Virtual Prototyping for Human-Centric Design

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Abstract: To prototype human-centric designs, it is necessary to prototype human manipulatory actions, such as manual assembly and disassembly, and reachability and manipulability of controls and surfaces. This project will employ a haptic interface, the Sarcos Dextrous Arm Master, to provide both external forces of contact and internal forces of grasping. Utilizing the underlying trimmed NURBS models of objects such as car interiors, real-time geometric algorithms will be developed to model surface-to-surface interactions. Haptic rendering methods, based upon measurements of real surfaces and controls, will return appropriate forces to the designer.

1 Introduction

The goal of virtual prototyping is to replace physical mockups with computational mockups, thereby greatly decreasing costs and speeding up iterations in the design. When a design's purpose is to be used by a human, or so-called human-centric designs, it is similarly desirable to prototype a human's interaction with the design without building a physical prototype. Ergonomic evaluation of car interiors are an example [10]: the location and feel of surfaces, and the accessibility and manipulability of controls. Other examples include manual assembly and disassembly.

To date only stereoscopic visual displays have been available to examine a design [1]. While much information can be obtained this way, it would be self-defeating if physical mockups had to be made because it couldn't be determined visually whether a design was ergonomically suitable for manipulation and manual interaction. Virtual manikins are often employed to assess how a human worker would fit into an assembly process or as users of the system being designed [7]. These virtual manikins are a purely geometric representation of humans which can be used to define the range of possible body motions of people, but they cannot provide an assessment of grasping and manipulation forces that a human might exert, and how these forces depend on posture.

A complete evaluation should allow designers to reach, touch, grasp, and manipulate virtual objects in the design, as if using their own arms against real objects. Under NSF support (DMI-9978603, start date 10/1/99, George Hazelrigg, PM), the sense of contact and force will be prototyped through force feedback from a haptic interface, the Sarcos Dextrous Arm Master (Figure 1). The use of the Sarcos Master allows a user to reach and grasp naturally, and to feel both external forces of contact and internal forces of grasping.

Utilizing directly the underlying complex geometries of the design (trimmed NURBS surfaces), surface-to-surface geometrical computations will be developed to model the bumping of the arm when reaching and the grasping by the hand of controls (Figure 2). A global minimum distance calculation will identify areas of potential contact, and then fast local surface tracing computations will model detailed geometrical interaction. Realistic surface models for friction, texture, and softness will be developed based on measurements of real surfaces. The mechanical action of controls such as switches will be similarly modeled.

2 Interactive Geometric Computations

The most difficult and encompassing problem in interactive virtual environments such as mechanical CAD systems is to compute geometrical interactions sufficiently fast. Whether or not one ultimately desires force feedback, interactive geometric computations are the cornerstone of any system. The computational difficulty is compounded for haptic interactions, because servo rates on

Figure 1: The Sarcos Dextrous Arm Master.

the order of 1 kHz are required to reflect forces convincingly and stably.

Since mechanical CAD designs are potentially very complex, the prospect of computing geometrical interactions at a 1 kHz rate is daunting. In computer-aided geometrical design, the most important representation is NURBS (non-uniform rational B-splines). When employed in combination with trimming curves, NURBS compactly and exactly represent sculpted objects. Previously it was thought that NURBS computations were too complex for real-time calculations, and simplifications had to made to the geometry to facilitate interactivity. A model translation step is typically performed to convert from NURBS to polygonal representations, which lend themselves to fast collision detection methods [9]. The drawbacks to polygonal representations of objects are parsimony and precise modeling of sculpted objects.

Under support of a previous NSF grant (MIP-9420352), we showed that interactive computations are possible utilizing trimmed NURBS surfaces directly in terms of point-to-surface. The Sarcos Dextrous Arm Master has two fingers, a two degree-of-freedom thumb and a one degree-of-freedom finger, which can engage in generalized opposition grasps. These fingers are modeled as points when probing a surface or grasping an object, which themselves are modeled as trimmed NURBS. The geometric computations are broken into two stages.

Global Minimum Distance Computation: The global minimum distance computation is pre-contact: points where contact might occur are identified (Figure 3). Because all objects have to be considered for possible contact, the global minimum distance computation is complex. The mitigating factor is that contact has not been

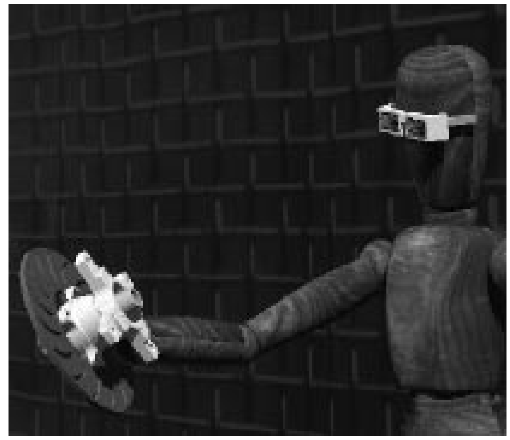

Figure 2: Depiction of a user employing a haptic interface to interact with a virtual brake assembly.

Figure 3: Closest point from a fintertip to a trimmed NURBS model.

made yet, so lower update rates are acceptable. The global minimum distance calculation is broken into two steps [3].

1. **Bounding boxes.** Most NURBS surfaces can be quickly eliminated from consideration by using bounding boxes. Taking advantage of coherence between time steps can speed up this computation [5].

2. **Nodal mapping.** The control mesh forms a convex hull for its NURBS surface (Figure 4). Once the closest point is found to the polygonal control mesh, then the associated point on the surface is approximated by an interpolation process called *nodal mapping* from the control mesh.

Local Surface Tracing Computation: The closest points then act as seed points to the local surface tracing

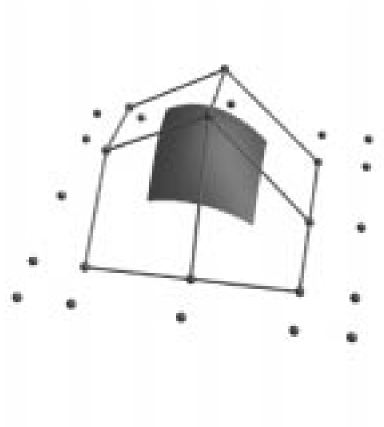

Figure 4: The control mesh forms a convex hull of a NURBS patch.

computation, where contact forces are determined. Local surface tracing is efficiently accomplished by projecting onto a tangent plane in parametric space [4, 11, 12]. Transitions along and across trimming curves require special attention [13].

Surface-to-Surface Contact: The next step is to generalize from point-to-surface contact to surface-to-surface contact, and this is one of the main goals of this project. This is required to model the interaction of the user's arm with a surface, to model rolling contact between finger and object, and to model general object-to-object interaction. The latter requires NURBS-to-NURBS computations to be performed. In the case of modeling the human arm and hand, simpler surface primitives such as tapered cylinders or implicit surfaces will probably suffice.

3 Haptic Rendering

Surface contact gives rise to forces, which result from associated dynamics of the virtual environment (object motion) as well as surface properties (hardness, friction, texture). In the context of evaluating a car interior, we may wish to display mechanical properties of knobs or switches being manipulated, and different surface properties. Haptic rendering of surface effects is getting to be reasonably understood [2]. The usual approach has been a priori modeling, but another approach is haptic recordings, in which contact effects are measured and played back by the haptic interface. Examples include recordings of textures [8] and flicking a switch [6]. The advantage of haptic recordings is potentially greater fidelity of the haptic experience. We plan to use both a priori models and haptic recordings. A closely related issue is verification of virtual environment mechanical effects, an urgent topic for which there has been little work.

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