Human-Scale Haptic Interaction Using the SPIDAR

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Abstract

This paper describes the human-scale virtual reality (VR) platform with force feedback developed at the LISA laboratory in Angers (France) in collaboration with Professor Makoto SATO. A human-scale SPIDAR system provides force feedback to user's hands using 8 motors placed on the corners of a cubic frame (2m x 2.5m) surrounding the user. Stereoscopic images are displayed on a rear-projected large screen and are viewed using polarized glasses. We present different VR applications that benefit from SPIDAR properties such as human-scale workspace, lightness, low intrusion, and safeness. These applications include virtual prototyping, collaborative work, human factors, virtual fashion design and education.

1. Introduction

Most of haptic interfaces used in virtual reality (VR) applications are intrusive, expensive and have a limited workspace. Moreover, these interfaces involve only one hand [Sri95, Ric96, BIJ*00, RC99]. Attempts to add force feedback to large-scale virtual environments have been proposed such as one from the UNC [BOYBK90, BGAM04] and work from the University of Utah [GH98]. Both approaches are quite similar, they employ a one-screen workbench and propose installing an arm-type force feedback device. More recently, a floor-grounded haptic device for aircraft engine maintainability (LHIfAM) has been developed [BGAM04]. This device is used to track hand movement and provides force feedback within a large workspace. Lécuyer et al. experimented with a portable haptic device, which could follow large-scale user's displacements in front of a two-screen workbench [LMB*02]. This interface called the Wearable Haptic Handle (W2H), developed by CEA, is made of two parts. The upper part is a small platform, which moves in 6 Degrees of Freedom (DOF) actuated by a wire driven based Stewart platform. The user feels the displacements of the platform through his/her hand while interacting with the virtual environment. The W2H has a wide workspace, which can match the large visualization space of the workbench and is small enough not to obstruct the user's field of view. Since 1989, other kinds of haptic interfaces have been developed by Professor Makoto SATO in Yokohama (Japan). For more than ten years, these interfaces called SPIDAR (Space Interface Devices for Artificial Reality) have been used for education, entertainment and industrial applications [IS94, WIKS01, KHKS02, TCH*03, PTC*04]. These alternative interfaces are composed of actuators providing a force through a set of strings adequately linked together or to a manipulation tool. Such interfaces have very interesting properties i.e. fixed-base, large workspace, and low intrusion. Additional properties like lightness, safeness, or low cost are also satisfied. In this paper, we present a human-scale VR platform with force feedback developed at the LISA laboratory in Angers (France) in collaboration with Professor Makoto SATO. This platform is based on a human-scale SPIDAR. In addition, VR applications that benefit from SPIDAR properties such as human-scale workspace, lightness, low intrusion, and safeness are described. These applications include virtual prototyping, collaborative work, human factors, virtual fashion design, and education. The remainder of the paper is the following. Section 2 describes our VE called VIREPSE (Virtual Reality Platform for Simulation and Experimentation). In section 3, we present some SPIDAR based VR applications that have been developed at the LISA laboratory. The paper ends by a conclusion and describes future work.

2. Description of VIREPSE

2.1. System workspace

VIREPSE workspace could be divided into two spaces: (i) the reachable space that gathers every point users can reach with hands, and (ii) the haptic space that gathers every point where the system can produce a force in any direction. The global workspace is defined by the intersection of these two spaces. The workspace of the reachable space matches the cubic frame of the SPIDAR illustrated in Fig. 1. Haptic spaces are illustrated in Fig. 2a (right hand) and Fig. 2b (left hand). Motors positioned at corners 1-3-6-8 are used to display forces on the user's right hand while motors positioned at corners 2-4-5-7 are used to display forces on the user's right left. Note that the haptic space is described by a tetrahedron.

$$
\begin{cases}
{l_0}^2 = (x+a)^2 + (y+a)^2 + (z+a)^2 \\
{l_1}^2 = (x-a)^2 + (y-a)^2 + (z+a)^2 \\
{l_2}^2 = (x-a)^2 + (y+a)^2 + (z-a)^2 \\
{l_3}^2 = (x+a)^2 + (y-a)^2 + (z-a)^2
\end{cases}
\tag{1}
$$

2.2. Position measurement

Let the coordinates of the right hand attachment position be P(x,y,z), which represent both the hand position, and, l_i, the length of the i^{th} string ($i = 0,1,2,3$). Let the four actuators (motor, pulley, encoder) be on four non-adjacent vertices of the SPIDAR cubic frame (motors 2-4-5-7). Then P(x,y,z) must satisfy equations (1).

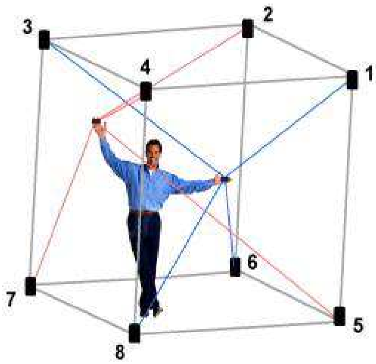
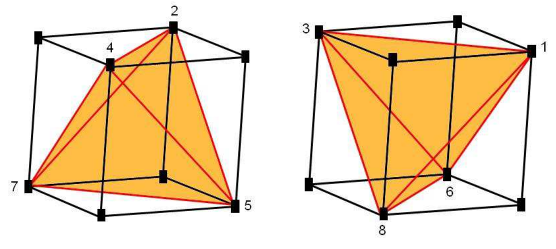


Figure 1: *Illustration of the SPIDAR cubic frame.*

Let the length of the cube be 2a (Fig. 3). After some mathematical manipulations, we can obtain the position of the hand attachment (Eq. 2) in function of the lengths l_i:

$$
\begin{cases}
x = \frac{({l_0}^2 - {l_1}^2 - {l_2}^2 + {l_3}^2)}{8a} \\
y = \frac{({l_0}^2 - {l_1}^2 + {l_2}^2 - {l_3}^2)}{8a} \\
z = \frac{({l_0}^2 + {l_1}^2 - {l_2}^2 - {l_3}^2)}{8a}
\end{cases}
\tag{2}
$$



(a) (b)

Figure 2: *Illustration of the SPIDAR haptic workspaces : right hand (a), left hand (b). The rear-projected screen is placed at the back of the frame (motors 2-3-6-7).*

2.3. Force control

The system uses the resultant force of tension from strings to provide force display. The hand attachment is suspended by four strings, giving certain tensions to each of them by means of motors. The resultant force occurs at the position of the hand attachment, where it is transmitted to and felt by the operator's hand. Let the resultant force be $\overrightarrow{f}$ and the unit vector of the tension be $\overrightarrow{u}_i$ ($i = 0,1,2,3$), the resultant force is given by equation 3, where k_i represents the tension value of each string. By controlling all the k_i, a resultant force in any direction can be composed.

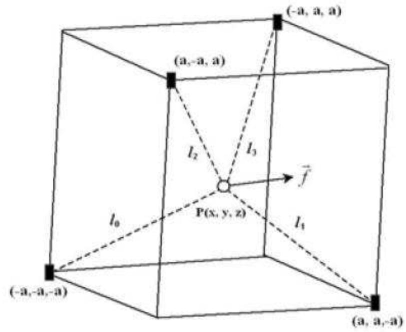


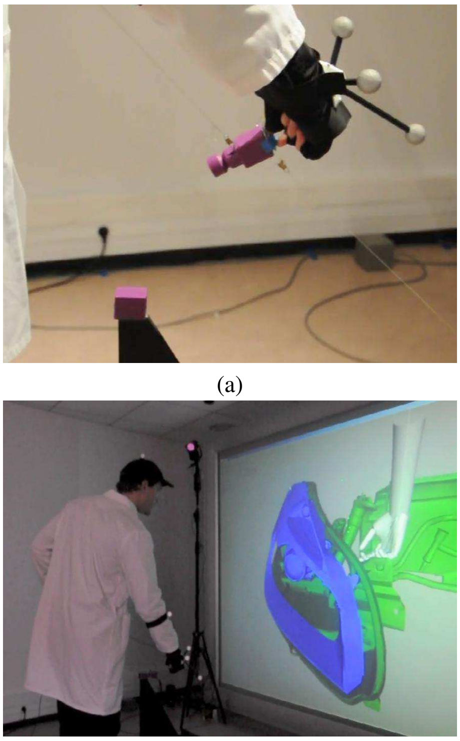
Figure 3: *Position measurement and resultant force within the cubic framework of the SPIDAR.*

$$
\overrightarrow{f} = \sum_{i=0}^{3} k_i \overrightarrow{u_i}, k_i > 0 \tag{3}
$$

3. SPIDAR based VR applications

3.1. Virtual prototyping

Nowadays, car manufacturers use computer aided design (CAD) to reduce costs, time-to-market and to increase the overall quality of products. In this context, physical mock-ups are replaced by virtual mock-ups for accessibility testing, assembly simulations, operation training and so on. In such simulations, sensory feedback must be provided in an intuitive and comprehensible way in a large-scale setup. In situation involving complex virtual mock-ups, it may be useful to provide the operator with force feedback or some sorts of guidance that facilitates task accomplishment.

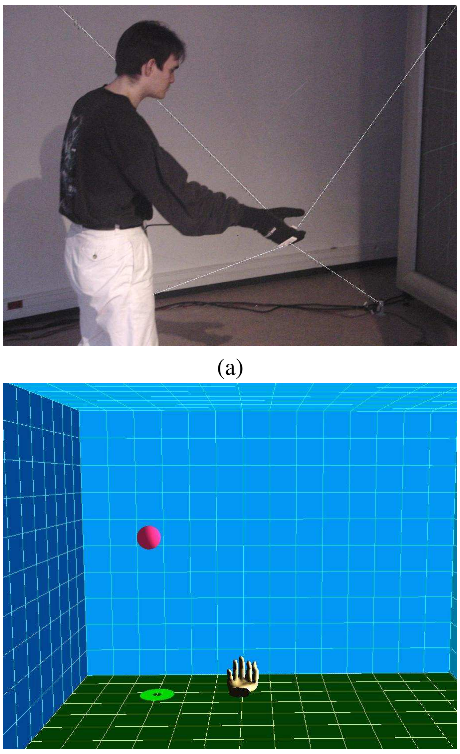


(a)

(b)

Figure 4: *Human-scale interaction with virtual mockup : a prop is attached to the SPIDAR strings (a), operator performing a lamp extraction task (b).*

In 2004, we started to investigated the benefits that haptic and multimodal feedback can provide in human-scale interaction with virtual mock-ups using the SPIDAR [IJRS05, RCI*06, CR08, CRF09]. More recently, we have carried out a user study that consisted on two experiments where participants had to perform an accessibility task. In the first experiment, the effect of haptic and visual cues to render collisions was investigated. In the second experiment, we investigated the effect of haptic guidance on operator performance. In both experiments, the 3DOF human-scale SPIDAR (right hand) was used to provide the operator with haptic stimuli. In addition, a prop was used to provide grasp feedback (Fig. 4a). A mocap system was used to track user's hand and head movements.In addition, a 5DT data-glove was used to measure fingers flexion (Fig. 4b). The results were analyzed in terms of task completion time and collision avoidance. We showed that haptic stimuli proved to be more efficient than visual ones. In addition, haptic guidance helped the operators to correct trajectories and hence improve their performance [CMUR09].



(a)

(b)

Figure 5: *Subject catching an approaching ball using the human-scale SPIDAR (a), snapshot of the simulation : the red disc provides a visual predictive cue for catching (b).*

3.2. Ball catching with haptic cues

VR offers a very interesting tool for human factors studies. For example, catching experiments have been done for many years to investigate eye-hand coordination in humans. However, although haptic cues plays a crucial role in (real) ball catching, this modality was neglected and experiments focussed on visual aspect only.

Five years ago, we carried out ball catching experiments in our human-scale VR platform [Ing06]. The SPIDAR was used to track the subject's hand position and to provide haptic cues that simulate the impact of the approaching ball on the user's hand (Fig. 5a). The aim of the experiments was to evaluate the effect of dynamic virtual cues (Fig. 5b) on human performance in catching task. Users were instructed to catch randomized approaching ball with their right hand. Results validated the efficiency of the proposed virtual cues. Interestingly, we observed that haptic cues provided by the SPIDAR had a significant effect on users performance. In addition, the subjects found the simulation much more realistic when haptic cues were present. A work is underway to develop an human-scale ball game with a virtual robot [HIR07]. The robot catches approaching balls thrown by a human using the SPIDAR. The next step will be to teach the robot so that he gives back the balls to the human. Thus, with human-scale haptic cues, the human-robot cooperation will be more engaging and realistic.

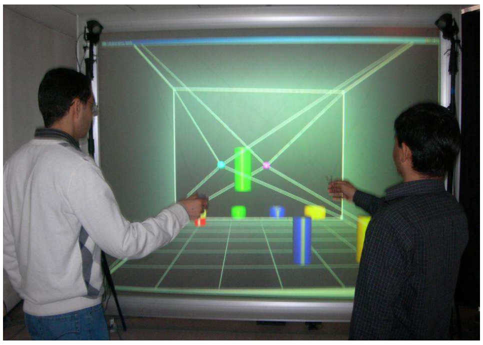


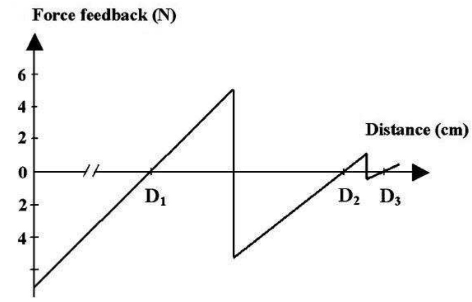
Figure 6: *Human-scale cooperative peg-in-hole task using the SPIDAR.*

4. Haptic guides and collaborative work

In this section, we describe some experiments carried out within the framework of the VARSCW (Virtual and Augmented Reality for Supported Collaborative Work) project. This project involving the LISA laboratory (Angers) and the IBISC Laboratory (University of EVRY) aims to develop and evaluate haptic-based interaction techniques and haptic guides in Collaborative Virtual Environments (CVEs). Collaborative tasks involve different users operating from the same (local) or distributed VR platforms. In the latter case, the immersive VR platform of IBICS will be used. This platform called EVR@ provides haptic feedback using a human-scale SPIDAR-G [KHKS02]. In preliminary work, we have proposed and evaluated the effect of haptic guides on human performance in mono-user experiment using a large-scale SPIDAR-G [UOR07, UOO*09, UORM09].

Then we carried out some experiments involving a cooperative peg-in-hole task performed locally on the VIREPSE platform (Fig. 6). The users have to cooperatively manipulate virtual pegs using our human-scale SPIDAR. A stringed-based robot has been modeled in the simulation. Different haptic guides have been designed and evaluated. Results have revealed that haptic guides had a significant effect on task completion time and error rates. In addition, we found that these haptic guides not only increased users performance but also enhanced the sense of co-presence and awareness [URN*09].

(a)



(b)

Figure 7: *Illustration of the "Haptic Atomic" application : a student operates the electron and feels the electon attraction force using the SPIDAR(a), force magnitude vs. proton neutron distance (b).*

5. Education in physics

In the context of our research concerning VR for education, we developed an application called "Haptic Atomic". This application allows to experience the abstract concept of the Bohr atomic model and the quantification of the orbits level energy. Human-scale haptic immersion is used to support a better understanding of the Bohr atomic model in which the electron is restricted to discrete orbital levels and some external quantified quantity of energy is required to make it jump from the given energy level to a higher one (Fig. 7a). Fundamental state n=1 up to the n=3 excited energy level of the Bohr model can be explored. Moreover, corresponding atomic orbitals (hydrogenic solutions of the Schrödinger equation) could be visualized. Concentric spheres surrounding the proton (nucleus) represent the different energy levels. This application was developed using C/C++ language and OpenGL. Four different configurations have been developed. These involve the keyboard, the CadMan motion controller, the PHANToM Omni^{TM} and the SPIDAR haptic interface [RTR06,RTRF06]. The last configuration is more immersive since the Bohr atom and atomic orbitals are viewed stereoscopically on the large rear-projected screen. In this configuration, the proton is positioned at the center of the cubic frame of the SPIDAR. The radial force feedback is applied according to the plot illustrated in Fig. 7b (D1 = 20 cm, D2 = 53 cm, D3 =60 cm).

Figure 8: *Using the SPIDAR for fashion design : human-scale haptic interaction with a virtual mannequin.*

6. Virtual fashion design

The ability to manipulate virtual textiles intuitively using dedicated devices has not been much investigated. However, using the sense of touch to interact with computer-simulated clothes would significantly increase the realism and ease the creation process in the context of virtual fashion design. In the context of the HAPTEX Project, a novel haptic interface has being developed, consisting of a hand exoskeleton expressly conceived for the accurate generation of light forces. This device seems to be appropriate for handling and feeling mechanical properties of the fabric itself. However, it is complex, bulky and is not appropriate for human-scale interaction with clothes on virtual mannequins.

Another approach is been developed in our laboratory. This approach, based on the human-scale SPIDAR, enables the user to touch and feel the surface of the virtual clothes (Fig. 8). The mannequin and the clothes mechanical properties are rendered using the PhysX engine (Nvidia). In order to extend the haptic rendering capabilities of the system, a wireless vibro-tactile glove has been developed and integrated to the SPIDAR. Interaction techniques are also been developed in the context of virtual try-on. Force feedback will then be used to control the rotating movement of the mannequin and simulate the friction forces of the fabric on the mannequin's body.

7. Conclusion and perspectives

We described a human-scale VR platform (VIREPSE) with force feedback developed at the LISA laboratory in Angers in collaboration with Professor Makoto SATO. The human-scale SPIDAR system provides force feedback to user's both hands. Stereoscopic images are displayed on a rear-projected large screen and are viewed using polarized glasses. Different VR applications that benefit from SPIDAR properties such as human-scale workspace, lightness, low intrusion, and safeness have been presented. These applications include virtual prototyping, collaborative work, human performance, virtual fashion design and education. Moreover, experimental studies have revealed that haptic feedback provided using the SPIDAR increased users performance in human-scale mono-user and cooperative tasks, enhanced the sense of co-presence and awareness. In the future, new experiments will be carried out in the context of the VarSCW Project that involves our SPIDAR-based VR platform and EVR@, the human-scale VR platform developped at IBISC Laboratory (University of EVRY, France).

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