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evaluate texture function at (u, v) and four surrounding points;
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Within each cycle, the location of the stylus is reported, and its collision with all objects is determined. If the stylus is in contact with any object, the force in the direction of the object surface normal is computed as well as forces from specified surface properties (friction, damping, texture). Force contributions from all objects are added to global drift or damping forces, and the result is displayed to the user. Object state, as shown above, is updated as necessary. Any requests from the client are then addressed before position polling repeats.

There are obviously many ways to model the surface and bulk properties of materials, and the computation of forces generated when we interact with them. Because the only directly measured state provided by the PHANToM is position, indirect methods must be used for computing physical quantities involving velocity and acceleration. Below, we provide a brief description of some simple modeling which has yielded satisfying simulation of some haptic phenomena.

Friction and damping modeling

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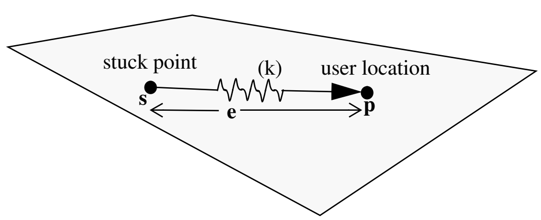
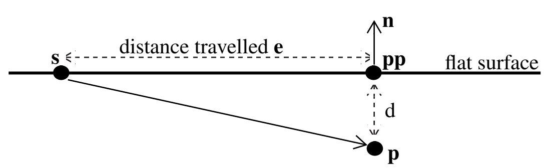
Thus, if $k\mathbf{e} < (c_s\,|\mathbf{F}_n|)$, then $\mathbf{F}_f = k\mathbf{e}\mathbf{f}_t$; else $\mathbf{F}_f = (c_k\,|\mathbf{F}_n|)\,\mathbf{f}_t$, where c_s is the coefficient of static friction, c_k is the coefficient of kinetic friction, and $\mathbf{f}_t$ is the unit vector in the direction of the tangential component of force. The stiffness coefficient, k, of the “resisting” surface is currently not user-specified. Computation of the distance travelled, **e**, along a flat surface, textured surface, or sphere is shown in the diagram below.

Friction modeling on a surface



Computing the distance travelled on flat surfaces

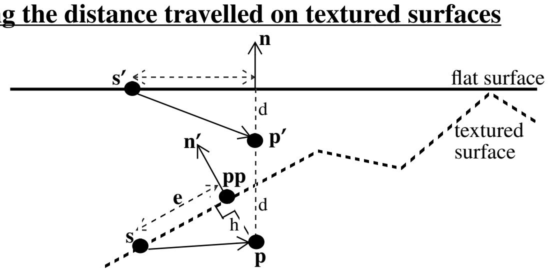


$d = (\mathbf{p} - \mathbf{s}) \cdot \mathbf{n}$

$\mathbf{pp} = \mathbf{p} - d\mathbf{n}$

$|\mathbf{e}|$ = distance travelled in surface = $|\mathbf{pp} - \mathbf{s}|$

Computing the distance travelled on textured surfaces



$h = d(\mathbf{n} \cdot \mathbf{n}')$

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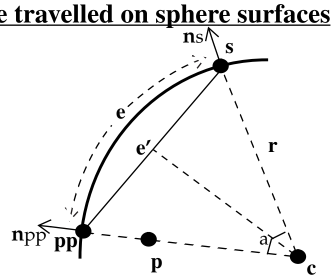
$|\mathbf{e}| = |\mathbf{pp} - \mathbf{s}|$

Computing the distance travelled on sphere surfaces



$\mathbf{e} = |\mathbf{r}|a$

$a = 2\text{asin}\{\ |\mathbf{e} - \mathbf{s}| / 2|\mathbf{r}|\ \}$

$|\mathbf{e}| = 2|\mathbf{r}|\ \text{asin}\{\ |\mathbf{e} - \mathbf{s}| / 2|\mathbf{r}|\ \}$

or, **e** can be approximated with **e′**:

$|\mathbf{e}'| = |\mathbf{pp} - \mathbf{s}|$

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Wendy Plesniak, John Underkoffler
MIT Media Laboratory
wjp@media.mit.edu jh@media.mit.edu

Abstract

For haptics applications in which the PHANToM haptic interface is controlled by a PC, we have built a network-based client-server system so that high-quality computer graphic rendering can accompany haptic simulation. The system currently consists of a 586 (Pentium) PC to drive the PHANToM and an SGI Indigo Elan to render stereo computer graphics. The machines communicate over Ethernet using TCP/IP.

Position query and object creation commands are sent from the graphics host to the PC running the haptics simulation. Informational replies and automatic notifications are sent from the PC back to the graphics host. Thus the PC-based haptics library is made available to applications running on higher-end graphics workstations.

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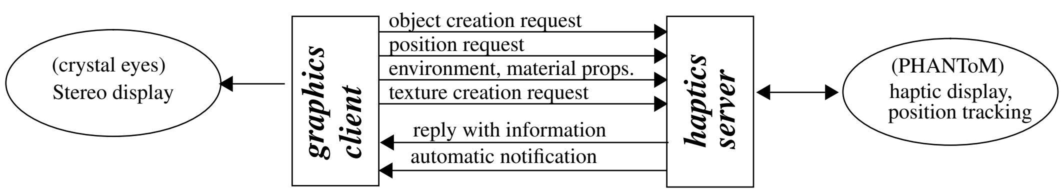
Haptics client-server

Our network-based client-server system has been developed for applications demanding both high quality haptic and visual rendering. The haptics server recognizes commands from a client graphics machine for object creation and deletion, activation and deactivation, setting global drift forces and global viscosity, specifying surface damping and friction (static and kinetic), creating textures on objects, and for position-query. In turn, the client receives confirmations of successfully-completed commands, requested position information, and automatic notifications when buttons tagged as "active" have been touched. This system, which models a world of static objects, has proven to be robust; the only noticeable visual latency occurs when network traffic is heavy. The basic system is shown below.



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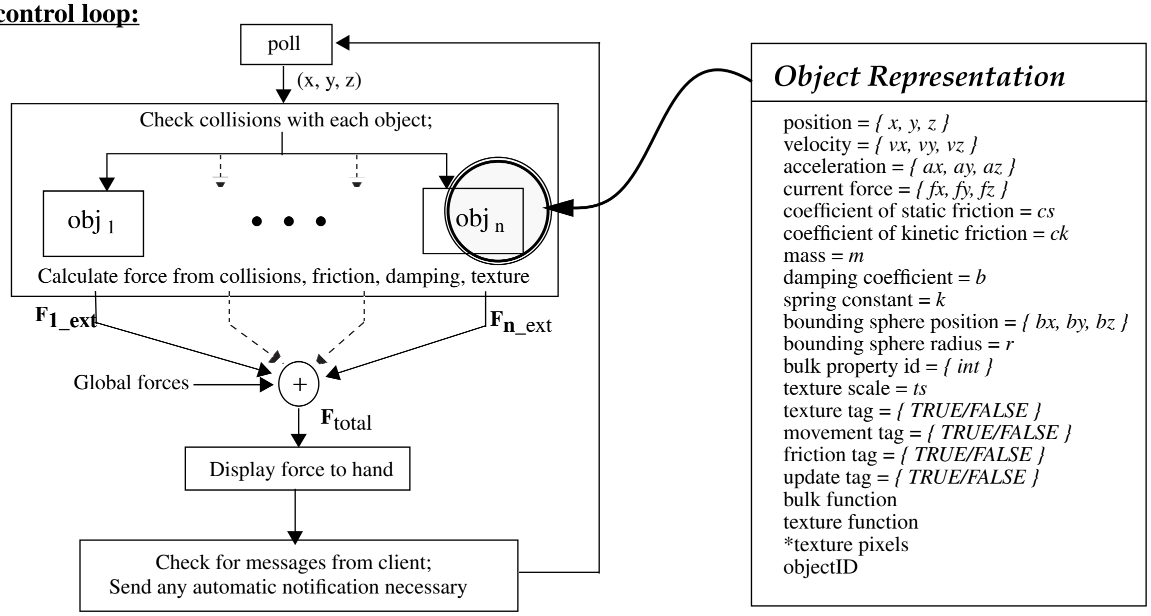

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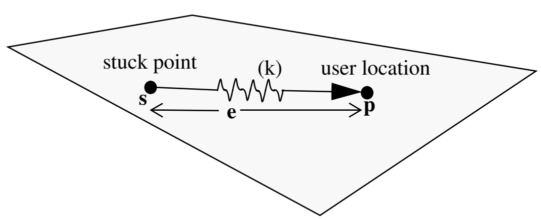

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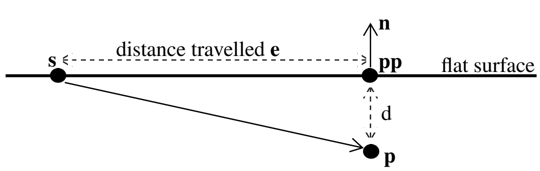

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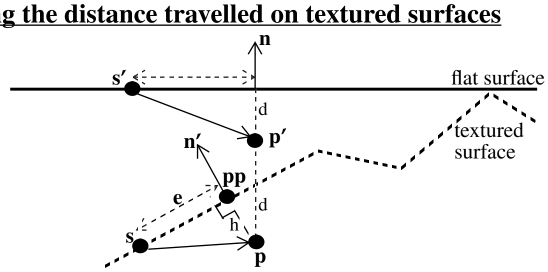

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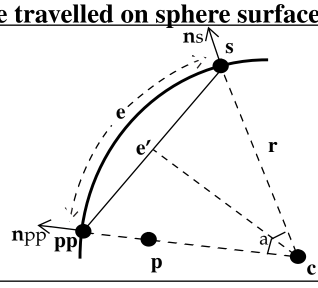

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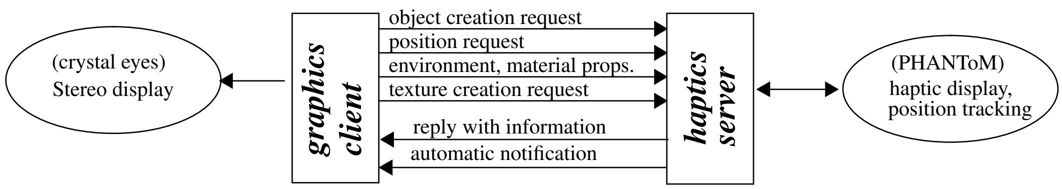

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