locations in the same, or in another different virtual place. Figure 3 illustrates the application of this concept in "The Art Gallery", one of the contents made to test the system.

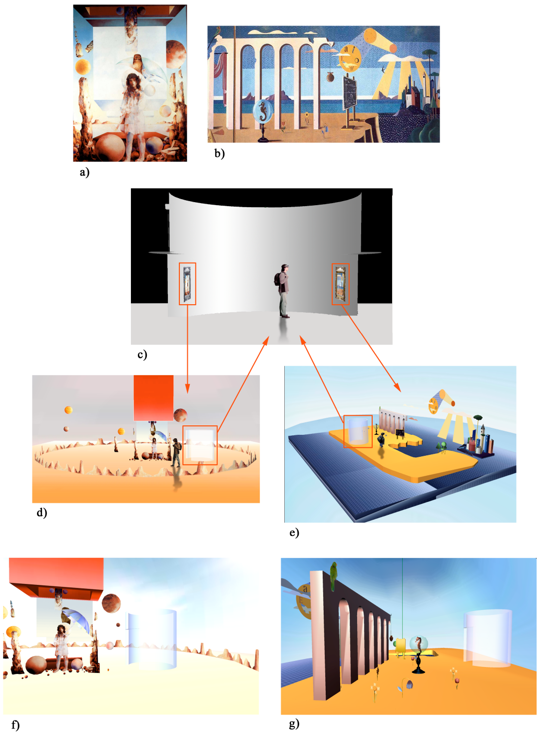

Figure 3. The Art Gallery: a) and b) Original paintings c) Art gallery with the paintings exhibited. (The arrows indicate the location of the teleport elements and their destination). d), e) The user inside a 3D version of painting. f), g) User's view

4. PERCEPTION IN THE WALKABLE VIRTUAL SPACE

We can define reality as the cognitive interpretation of what we perceive, that is, the interpretation of the information an individual receives from the surrounding environment through his or her senses. Therefore, to make a person feel immerse in a reality that is different from the real, physical world, you must fill that person's senses with information of the virtual world you want to introduce him or her into. If you only stimulate some of the senses in this way, the user will be receiving information from two different environments simultaneously, allowing him or her to distinguish which one is real and which virtual. The more senses you artificially stimulate, the more the user becomes immersed in the virtual world.

Real movement inside the room adds strongly to the sense of realism of the virtual space because, when you move, your own kinaesthetic and vestibular systems provide you with information that corresponds to what you are seeing. To this we add the traditional stimulation of visual and auditory senses.

The degree of immersion into the VR can be observed from the outside, through the expressions and gestures of the users who are exploring the worlds. It is frequent to see them moving to avoid obstacles, even though these are virtual and do not present any physical adversity or obstruction, i.e. the pillars of a virtual building. Brisk movements can also be observed when encountering animations of objects that are potentially dangerous, i.e. to avoid collision with a virtual toy car that is chasing around the floor, or a startled jump back in surprise (figure 4).

Figure 4. Interaction with the virtual objects.

Sound plays an important role, because the spatialization of the different noises generates a sound landscape inside the room, which changes according to the user's position. This way, the user can locate objects of interest through their sounds or produce emotions of anxiety or alarm when hearing threatening noises. In this sense, we must point out the enormous potentiality of the Empty Museum as an audio-based spatial training system.

5. CONCLUSIONS

In this paper we have described how we built a wireless, multi-user networked VR system using "off the shelf" elements. This system solves great part of the constraints found in the conventional VR systems in which the user is connected to a computer through a cable. We have also outlined the characteristics of a new paradigm for three-dimensional navigation through virtual worlds and started to study this paradigm's potentiality.

The fact of being able to move and interact as in the real world allows the users to explore the space immediately, without technical skills and without receiving previous instruction on how the system works. Moreover, feedback through the kinaesthetic and vestibular senses introduces the user into the world with a level of immersion that is otherwise difficult to achieve.

Certain restrictions of previous paradigms of movement in three-dimensional environments (clumsiness, slowness, impossibility of certain movements, etc.) disappear, offering the user good movement abilities and a capacity of reaction superior to other conventional devices or metaphors for simulating movement. The possible size restriction owing to real space dimensions is reduced, if not eliminated, with the possibility of scaling the movement and the "teleport chamber" metaphor as a means of transition between different worlds or between areas in one same world.

The Empty Museum allows several users to share physical and/or virtual space. There can be users in the same physical space exploring different virtual worlds mapped to that space as well as users in different physical spaces can be exploring the same virtual world and interacting each other.

The described system not only improves the way of exploring conventional 3D worlds, but is also a new way of focussing the design of virtual spaces and VR applications. It opens a new field of research in spatial perception and interaction through the user's own movement, position or viewpoint.

6. FUTURE LINES OF RESEARCH

The most immediate extension of the developed prototype is to facilitate the user possibilities of interacting with the environment, other than through own location or movement, as long as it is using natural forms that conserve the system's philosophy and does not reduce the sense of immersion. Among the more interesting ways of interaction we can mention interfaces using gestures, conversational interfaces or the use of the line of vision as pointer for selecting elements in the virtual world. Also hand tracking will be added to give a direct and intuitive way of interaction and selection of points in space.

One of the most interesting applications of the Empty Museum on which we are actually working is the so-called *Art V-Space*. Inside a 3D world, users can create works of art from nothingness, with the simple gestures of their hands, using them as different instruments or tools. Apart from the basically 2D arts (sketching and painting), the system adapts excellently to others, i.e. architecture, sculpture or music, offering a promising potentiality for the creation of new means and contents.

The interaction with other users for the exchange of information, for the joint creation inside the Art V-Space (for example, creating music between various artists), for co-operative work or simply for entertaining applications, offers new possibilities in this environment. Also, due to the Empty Museum's networked modular architecture, users can share the same virtual space without sharing the same real space, enabling a form of telepresence and completely immersive, three-dimensional interaction between users located in distant geographical locations.

7. REFERENCES

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