Higher Precision in Volume Haptics Through Subdivision of Proxy Movements

Karl Johan Lundin Palmerius and George Baravdish
Visual Information Technology and Applications
Linköping University, Sweden

Proxy-based Volume Haptics
Proxy-based methods for volume haptics use a proxy point to internally represent the haptic probe. The haptic behaviour is controlled by moving the proxy and the force feedback is calculated from a virtual spring-damper connecting the proxy and the probe.

Results
A time budget of 0.9 ms is used, thereby leaving some time for synchronizing the data with the haptics device before reaching the 1 ms limit in a 1 kHz update rate. With these settings the presented method shortens the average step length from 349 μm to 8.7 μm in the test application. The algorithm performs at an average 46 sub-steps for each estimation of the haptic feedback which with linear approximation results in an equivalent reduction in the error, which can be seen in the figure.

Penetration of a concave surface due to numerical errors.

Applications
CFD Simulation
The SHARC aircraft is an experimental unmanned aerial vehicle (UAV). In this example the air flow from a computational fluid dynamics simulation (CFD) is explored using multi-modal interaction. While only simple properties can be rendered visually without cluttering the display, the haptic feedback provide continuous representations of the data and physical guidance throughout the volume.

Heart Blood-flow
Modern MRI-scanners are capable of acquiring animated blood-flow data from within a beating human heart. Both the poor tissue contrast of this kind of data and the fact that the noise of MRI data makes automatic extraction of features difficult, makes it an interesting target for multi-modal methods. The haptic feedback helps the radiologist understand the flow and guides the exploration both physically and mentally.

Time-varying CT Heart
A CT volume sequence of a beating human heart has been acquired by synchronizing a CT scanner with EKG. This data contains important information about the dynamics of valves, atria and ventricles. The dynamics of the data are, in this example of multi-modal exploration, reflected through both visual and haptic feedback thereby facilitating the understanding of complex phenomena for medical diagnosis, for example. The interaction mode allows surface palpation as well as penetration.

Volumetric Data
Data (value, gradient, curl, etc) are extracted at the probed position in the volume and used to control the parameters of the haptic primitives, thus indirectly controlling the haptic feedback.

Haptic Primitives
The haptic primitives controlled by the volumetric data properties define the local haptic behaviour which then reflects the local data in the volume. Depending on which primitives have been selected as a representation of the data, and depending on how their parameters are controlled, the resulting haptic mode produces different haptic behaviour. Each primitive has an individual strength, direction and position.

Three haptic primitives are representing yielding constraints, point, line and plane primitive, with different degrees-of-freedom. One primitive provides a directed force.

Haptic Mode

Volumetric Data

Point primitive: 3D constraint
Line primitive: 2D constraint
Force primitive: directed force
Plane primitive: 1D constraint

Iterative Approximation of Solution

Primitives Solver
The proxy position that through the virtual spring-damper represents the haptic feedback is found by balancing the force feedback from the spring-damper against the force from the primitives. This is done by a chain of primitives solvers. First the system tries a fast and high precision analytical solver, and if this fails the system falls back on a second, numerical and more general solver.

Proxy Motion Subdivision
There is no step direction or step length in the system which can be shortened to improve the precision. Instead the integration steps are simulated by considering the change in proxy position done by the solver to constitute the step. If there is time for another call to the solver the proxy is moved back to shorten the “step length”, the primitives are reconfigured with the data at this new position, and the solver is called again to find a new position for the proxy.

When the time budget is spent the last computed proxy position is used to estimate the haptic feedback using the virtual spring-damper connecting the proxy and the probe.