

Design guidelines for generating force feedback on fingertips using haptic interfaces

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Introduction

Manipulation and grasping have key importance in most types of interactions between humans and the world surrounding them [1, 2]. Even if almost all existing haptic interfaces provide a user interaction based on a single contact point, an increased number of contact points, not only allows to display a more natural haptic interaction [3, 4], but also improves the quality of interaction that users can perform in the environment. Haptic exploration is highly dependent on the number of fingers used for exploration of common objects [5], the largest difference appearing between the ‘one finger’ and the ‘two fingers’ conditions [6], and as proven by Jansson et al. [7] by the ability to discriminate a precise tactile pattern during the exploration. In [8], we found an experimental confirmation of this hypothesis: the haptic exploration do not improve with the increase of contact points, from one to two fingers. This suggests that the restriction imposed on the fingerpad contact region can blunt the haptic perception of shape and so indicates that local haptic cues play an important role in haptic perception of shape. Factors that can account for the observed performance in these experiments are lack of physical location of the contact on the fingerpad and lack of geometrical information on the orientation of the contact area, that constitute interesting insights and suggestions for the design of haptic displays.

Multipoint haptics [9, 10] are devices that can simultaneously interact with the user through more than one contact point. These systems allow both force and torque feedback during

the simulation of dexterous manipulation and complex manoeuvring of virtual objects and can improve the interaction in several applications, e.g., assembly and disassembly in virtual prototyping [11, 12], medical palpation during simulated physical examination of patients [13] and many other ones.

In this chapter we present different approaches to improve the quality of haptic feedback during virtual manipulation of objects. Four different aspects of modelling perception and manipulation are proposed and investigated through conducted experimental studies.

Initially we investigate the capabilities of using a haptic system for grasping and manipulating virtual objects, by means of a two contact points haptic device. The work also investigates the relationship between human prehension and features of the physical model of the grasped object, finding out how grasping in virtual conditions present higher forces and safety margins than in real conditions. A possible motivation of this observed difference is due to the limitations of kinesthetic devices in stimulating local mechanoreceptors.

A possible improvement in this sense to kinesthetic haptic devices is presented, where we wonder whether local haptic cues provided at the fingertip can improve haptic perception of shape. We adopt a prototype of a new encountered haptics, allowing haptic exploration of three dimensional shapes, and show how discrimination threshold for curvature perception can be significantly improved by providing both kinesthetic and local haptic cues at the contact point.

We also introduce an alternative approach to enhance haptic perception, by using haptic

illusions to elicit haptic sensations, and discuss potential applications and ways to simplify the design of future haptic devices.

Finally we evaluate the usage of high frequency vibrotactile factors to render the feeling of contact during the manipulation. Such a device consists in an active digital glove integrated with an array of vibrotactile actuators placed at level of fingers phalanxes. The device is equipped with embedded electronics that allows to control the motors directly from the virtual environment.

An investigation of manipulation capabilities in virtual environments

Grasping an object allows us to identify some of its properties (geometry, material, surface textures, [14]), change its physical state (position in space, internal structure) and use it for mediated interaction with other objects. The possibility of interacting with more than one point of contact is fundamental for the manipulation of objects in virtual environments. Humans unconsciously use suboptimal [15] algorithms for the prehension of objects when performing tasks with their hands. For instance, during a peg-in-hole task, they precisely adjust the relative position and interaction force between the peg and hole. Johansson and Westling conducted a series of experiments, relating tactile information to grip force when performing a lifting task [16]. The ability to adjust grip force appears to be independent of the surface friction characteristics, but further studies from the same authors confirmed that this is not true for the case of objects with different curvature, and propose an active role of rotational friction for the stabilisation of the grip [17]. The nature of contact during slip provides important tactile cues regarding features on the surface as well as the nature of movement of the object, and can explain how humans take advantage of slip sensitivity when perceiving objects.

In this study, we used a GRAB haptic system [18], composed of two identical robotic arms, to

provide the force-feedback for the two fingers during simulated grasping operations. The user can operate the device by inserting his fingers in two thimbles placed on the end-effectors of both the arms, as show in Figure 1, so that both single hand (thumb and index) and two hands (right and left indexes of two hands) interaction are possible.

A set of rubber thimbles of different sizes allow any finger size to properly fit in the device. Each arm has six degrees of freedom (dofs), of which the first three, required to track the position of the fingertip in the space, are actuated, while the last three, required to track its orientation, are passive. While the user is grasping and manipulating objects in the virtual environment, the device is controlled by multiple concurrent threads, from the fastest internal 1 KHz haptic loop to slower external collision detection loops, physical modelling, up to the slower 20 Hz graphical loop (see Fig. 1). The collision detection is actually implemented using an external module based on bounding volume hierarchy and running at about 100 Hz. The simulation of the dynamics of the objects is achieved through a dynamic simulator that is carried out through a separate thread running at about 200 Hz.

Whenever an object is grasped in virtual environment by the user's fingers, it is virtually tied to the contact points through a couple of springs representing the virtual stiffness of the environment. The application allows the experiment to change the working parameters in terms of size, weight and surface stiffness. While the size was kept fixed, in our experiments we interchanged weights from 0.1 to 0.5 Kg, and surface stiffness from 500 to 2,000 N/m.

The control loop also implemented a linear friction model who generates the force information for determining the object motion. The position of each contact point is measured directly by the haptic interface (x_h) and the relative feedback force (F) is computed through a constraint-based proxy method with friction, based on [19, 20]. The haptic rendering algorithm computes the position of an additional proxy point x_p , lying