Using Haptics to Improve Immersion in Virtual Environments

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Abstract. Current immersive Virtual Reality (VR) system strategies do not fully support dynamic Human Computer Interaction (HCI) and since there is a growing need for better immersion, due consideration should be given to integrate additional modalities for improved HCI. While feedback in Virtual Environments (VE) is predominantly provided to the user through the visual and auditory channels, additional modalities such as haptics can increase the sense of presence and efficiency in VE simulations. Haptic interfaces can enhance the VE interaction by enabling users to "touch" and "feel" virtual objects that are simulated in the environment. This paper examines the reasons behind its integration based on the limitations of present immersive projection system.

Keywords: Virtual Reality, Haptics, Tactile feedback, Force feedback.

1 Introduction

There are three main categories of virtual reality systems whereby each implementation is ranked by the sense of immersion or the degree of presence it provides to the user. While moving from desktop systems (non-immersive) through semi-immersive (power-walls) to finally, a fully immersive system (e.g. the CAVE [20]) end users are provided with a much richer and engaging experience [2].

Virtual reality permits the user to 'step-into' a computer generated world or a Virtual Environment by immersing the user in the synthetic world. Considering that virtual worlds are completely conceived and created by the user, it is under their complete control and is therefore not confined to the laws of physics [3]. Human interaction capabilities are restricted if VEs deprive the users of sensorial cues that they experience in the real world; not only do we rely on our visual and auditory cues but we also depend on information that is conveyed through touch and force. These haptic cues complement the usual visual (graphics) and sound feedback modalities used in current VR simulations [1]. As such, providing greater realism to users could be achieved by integrating these sensory cues during the manipulation and interaction of virtual objects in VEs. A virtual object is a representation of an object in the virtual environment.

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2 Haptics and Limitations of Our Current System

Haptic is a term derived from the Greek "haptesthai" which means "to come in contact with" by providing the sense of touch with both tactile (cutaneos) and kinaesthetic (proprioception) feedback [4]. Tactile, or touch feedback describes the sensations felt by the skin. Tactile feedback permits users to feel things such as the texture of surfaces, temperature and vibration. Kinaesthetic force feedback on the other hand enables us to recognise a force that is applied to our body by the help of sensoric cells located at the end of the tendons or between the muscle strands. This permits us to measure the weight of grasped virtual objects.

Haptics can be further broken down into three different areas.

1. **Human haptics**: Understanding the roles played by the mechanical, sensory, motor and cognitive subsystem of the human haptic system.
2. **Machine haptics**: Constructing haptic hardware device interfaces to replace or enhance the human touch.
3. **Computer haptics**: Considers the techniques to generate and display touch and feel sensations to users by using a force reflecting device. It considers both the behaviour of virtual objects as well as the rendering algorithm for the time displays.

Input devices such as computer keyboard, mice and wands can convey the user's commands to the computer but are unable to provide a natural sense of touch and feel to the user. It is crucial to understand the nature of touch interaction, since we react to our surroundings based on what and how we perceive things [5]. A study conducted by researchers at Texas University to identify the effects of the visual component of haptics proved to show, that by adding sensory cues end-users were able to identify hidden objects. The tests carried out consisted of introducing a 3-dimensional object that could be made invisible [6]. By separating the haptic and the visual components the user had to rely on the sense of touch to identify the object in question. The results obtained made it possible to quantify the effectiveness of using in this case, point-based haptic devices and was considered to be beneficial for applications for visually impaired users. The user's sensorial experience in a virtual environment is a fusion of information received through his perception channels. Based on the above observations and on[1][7][8][9] there is great potential to improve VR simulations. By adding haptic enabled interfaces in our current immersive projection system at Reading University it is hoped that by providing tactile and force feedback human performance and efficiency can be enhanced if the realism of the VE is closer to the physical world. The additional information from haptic feedback makes certain tasks such as manipulation much easier compared to that of the traditional computer interface [5][11]. The next section provides an overview of haptic rendering techniques.

3 Haptic Rendering Algorithms

The haptic algorithm consists of 2 steps:

1. A *collision detection* step that determines if the user's pointer is colliding with a virtual object. Information about the extent of penetrations and where collisions have occurred is determined during this step.
2. A *collision response* step that computes the interaction force between the user's pointer and virtual objects when a collision is detected. The return values are normally force and torque vectors that are applied to the haptic interface. If there is a collision, the contact information is sent to the collision response algorithm which generates the relevant tactile feedback based on the force model used.

There are several collision detection algorithms and each one of them possesses certain advantages in different situations. The choice of the algorithm will depend on the speed of calculation to detect the collision and also on the haptic interface used. For the purpose of our implementation we will consider using the friction cone algorithm with the associated face transition algorithms discussed in [12].

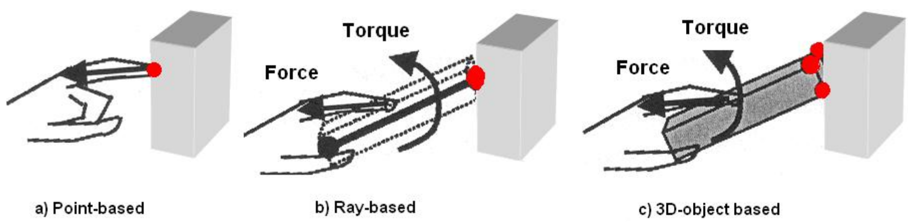

Fig. 1. Interaction methods [5]

Haptic rendering with force display also depends on the techniques used to model the probing object. Figure 1 provides models of the probing object.

- The simplest one is the point-based model Figure 1a where the probe is modelled as a point. Here only the tip of the end-effector is used to explore and manipulate objects. Checks are made to verify whether the tip of the end-effector is inside the virtual object and if so, the penetration depth is calculated based on the difference between the current position of the probe and the surface contact point.
- Ray-based interaction Figure 1b is where the probe is represented as a line segment. In this case the entire length of the line segment as well as its tip is used to explore and manipulate objects.
- The probe can be modelled as a 3D-object and is made up of points, line segments and polygons as shown in Figure 1c. Collisions between vertices of its geometry and the objects of the scene are checked every time the probe is moved. This is the most realistic technique but is also the most computationally expensive one [5][14][15][16].

The type of interaction method used in simulations greatly depends on the needs and complexity of the application. Moving from point based, ray-based to 3D-object we increase the accuracy but while so doing we would require intensive computation to detect collisions [13][17]. We therefore have to consider the trade offs between realism of the VEs and computational costs. For our implementation we will consider the ray-based technique. The next section covers some of current haptic device operations that have been implemented.

4 Current Feedback Device Operations

The device operations are methods that are concerned with setting and getting state. The device will require initialisation before use and will be initialised by setting the values to zero. In our implementation we have a instrumented tactile glove and a grounded haptic mobile platform both are currently being developed at Reading University. The tactile glove can replace or be used in conjuction with the traditional wand to provide a more realistic and intuitive way of manipulating virtual objects. The haptic mobile platform will be replacing the traditional joystick and will permit the user to navigate within the virtual environment. It could mimic several devices ranging from a bicycle to a trolley or hang glider.

4.1 The Instrumented Tactile Glove

The instrumented glove provides the following information:

- Position of the hand
- Finger angles - provides the information on whether the hand is clenched or open. To be noted that in our implementation of the haptic glove only three fingers (thumb, index and the middle finger) are actively being used and calibrated.

The device state and other information will be retrieved by using the haptic glove functions. The functions return -1 on failure indicating a hardware or network problem and 0 on success. The existing functions can retrieve the hand orientation and finger angles. Based on these values and on a collision detection algorithm we can render the appropriate feedbacks. If collision is detected with a manipulatable object the person would be able to interact with and manipulate the object. While the grasp aperture (the distance between thumb and fingers) is less than a critical distance (Gc) the object will be attached to the glove. If the grasp aperture is greater than Gc then we apply object physics to the object. Gc could either be set to a fixed value or vary depending on the size of the object being grasped. In order to produce the tactile cues on contact with virtual objects we need to generate some kind of reaction to the user's skin. While the skin responds to several distributed physical quantities such as high-frequency vibrations, pressure distribution and thermal properties in our first attempt, we will incorporate a vibro-tactile actuator in the centre of the palm.

The actuator will vibrate informing the user when he/she has made first contact with the object upon which the user can then manipulate the virtual object by picking it up (clenching the hand).

4.2 Grounded Haptic Mobile Platform

The grounded haptic mobile platform provides information on the following:

- The forward and backward velocity,
- The platform turn rates
- The amount of inertia, damping and friction - this would be dynamic depending on the force applied by the end-user onto the mobile platform handle.

The haptic enabled mobile platform functions will have similar error checks to that of the tactile glove. The class functions can retrieve the force applied, the displacement forward or backwards and the angle of rotation and can set the relevant constraints on the grounded mobile platform. If the mobile platform comes in contact with a surface in order to imitate what is experienced in real life, it should not be able to rotate or move forward. The programmer should also be able to query the forces applied as well as being able to define and set new forces to the object (in this case the mobile platform).

5 Future Work

We are currently in the early stages of the project and the main focus has been on the development and integration of the haptic hardware interface. Our future work will concentrate on the refinement of the current haptic device operations. We could enhance and provide more functionalities to the instrumented glove by increasing the number of vibrotactile stimulators (incorporating them onto each finger and not only in the palm) where, each stimulator can be individually programmed to vary the strength of touch sensation. Complex tactile feedback patterns can be produced by using a combination of stimulators to generate simple sensations such as pulses or sustained vibration. This would bring an enhanced realistic mode of interaction in immersive VEs whereby the user can pick up and maniputate for instance objects in a the virtual museum, it can also be used during the simulation of complex surgeries [18] by rendering accurate tactile information and by providing a natural and more intuitive way of control and manipulation.

Development of our own haptic library to provide collision detection or the integration of existing haptic rendering software subsystems will also be considered. Future investigation is required as to the possibility of using open source haptic software frameworks that are available for haptic programming and control of haptic force feedback devices. Other issues that can be considered is the fact that haptic rendering complex objects in virtual environments is computationally intensive and therefore due consideration should be given to the reduction of computational cost. We should have the ability to control the Level of Detail (LoD) of objects in VEs by substituting fine models with coarser ones to reduce the computation cost [19].

6 Conclusion

While several architectures have been reviewed it has been found that fewer fully immersive systems make use and integrate haptic feedback devices. By integrating sensorial cues in our immersive projection VE system, end-users would be provided with a more intuitive and efficient way of manipulating and interacting with virtual objects. The interface has been successfully developed and permits both the tactile and force feedback devices to integrate with our immersive system, and is being used in ongoing application development.

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