# Spherical Harmonic Representation based Haptic Rendering for Medical Image Perception


**Z. Yang[1], Q. Tieng[1], V. Vegh[1], and D. Wang[1]**

[1]Centre for Magnetic Resonance, University of Queensland, Brisbane, Queensland, Australia


**Introduction**: Medical images generated in MRI are loaded with large amounts of information, posing challenges for human sight to identify and perceive the level of detail provided within these images. A solution is to use additional senses, such as the sense of touch, which is known as haptics. Haptics is also referred to as the technology of generating artificial sense of touch by interacting with objects in virtual space. The use of visual interpretation in conjunction with a haptic device can provide a higher level of perception towards diagnosis and treatment planning. A haptic device, such as the one shown in Figure 1, provides forced feedback to the user and can be employed as an object probing tool that is defined in virtual space. The haptic device used here is a two-way interface for defining the position and orientation of the probe and providing virtual reaction feedback in terms of a force and torque response to the user. The addition of a haptic device is shown to have improved interaction, as the depth cue added by touch elucidates ambiguities identified in the 2D image of a 3D virtual object.

The main challenge in haptic rendering is to limit the underlying computational physics to above 1 *k*Hz, which is significantly faster than the 30 Hz graphical rendering update rate. In each rendering cycle two primary tasks are performed, namely collision detection and reaction force generation. Collision detection is the ability to identify whether the object is touched and consequently allows for the identification of the collision point, and force generation performs the calculation of the magnitude and direction of the reaction force to be transmitted to the user through the haptic device. It is vital that collision detection and reaction force generation are rapidly computed for the haptic device to provide appropriate user feedback, which varies with different object representations. In this work spherical harmonics are used to represent the virtual object. The implementation permits interaction with organs that have been segmented from MR images, such as the prostate in Figure 2.

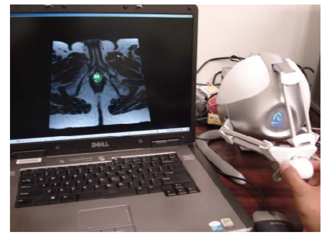

**Figure 1** A Falcon® haptic device.

**Methods**: The spherical harmonic representation of a complicated 3D closed surface is [1]:

$$Y_{lm}(\theta,\varphi)=\sqrt{\frac{2l+1}{4\pi}\frac{(l-m)!}{(l-m)!}}P_{lm}(\cos\theta)e^{im\varphi},\quad R(\theta,\varphi)=\sum_{l=0}^{\infty}\sum_{m=-l}^{l}r_{lm}Y_{lm}(\theta,\varphi),$$

where, $R$ is the radius, and $\theta$ and $\varphi$ are the polar and azimuthal angles. Coefficient $r_{lm}$ can be generated by solving an over determined linear system by regressing on a set of data points. This research work is focused towards prostates, and hence a prostate was segmented from 2D acquired MR images. To estimate $r_{lm}$, the prostate surface was sampled over the unit sphere using icosahedron subdivisions [2]. Subdivision level was set to 20, which provided 4,002 sample points, from which a 12$^{th}$ degree spherical harmonic representation corresponding to 169 harmonic coefficients was used to reconstruct the virtual prostate. A proxy-based method was used for the haptic rendering [3], which decouples the cursor, or 'probe' position from the actual haptic device probe position. The cursor is placed at the so-called 'proxy' position. The proxy does not penetrate the surface being touched, while the real probe has the ability to penetrate the surface. Reaction forces applied to the haptic device are calculated using the distance of the proxy to the real probe position according to the input device. In each haptic cycle the probe position was obtained from the device and was converted to spherical coordinates ( $\theta$ , $\varphi$ , $R_{\text{probe}}$).

$R_{\text{proxy}}(\theta,\varphi)$ by definition is the radius to the surface represented by the spherical harmonics calculated using the above equation. Collision detection was achieved by comparing of $R_{\text{probe}}$ and $R_{\text{proxy}}$. The reaction force that the haptic device transmits to the user was calculated according to:

$$\mathbf{F}=\begin{cases}k(\mathbf{x}_{\text{proxy}}-\mathbf{x}_{\text{probe}})+d(\mathbf{v}_{\text{proxy}}-\mathbf{v}_{\text{probe}}), & R_{\text{probe}}<R_{\text{proxy}}\\ 0, & R_{\text{probe}}\geq R_{\text{proxy}}\end{cases},$$

where, $\mathbf{x}_{\text{probe}}$ and $\mathbf{x}_{\text{proxy}}$ are the position vectors, $\mathbf{v}_{\text{probe}}$ and $\mathbf{v}_{\text{proxy}}$ are the velocities, respectively, and $k$ is the stiffness factor with associated damping ratio $d$. The Novint® haptic device supports position input and force output, with a workspace of $10cm\times10cm\times10cm$ , resolution of $400dpi$ and force capabilities larger than $2kg$ . Tessellation using icosahedron subdivision was used for the graphical rendering, which was represented as an indexed facet list according to the X3D standard and displayed using OpenGL. The haptic and graphical cycle synchronisation was implemented using C++ with H3D APIs.

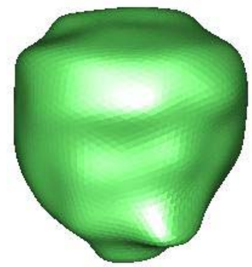

**Figure 2** Prostate model.

**Results & Discussion**: The surface illustrated in Figure 2 felt smoother using the spherical harmonic representation based haptic rendering, when compared to the facet representation. The spherical harmonic force calculation update rate was faster (850-1,200*Hz*) compared to the facet representation (400-900*Hz*), given the same number of facets. Two improvements of the implementation have been identified, that is force interpolation between cycles can reduce the vibration caused by sudden changes in the magnitude or direction of the force, and the reaction force direction may be refined by the surface normal at the collision point, which can be analytically computed using spherical harmonics [4]. Spherical harmonics were found to be a feasible representation for haptic rendering with very good feedback characteristics.

Spherical harmonics are a compact representation and can be efficiently used for both graphic and haptic representations. A greater number of subdivisions could be used to generate more vertices and facets, to obtain a better graphically rendered visual illustration without increased burden on force calculations. More realistically, deformable objects with heterogeneous properties are of greater interest, as these can be representative of many organs. Future work will seek to define appropriate spherical harmonic representations for the heterogeneous elastic deformation case, where the virtual object is also defined through reconstruction of segmented MR images.

Haptic feedback provides another avenue for the information flow in medical image perception. Multimodal images can be displayed simultaneously with less confusion by using visual and haptic feedback separately, which is envisaged to be a better technique for image fusion interaction. Haptically guided medical image exploration can aid the user in various tasks, such as locating and measuring anatomical and pathological features, or investigating the spatial relationship between these features. Forced feedback can ultimately improve user performance in image manipulation tasks, such as interactive landmark selection, organ delineation and image registration.


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**References:**


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