Art Touch with CREATE haptic interface

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Abstract

A novel approach to the synthesis and the interaction of (with) virtual Environment is presented.
In the following paper, the description of a novel multi-point VE-haptic system is given.
The system has been developed with the intent of interacting with an interactive VE, based on the constructivist approach.
In what follow the main feature of the VE and of the interface are given. A special focus has been given to the design philosophy: several performances optimizations in terms of user interaction and object manipulation, devices joined workspace, isotropy, arms interferences, continuous force, VE and inter-arm positional coherence have been performed during the design.

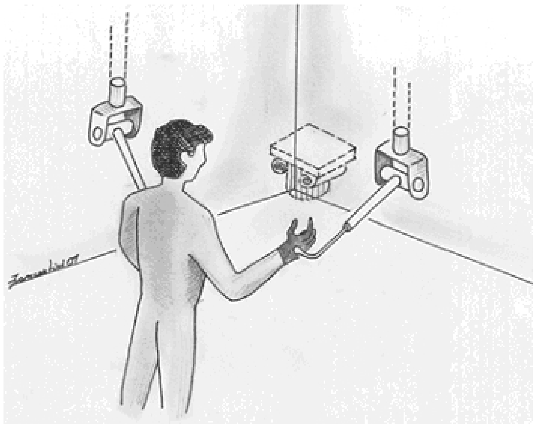

Figure 1: *Sketched concept.*

1 Introduction

Virtual reality (VR) and mixed reality (MR) technologies are now becoming sufficiently developed so that simulations of cultural or architectural sites, or virtual environments (VEs) for design are successful in making users feel truly immersed in the environment, especially when using head-mounted, workbench, cubic or curved screen type displays [1]. Coupled with interactive technologies that allow visitors of the virtual sites to make their own choices or perform actions that trigger responses from the VE, these virtual experiences become significantly richer and more interesting. Up to now, several successful examples of virtual worlds have been developed worldwide for research and design, training, manufacturing, and entertainment. Nonetheless, such environments suffer either from a lack of realism or a low degree of interactivity, due to technological and methodological constraints.

Haptic interfaces have became the primary means of interaction within the virtual environment. Several experiments during the past 15 years have shown how these interfaces can strongly improve the user performances during the interaction with virtual objects [11][14][17].
The capability of reflecting digitally programmed forces, representing the contact interaction with the object, physical properties, and/or several digital force effect, highly increments the user performances and his capabilities to understand what is happening within the virtual environment [5][6].
The main limitation to the VE interaction based on haptic interfaces is mainly related to the mechanical limits of the interface in itself [16]. While the graphical feedback is now able to represent high quality and large-scale immersive environments, the haptic interfaces (wearable or with grounded base) still behave some limitation in the force/position workspace [18]. Therefore in order to provide a good quality to the force feedback, for these immersive environments, the design of novel interfaces is required.

2 The CREATE project

The global scope of CREATE[1] (Constructivist Mixed Reality for Design, Education, and Cultural Heritage) is to develop a mixed reality framework that will enable highly interactive real-time construction and manipulation of realistic, virtual worlds based on real data sources. This framework will be tested and applied to cultural heritage content in an educational context, as well as to the design and review of architectural/urban planning settings.
The CREATE project:

- Develops design methodologies to determine user requirements, based on a human-centred, "**constructivist**" approach to working and learning, with special attention paid to **evaluation** of the resulting mixed reality experience.

- Adapts, develops, and combines novel content creation, display and audio technologies based on the requirements thus defined, to enable **realism with interactivity**, specifically for immersive VR platforms (single/multiple-screen stereoscopic displays).

- Constructs prototypes for two specific applications, **cultural heritage** and **architecture/urban planning**, that incorporate more natural and usable interface approaches and permit assessment of both the methodology and the technology employed.

This project is user-centered and therefore the haptic-interface development should answer to the user requirements as defined to correspond to the working and learning constructivist approach. The interface needs to be intuitive and to correspond to natural interaction. The users of the interface will range from experts in the domain being learnt (not in virtual reality nor haptic) to visitors of the museum[2] including children. It is important therefore that the support structure is scalable and the complete system safe and easy to use. We believe that to provide the user with more natural means to interact with the environment to perform actions such as grabbing literally virtual objects will allow them to get immediately into the process of learning without having to learn how to use the system and the interaction modules. Moreover the use of this haptic interface within immersive virtual environments, combining 3D-display and 3D-sound simulation should allow the user to focus immediately on the tasks assigned.
At the current state of the project, the haptic interface has been fully designed inspired by a previous haptic interface developed for the GRAB[3] project. In the following section will be presented the descriptions of the mechanical subsystem and of the control subsystem that compose the HI. In the next steps of the CREATE EU project, the system will be built, assembled and then evaluated.

3 Haptic rendering

The discovery or exploration of an artwork involves multiple sensorial channels, such as the visual, auditory, haptic, smell, and taste ones. The majority of today's virtual reality simulations use the visual modalities as 3-D stereo displays, and auditory modalities as interactive or 3-D sound. Virtual reality technologies are now becoming sufficiently developed so that simulations of cultural or architectural sites, or virtual environments for design, especially using immersive displays, are successful in making users feel immersed in the environment. Haptic technology also allows for more direct manipulation, which could specifically be relevant to 3D shape conceptualization [7][8].
Haptic feedback groups the modalities of force feedback, tactile feedback, and the proprioceptive feedback [1]. Force feedback integrated in a virtual reality simulation provides data on a virtual object hardness, weight, and inertia. Tactile feedback is used to give the user a feel of the virtual object surface contact geometry, smoothness, slippage, and temperature. Finally, proprioceptive feedback is the sensing of the user's body position, or posture. The haptic rendering consists in touching object, and to feel its mechanical characteristics, sensitivity specific to the bones, muscles, tendons and joints which give information about its static, balance and the displacement of the body in space [3].

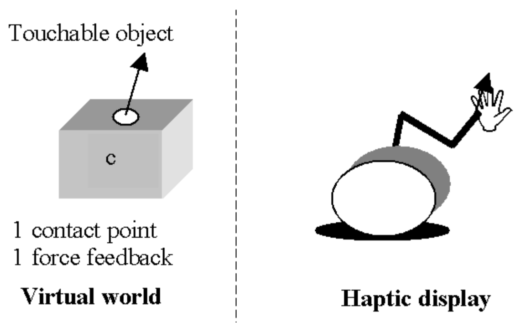

Figure 2: *Desktop touch.*

[1]CREATE is a 3-year RTD project funded by Information Society Technologies (IST) Programme of the European Union (EU). The official contract with the EU was signed under the contract number IST-2001-34231. The project started in March 2002.

[2]In the case of the CREATE project, the museum is in the Foundation of Hellenic World, partner of the European project.

[3]Computer GRAphics access for Blind people through a haptic virtual environment, IST-2000-26151

Force feedback interfaces can be viewed as computer "extensions" that apply physical forces, and torques on the user. The interfaces that are most used today are those that are desktop, are easy to install, clean and safe to the user. For example, the SensAble PHANToM haptic robot is a device that has 6 degrees of freedom and renders a three-dimensional force information, [2]. It can track the position and orientation of the tool within a workspace of 16 cm wide, 13 cm high and 13 cm deep. With such haptic device the haptic rendering is done on virtual touchable object, see Fig. 2, and it provides data on virtual object hardness, weight, and inertia. Each input device has its own strengths and weaknesses, just as each application has its own unique demands. With the wide range of input devices available, one of the problems that confronts the designer is to obtain a match between application and input technology. Part of the problem has to do with recognizing the relevant dimensions along which the application's demands should be characterized. The other is knowing how each technology being considered performs along those dimensions. With this haptic device, the aim is to get a stable interaction with virtual environment in a large workspace and by two contact points. The Haptic Workspace clue and the Force intensity clue enhance the haptic rendering. By using the GRAB haptic device for art and cultural heritage discovery in virtual environment, the haptic rendering is more effective. In the context of CREATE, the haptic device provides two large workspaces, that may be combined for actions using the two hands in cooperation, and also two contact points c1 and c2, see Fig. 3. It allows the design of objects (scaling, modeling) or moving objects by the way of the two hand contact points, or by the grip movement. With such a device, the user can feel more effectively the weight, the global shape and contour following, and it also provides data on virtual object hardness, weight, and inertia.

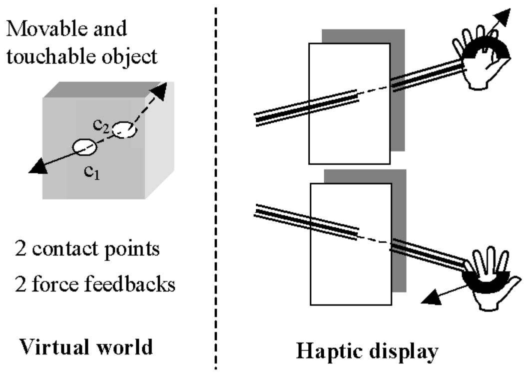

Figure 3: *CREATE touch.*

It appears that the CREATE haptic interface brings more realistic direct manipulation of haptic object for being touchable and movable. This particular feature will benefit in simulating art, cultural or architectural sites.

4 Mechanical subsystem

The typical workplace of the CREATE Haptic Interface will be within a cubic immersive display, as sketched in the original concept drawing and in the preliminary design configuration (see Fig. 1 and 4), even if it can be used also in a desktop like environments. The workspace is located in front of the user that can interacts with the virtual scenarios trough two contact points (the 2 fingertips of the thumb and the index of the same hand or the indexes of both hands).

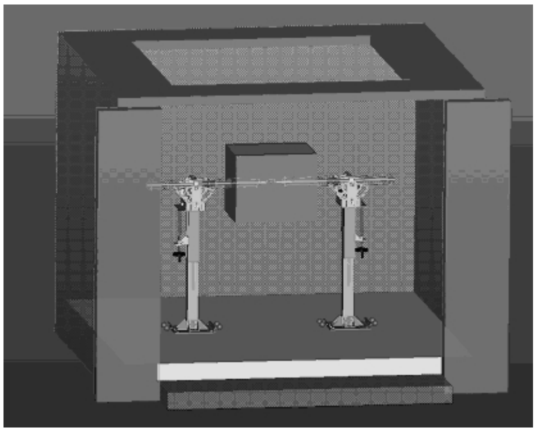

Figure 4: *CAD Model of the layout of the CREATE HI.*

The mechanical sub-system is composed by two identical robotic devices, each having a serial kinematics with a total of 6 Degree of Freedoms (DOFs). For the implementation of the first 3 DOFs, 2 orthogonal rotational pairs followed by a prismatic pair have been selected, while for the last 3 DOFs 3 intersecting rotational pairs have been used to realize a spherical joint (see Fig. 5). The first 3 DOFs are actuated and sensorized to be able to replicate an independent force vector with an arbitrary orientation on the fingertip and track the position of the fingertip within a large 3D workspace. The remaining 3 DOFs are passive and not sensorized because only the evaluation of the absolute position of the fingertip is required and no moments have to be exerted.

This solution allows a very high degree of isotropy of the device w.r.t. other kinematics solutions. A high degree of isotropy is important in order to achieve a uniform use of the actuators in the workspace of the device and to have a uniform reflected inertia.

In order to improve the transparency of use of the

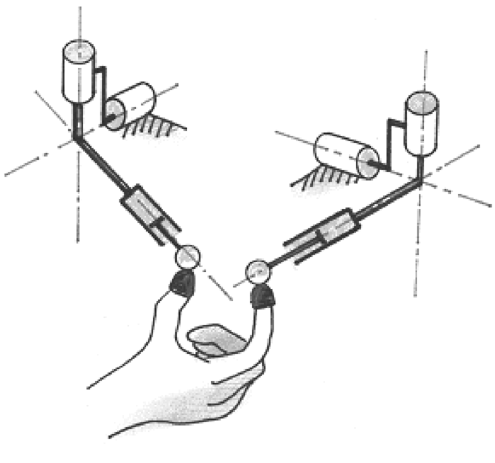

Figure 5: *Kinematics scheme.*

device and the force feedback accuracy, the following technical requirements have to be adopted:

- Low mass of the moving part that means a low perceived inertia;
- High stiffness of the structure;
- Low friction;
- High bandwidth force feedback.

The design guidelines to satisfy such requirements are:

- Localization of the motors on the fixed parts;
- Selection of motors with high torque to mass ratio and high torque to rotor inertia ratio;
- Use of tendon transmissions;
- Use of low reduction ratio geared reducer;
- Use of light materials for the construction of the moving links;
- Low or zero backlash implementation of the joints;
- High resolution sensors.

In our case, all the above guidelines have been implemented, in particular:

- The first 2 actuators have been mounted integral with the fixed link (base) developing a differential cable mechanism capable to increase isotropic performances, while the third actuator has been mounted integral with the second moving link (link2) having its center of gravity very close to the intersection of the yaw and pitch axes of the mechanism that is fixed w.r.t. ground;
- As actuators, brushed DC servomotors have been selected;
- Metallic in tension tendons routed on idle pulleys have been used as means of transmission of forces form the actuators to the joints;
- No geared reducer have been used;
- All the structural parts have been realized in aluminium and carbon fiber.

The modulus of the exertable forces can be modified within the following ranges (for each contact point):

- Peak Force Range: $0 < |F| < FP = 40N$ in the case of forces to be exerted for a limited period of time ($\leq$ 1 min);
- Continuous Force Range: $0 < |F| < FC = 4N$ in the case of forces to be exerted for a long of time ($\geq$ 1 min). This limitation is due to the heat dissipation of the electric motors (actuators of the HI).

The allowable workspace is a parallelepiped, having the base at a variable distance ZWS from the upper surface of the floor. The dimensions of the parallelepiped are:

- HWS = 600 mm;
- DWS = 600 mm;
- WWS = 700 mm.

The stiffness of the structure in the worst case is greater than 5 N/mm.

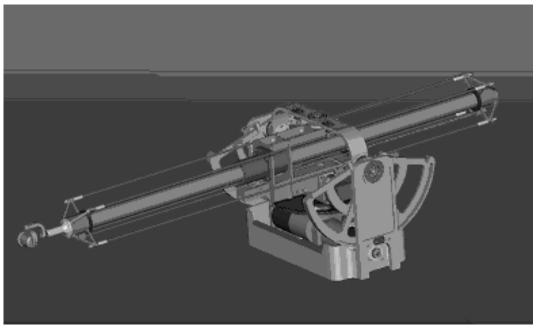

Figure 6: *CAD Model of the robotic device.*

5 Control Features

The main control architecture of the haptic interface is represented in the figure 7.
Low level control software has been implemented in order to provide whole Virtual Reality system the following main functionalities:

- manage the communication with Host VE computer;
- verify, change and store the value for system tunable parameters;
- provide an elementary safety sound feedback which improves the SW development;
- Model dynamic and kinematic of both haptic arm;
- Compensate for non linear effects such as the gravity acceleration on the display and the friction;
- Serve the host VE as a position controller (during the wearing phases) and as force display (when used as haptic display);
- Monitor simulation parameters in order to prevent that SW and simple HW damages can hurt the user;
- Generate the correct HI control motors signal for moving two arms and for activating the force feedback functionality.

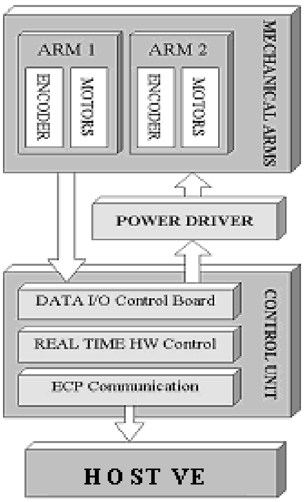

Figure 7: *Control Architecture.*

All feature below have also to be synchronized and monitored in order to allows whole system to correctly execute all tasks requested by the host VE.
Moreover, the control system has to present the following general characteristics:

- the force feedback have to be realistic for allowing an easy recognition of little shape particulars;
- ensure high safety level in all control phases;
- implement the software interface with host VE computer based on easy communication protocol and able to set some system parameters.
- Implement auto calibration features with the arms' relative position and the VE objects.

6 Calibration Features

Multi contact point virtual environments as well as haptic and virtual immersive environment share a common problem of coherence. Whenever the interaction between the user and the system makes use of several afferent channels (see Bergamasco [16]), it is required that all the channels have time, force and spatial synchronization.
Research experiences in this fields demonstrates that the lack of synchronization in one or more of the afferent channels can create in the user perception from a lack of sense of presence up to a sense of sickness during the virtual interoperation [6].
The proposed system has to synchronize three different interaction feedback: two haptic information and the relative graphical representation [13].
The inter-calibration among these components will be achieved with a set of semi-automatic procedure described hereafter:

Haptic graphic calibration procedures
The arm to graphic calibration is achieved by a set of "point and click" procedures. The user is required to place the tip of the haptic device into a set of point which have been graphically produced.
Even is a minimum requirement of three point is required for having a realistic match, the procedure is iterated on a larger number of points in order to have a better match which keeps into account statistical error reduction and spatial distorsion of the graphical feedback.

Inter Haptic calibration procedures
Two arms are placed and fixed, a simple mechanical device links them reducing the relative mobility as shown in following figure 8. This arrangement leaves only 3 translation degrees of freedom to system and allows the to keep the centre of Cardano's joint in fixed position respect to third body of both arms.
During the calibration procedure, the right arm is moved by a position control while the left one is leaved free to be conducted and in the same moment the control software provide to compute coordinates of spherical joint expressed in local reference system of two arms.
Two local frames are associated to right (Σ_0) and left (Σ_1) arm and an independent frame (Σ_W) is set.

In order to calibrate the system a given motion is produced on the master arm. The relative positions

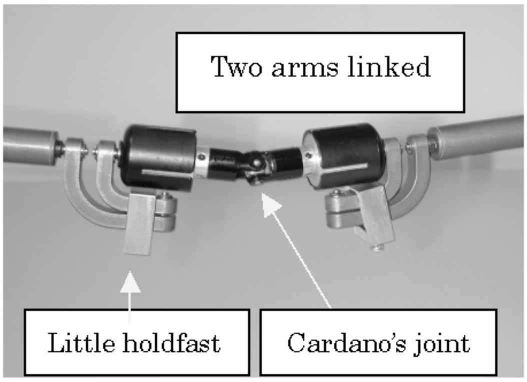

Figure 8: *Sketch of the intercalibration tool.*

vectors and are calculate for each arm by applying the direct cinematic equations for the mechanical device. A regressive and statistical algorithms described in [19], finally allows the computation of the relative position.

Acknowledgments

A novel VE system has been described. The system is based on the constructivist approach and allow user to higly interact with the VE objects. The whole CREATE consortium is acknowledged for their contribution to the definition of the project specification. The EU community is acknowledged for the financial support given to this research.

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