Six-Degree-of-Freedom Haptic Interaction Using Incremental and Localized Computations[*]

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MOTIVATION

Virtual environments and intelligent systems require intuitive interfaces for man-machine interaction. These may include visual, auditory, and haptic interfaces. However, compared to the presentation of visual and auditory information, techniques for haptic display have not been as well developed. The commonly used 3-degree-of-freedom (DOF) force display devices, such as PHANToM Desktop, typically provide only force feedback and do not offer sufficient dexterity and control for applications like virtual prototyping (e.g. assembly planning and maintainability studies), medical simulation, and teleoperation. 6-DOF force feedback can provide torque feedback in addition to force display within a large translational and rotational range of motion. However, the application of higher-DOF force feedback has been limited. This is mainly due to the complexity of accurate calculation of all contacts and restoring forces that must be computed at the desired force updates (a few hundred Hz or higher).

In this extended abstract, we present a novel six-degree-of-freedom haptic display algorithm using incremental and localized contact computations. It uses an incremental approach for contact and force computations and takes advantage of spatial and temporal coherence between successive frames.

OVERVIEW

As a pre-processing step, our algorithm decomposes each non-convex polyhedral object into a collection of convex pieces. Moreover, the algorithm computes a bounding volume hierarchy (BVH) for each object using the convex hull as the underlying bounding volume. Using BVH's, both separation and intersection of objects are handled uniformly.

At run time, our 6-DOF haptic rendering algorithm first checks whether convex pieces of two objects are overlapping or disjoint but within a given tolerance threshold value. If two convex pieces are disjoint and inside the tolerance, we determine the closest features between them along with their associated distance measures (Near Contact). If the pieces are overlapping, we identify the intersection regions and estimate the penetration depth (PD) and the associated PD features (Penetrating Contact). Each pair of closest features or PD features correspond to a single contact. The forces applied at near contacts can be regarded as elastic pre-contact forces.

Once we identify all the contacts, we cluster them based on some Euclidean distance δ between them. We use octrees to efficiently cluster the contacts. Then, for each clustered contact, we compute its position, distance value and direction for the force in terms of a weighted average, where the weights are the distance values associated with each pair of contacts in the cluster. Finally, for each representative (clustered) contact, force and torque are independently computed, and the net force and torque are applied to the haptic probe by summing up the forces and torques of all the representative contacts.

RESULTS

We have implemented this algorithm and applied it to complex contact scenarios consisting of multiple contacts. We demonstrate its effectiveness on electronic prototyping of complex mechanical structures and virtual exploration of a digestive system, as shown in Fig. 1.

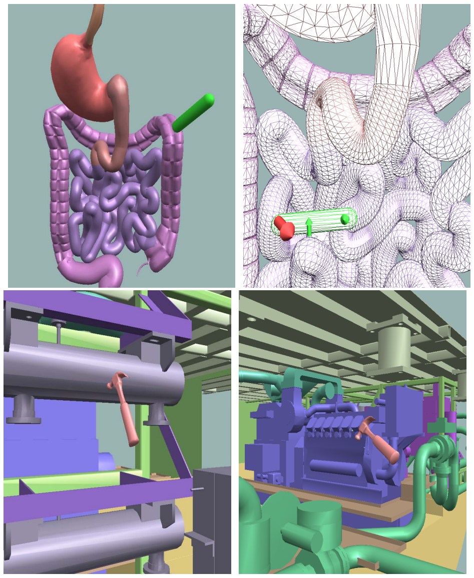

Figure 1: Haptic Interaction Scenarios: Virtual Exploration of a Digestive System Model (Top) and Virtual Prototyping of AMR Models (Bottom)

FUTURE WORK

We are currently investigating other approaches (e.g., multi-resolution techniques, coherence-based methods, etc) to design more robust and general algorithms to handle highly complex structures. The applications of 6-DOF haptic interaction techniques to information (intelligence, battlefield management, multi-dimensional or time-varying data, etc) visualization and medical training pose interesting challenges with promising potential.

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