Generation of Smooth and Accurate Surface Models for Surgical Planning

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Abstract

We compare selected mesh generation methods from intensity data and binary segmentions with respect to their application to surgical planning and make recommendations on how to receive smooth and accurate surface meshes for exemplary cases. We consider especially local curvature, distances between two meshes (before and after processing) and volume preservation as measures. Sample data from the field of neck surgery is used to evaluate the influences to relevant properties.

1 Motivation

Mesh generation methods, such as the Marching Cubes (MC) algorithm [3], Constrained Elastic Surface Nets (CESN) [1], or level-set methods [9] are often applied to binary segmentations of medical structures (e.g. bones, vessels, liver, lymph nodes, ...) causing several artifacts (e.g. staircases, terraces, plateaus). The application to non-binary data (e.g. [6]) is promising but may still not remove all critical artifacts reliably. Fine, elongated, and branching objects (e.g. vasculature, bronchial trees) often require specialized methods (e.g. Convolution Surfaces [12], MPU Implicits [11]).

Artifacts resulting from the limited resolution can be removed by appropriate mesh smoothing operations reducing the local curvature(e.g. Laplace filter, Laplace+HC [8], Mean Curvature Flow [7], or Taubin's $\lambda|\mu$ (LowPass) smoothing [10]). Many of the related methods focus on the removal of noise from non-medical models [4, 7] which does not fit to the application to anatomical structures exhibiting smoother shapes. Bade et al. [2] applied smoothing methods to medical data and identified the Laplace+HC and Taubin's $\lambda|\mu$ filter being most appropriate. Furthermore, they presented a smoothing constraint to preserve accuracy [5].

However, there are methods available to solve the specific problems but recommendations on how to parametrize, combine and apply them to support surgical planning, intervention planning or radiation treatment planning are missing.

2 Sample Application to Neck Surgery

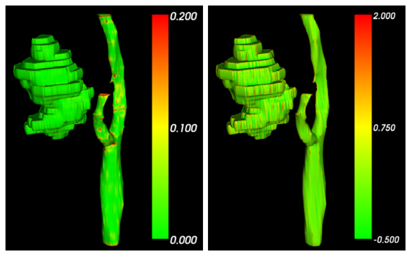

Figure 1: Smoothed MC models (Laplace+HC, λ=0.5, 10 iterations, node position constraint) of a tumor located near a vessel (vena jugularis). Left: colored by distance to the initial meshes. Right: colored by mean curvature.

In neck surgery, medical visualization is applied to evaluate the spatial relations (e.g. extent of a tumor and possible infiltration to surrounding structures). Hence, artifacts need to be reduced to allow for naturally looking structures without artificial sharp edges, staircases or terraces (caused by discretization and segmentation) but may not fail accuracy requirements (e.g. altering distances of critical structures).

Pathological structures such as tumors can usually not be identified automatically. Applying the MC algorithm the the binary mask gives an accurate representation of the segmented data. Further mesh smoothing with additional node positioning constraint (restricting to cubical or diamond cells) or CESN eliminates sharp artifical edges and

	Tumor			Vena jugularis			
	MC	Smoothed MC	CESN	MC	Smoothed MC	MPUI	CESN
Volume	100%	99.09%	97.63%	100%	99.56%	105.44%	85.75%
Mean Curv.	0.505	0.366	0.422	0.451	0.265	0.222	0.301
Max. Dist.	0	0.307	0.306	0	0.359	1.150	0.742

Table 1: Comparison of the initial MC mesh (from binary data) of a tumor (48k faces) and the vena jugularis (21k faces): smoothed MC mesh (Laplace+HC, 8-10 iterations, λ=0.5, node position restricted to cubical cells), CESN, and MPUI of the vessel (10k faces). Distances are given in relation to the specific voxel diagonal.

smaller staircase artifacts but does not alter the topology (see Fig. 1). As depicted in Table 1, an appropriate smoothing preserves the volume, whereas the mean curvature is reduced. Similar results can be achieved using the comparable CESN method which yields just a slight volume shrinkage. However, the tumor model suffers strongly from terracing artifacts due to segmentation and anisotropic voxels. A smooth model can only be achieved with very strong smoothing causing inacceptable inaccuracies.

For the extraction of e.g. vasculature, we use binary masks to exclude false additional or detached parts from the image data and apply MC (+smoothing), CESN and MPU Implicits. Again, MC with consecutive smoothing yields good results, whereas the CESN approach suffers from strong volume shrinkage (14.25%). MPU Implicits with oversampling of thin structures give acceptable results for smoothness and volume preservation, additionally exhibiting a more natural look at branching points, but the required parameters are very sensitive to minimal changes and the models even tend to grow.

3 Conclusion

Simple preprocessing steps, such as masking the intensity data with binary segmentations and slight 3D smoothing enable very common reconstruction algorithms (MC, CESN) to generate accurate and visually good surface models. Further mesh smoothing (and CESN) should be used carefully since especially fine and elongated structures tend to collapse which may be critical in surgical planning. For pathological and critical, close located structures, the mesh generation process should focus more on accuracy than smoothness. Thus, we recommend locally restricted and adaptive smoothing. A deeper examination of the influences of image preprocessing to relevant distances is necessary.

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