Dynamic Proxies and Haptic Constraints

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Summary. Haptic simulations strive to provide users with realistic renditions of virtual environments but often struggle to display convincing rigid constraints or impacts. They generally utilize a proxy representation of the physical haptic device inside the virtual world to detect collisions, enforce constraints, and compute feedback forces. Traditional implementations are quasi-static and do not capture the dynamic energy and momentum transfer of impacts or the associated characteristic impulse forces. To further the development of haptic interactions, we introduce and explore the concept of dynamic proxies. Associating dynamics with a proxy allows greater control over its motion and behavior and enables a general force-based simulation framework. We suggest first-order, massless dynamics to maintain a light feel and low computational update rate, while easily incorporating collisions and constraints as velocity limits. User feedback is improved and may include acceleration terms to replicate any sudden momentum changes. The resulting system shows greater realism and flexibility, allowing extensions to multi-user/multi-proxy applications with dynamic interactions.

3.1 Introduction

The field of haptics seeks to artificially create a sense of touch for users of haptic devices such as force-feedback joysticks and master manipulators. These computer-controlled devices combine input and output functionalities; they observe the user’s motion and display appropriate force signals to simulate contact and other touch-based interactions. Working together with graphic displays, they create an immersive feel which allows users to fully experience virtual objects inside virtual reality.

Interfacing the real user and master device to the computer-generated virtual world, haptics has long understood the need for a proxy representation of the physical master inside the simulated world. This proxy follows the

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actual master motions until a virtual contact is made, at which time it records
the contact location. This process prevents the user from tunneling through
or jumping over constraints even as the master position is only sampled at
discrete servo updates. Deviations between the proxy and master locations
indicate a virtual interaction, and appropriate restorative forces are generated
for the user.

Traditionally, the proxy is non-dynamic, immediately jumping to the mas-
ter location if contact is lost and having no dynamic states of its own. Further-
more, the force feedback is generally quasi-static, based solely on the deflection
between proxy and master position at each specific time step. This approach
has proven effective for haptic display of rigid and even compliant virtual ob-
jects on a single master device, allowing the user to “poke” and probe the
virtual world.

Herein we introduce the concept of dynamic proxies. Extending the kine-
matic master-proxy relationship into a dynamic one allows improved force
feedback of dynamic effects, as is needed to simulate impacts. It also provides
far greater control over the proxy motion and behavior in general. This exten-
sion facilitates the growth of haptic simulations toward multiple interaction
points, multiple proxies, and shaped proxies for applications which involve sev-
eral users, both hands, or virtual tools with complex collisions and kinematic
constraints [196].

These ideas have been previously utilized in the domain of telerobotic
minimally invasive surgery, where the dynamic proxies both augmented the
surgeon’s force feedback and shaped the slave motion commands [252, 212].
Their dynamic nature was used to smooth and adjust the user’s motions to
accommodate the slave manipulator’s dynamic capabilities. Expanding upon
these ideas, we are also studying dynamic proxy objects for use in haptic
surgical simulators and trainers [196]. Combining the dynamic properties with
surgical tool kinematics easily simulates multi-handed operations, including
soft and hard contacts with stationary or moving environments, as well as
inter-tool collisions.

We develop both first- and second-order proxy dynamics in this chapter
and show the first-order behavior to be superior; its response provides all of
the benefits of dynamic effects without incurring inertial forces. The result-
ing system preserves the the light feel and low computational update rate of
traditional static proxy implementations.

After reviewing the background of traditional proxies in Sect. 3.2, we dis-
cuss their basic behaviors and limitations in Sect. 3.3. In Sects. 3.4 and 3.5, we
develop the dynamic proxies and incorporate rigid constraints. Force feedback
to the user is detailed in Sect. 3.6 and we offer some brief concluding remarks
and possible extensions in Sect. 3.7.