

Colon Visualization Using Shape Preserving Flattening

Joseph Marino and Arie Kaufman

Stony Brook University, Computer Science Department,
Stony Brook, NY 11794, USA
{jmarino,ari}@cs.sunysb.edu

Abstract. Virtual colonoscopy is a well-known screening modality for colon cancer, and virtual colon flattening techniques have been proposed to map the 3D surface to the 2D domain. Performing this flattening with conformal geometry allows for the local shapes to be preserved. We explore here how these shape preserving flattened maps can be used for visualization of the colon and to enhance the VC environment. Our discussion focuses on two types of use of the flattened colon, using the flattened mesh alone and using it with integration into the 3D endoluminal view. For the mesh alone, flattened views can be generated using volume rendering to attain the same image quality present in a typical view. When integrated with the 3D endoluminal view, the flattened mesh can be used to assist in navigation through a colon, or in acquiring corresponding view points in two scans if there is a one-to-one and onto mapping between two flattened meshes.

Keywords: virtual colonoscopy, virtual colon flattening, visualization, medical imaging, volume rendering

1 Introduction

Virtual colonoscopy (VC) has been developed as a non-invasive screening method, whereby a radiologist can explore a colon surface in a way similar to that of a gastroenterologist performing an optical colonoscopy [1]. There has been significant research into a number of alternatives, improvements, and additions for VC systems. Of interest here, virtual flattening techniques have been proposed for the colon surface, whereby the entire colon can be mapped from the 3D domain to a 2D rectangular domain.

A variety of colon-flattening methods have been proposed which will deform a 3D mesh model of the extracted colon to a flat 2D plane. Methods based on cylindrical projections of segments [2] and on mass-spring unfolding have been proposed [3]. Other techniques using conformal mapping have also been suggested [4, 5]. A conformal map of the geometry results in a mapping where local area distortion is minimized while the local angle is preserved, thus preserving the local shape characteristics of the colon surface and providing as undistorted a view of the colon anatomy as possible. Because shape characteristics are of utmost importance in searching for colon abnormalities, we employ conformal geometry for all of our flattening work.

These flattened colons can have a variety of uses in a VC system. Other work has focused on using the flattened meshes to encode geometric details (such as curvature) or has simply used traditional computer-graphics mesh rendering to observe the colon surface,

whereby the normals for each vertex of the flattened mesh are appropriated from the original 3D colon mesh model. We demonstrate two general categories of using the flattened meshes in a VC system. In the first, we show how volume rendering can be used to give a view similar to that in the endoluminal view. For the second, we demonstrate how the flattened meshes can be used to assist in navigation through the 3D colon view.

2 Generating 2D Views

The flattened colon can be used alone to provide the user with an overview of the entire colon structure, ensuring that all areas are examined and no regions are missed due to folds or other structural obstructions. Because the flattened colon is in fact a mesh surface, conventional polygonal rendering methods have been used to visualize the colon [4]. Rendering the mesh as-is is of course inadequate, as only a rectangle without any structure would be seen. However, the per-vertex normal values from the original 3D colon mesh can be applied to the vertices of the flattened mesh. In this, rendering with lighting will give the sense of the structure of the colon surface. A common way of seeing the surface structure on this flattened mesh is to render with normals that are calculated on the original mesh surface rather than from the flattened mesh (where all normals will of course be in the same direction). Similarly, other geometric properties can also be rendered by encoding of values, such as curvature, as a color at each vertex, with interpolation at render time applying the correct colors across the entire surface.

However, these methods of polygonal rendering do not present to the user the same quality and look that are available in the endoluminal view of a VC system. In such an endoluminal view, the imagery is generated through the use of volume rendering through the original CT data using volumetric ray casting. We want to have this same sort of look and feel in our rendered 2D flattened colons, and thus we map the rendering from the 2D surface to the 3D volume, allowing us to present to the user a volume rendered image on the 2D flattened mesh. For each pixel in the 2D image, the starting position for the ray casting algorithm is given as the corresponding position in the original 3D model, with respect to the local coordinates of the CT volume. Rays are then cast from these points through the colon volume, using an appropriate transfer function to generate the desired image.

To obtain the direction of these rays, a view position must be obtained for each point. As the colon is a long, twisty, tubular structure, a single viewpoint for the entire structure is not feasible. As the flattened colon is created by slicing the colon open along an axis from cecum to rectum, each row of the image is equivalent to a loop on the colon surface. Therefore, by averaging the 3D positions across an image row, we can generate an estimated viewpoint which will be in the center of that row of pixels. Such a viewpoint can be generated along the entire mesh at a resolution equivalent to that of the desired final rendered image. These view points are then used to obtain the direction vectors inside the volume rendering algorithm. These viewpoints can also be combined through the entire colon to create what we refer to as the *flattened centerline*, which differs from the conventional 3D skeletal centerline extracted for automatic VC navigation [6] (hereafter referred to as *skeleton*). The flattened centerline closely approximates the skeleton, but is more suitable for working with the flattened mesh. Note also that, with our method of conformal flattening [5], the mapping is periodic in the 2D domain, and thus a rectangular final mesh (and image) can be generated, allowing for a much cleaner view than having ragged edges.

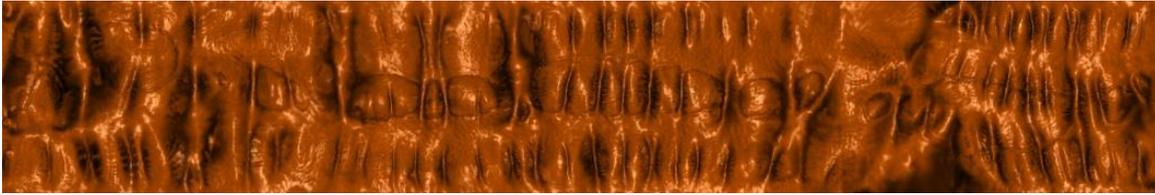


Fig. 1. Volume rendered flattened colon using an opaque transfer function.

Rendering with a normal opaque transfer function gives an image of the colon surface as shown in Figure 1. However, more interesting effects are possible. For example, rendering with a translucent transfer function can allow for an electronic biopsy version of the rendering to be presented to the user, wherein density differences within the colon wall can be observed [7]. An example of such a rendered image is shown in Figure 2.

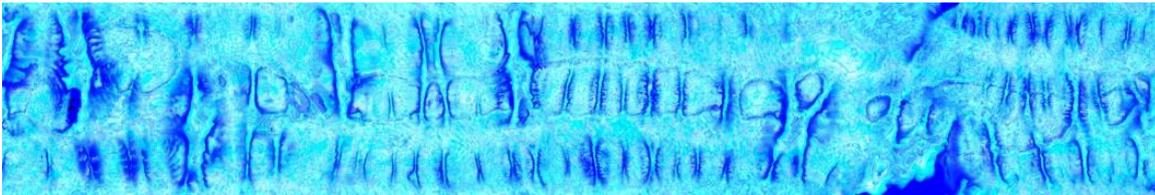


Fig. 2. Volume rendered flattened colon using a translucent transfer function.

Viewing flattened colons can also be extremely helpful if there is a registration between two flattened colons that is one-to-one and onto. If such conditions exist, then the two flattened colons will be the same size, and a pixel in one rendered flat colon will correspond directly to the same pixel in the other flat colon. Such a correspondence makes it trivial to observe a region in one colon, and then observe the corresponding region in the other colon.

3 Integration for 3D Navigation

The flattened colon can assist in guiding 3D navigation. The first use is as a general map, whereby the user can select a point on the flattened image, and an endoluminal viewpoint can be generated to look at the same region. To generate this view, a 3D viewpoint in the endoluminal view is required, as well as the three viewing vectors to orient the camera.

For this, in addition to the volume rendered structural colon image, a hidden image containing the first intersection point of the view ray and the colon wall is created. Selecting a pixel for a point to view on the volume rendered image then maps to selecting the same pixel in this position image, which will have encoded the (x, y, z) position in the 3D colon volume at which the view is to be directed. This point is referred to as p .

The viewpoint can be identified as the point on the flattened centerline for the row containing the selected pixel. If a viewpoint on the skeleton is desired, the closest point on the skeleton to the flattened centerline point can be used. The viewpoint is taken as the optical center of the camera, o . The two neighboring points on the flattened centerline (or skeleton) can be referred to as c_0 and c_1 . If desired, several points to the left and right could be averaged to provide a smoother version of the axis.

Using the four points identified above, we can create three view vectors as such:

$$v_0 = \frac{p - o}{|p - o|}, \quad v_1 = \frac{c_1 - c_0}{|c_1 - c_0|},$$

$$v_2 = v_0 \times v_1,$$

where the complete view frame can then be given as $\{o; v_0, v_1, v_2\}$. The vector v_0 is the view vector, formed by looking at the point of interest. Vector v_1 is the ground vector, formed along the flattened centerline (or skeleton). Vector v_2 is the up vector, taken as the cross product of v_0 and v_1 .

Flattened views can also be useful if a one-to-one and onto mapping is formed between colon surfaces extracted from two scans. Such a mapping allows for the immediate identification in one scan of the corresponding location from the other scan. This, too, can be used for obtaining corresponding endoluminal viewpoints, similarly to the method described above.

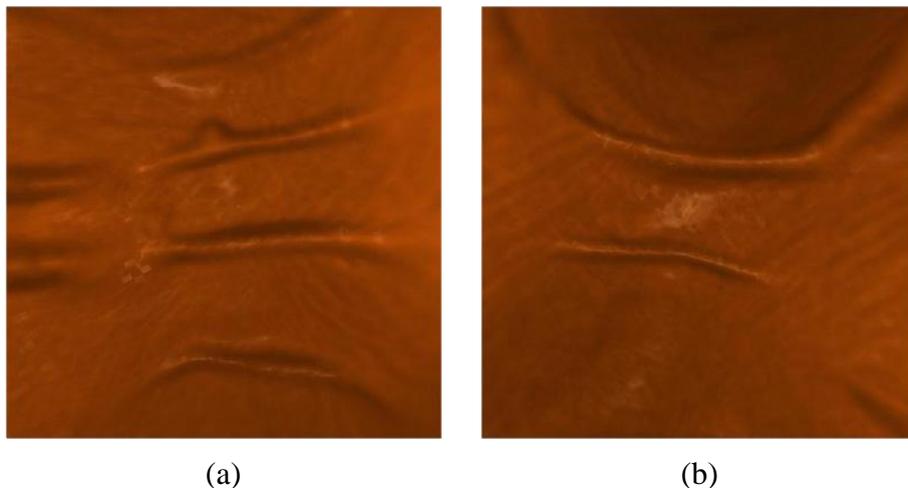
Given a view point o_s on the flattened centerline (or skeleton) in the supine scan, the corresponding view point o_p in the prone scan can be identified (or vice versa). For the supine view, the view vector and up vector intersection points can be identified as s_0 and s_1 . The corresponding points on the flattened prone colon can be then be identified as p_0 and p_1 . Given these points based on the supine view frame, the three view vectors for the corresponding prone view can be created as such:

$$v_{p1} = \frac{p_0 - o_p}{|p_0 - o_p|},$$

$$v_{p0} = \frac{(p_1 - o_p) \times v_{p1}}{|(p_1 - o_p) \times v_{p1}|},$$

$$v_{p2} = v_{p0} \times v_{p1},$$

where the complete prone view frame can then be given as $\{o_p; v_{p0}, v_{p1}, v_{p2}\}$. As before, v_{p0} is the view vector, v_{p1} is the ground vector, and v_{p2} is the up vector. An example of two corresponding endoluminal views using the flattened maps to generate the matching viewpoints is shown in Figure 3.



(a) (b)
Fig. 3. Corresponding views from (a) supine and (b) prone position.

4 Conclusion

We have demonstrated the visualization possibilities presented by integrating shape-preserving flattened colons into a VC system. Using shape-preserving flattening allows for the flattened mesh to be used directly for visual inspection of the colon surface without obstruction due to haustral folds and bends. By using advanced rendering techniques, volume rendering can be used to generate 2D flattened images which preserve the look and feel of the traditional 3D endoluminal view. Also, the use of volumetric ray-casting allows for other rendering techniques, such as electronic biopsy, to be used.

The flattened mesh is not useful only for its own sake. The flattened colon can be used for integration into the 3D endoluminal view present in the typical VC user interface. The flat colon can be used to guide navigation, whereby a point selected on the flattened colon can be used to generate a corresponding view point in the endoluminal view which will present the same region to the user for inspection. If a correspondence between two flattened colons is present which is one-to-one and onto, then they can be used as intermediaries to generate corresponding view points between two different scans in the endoluminal views.

In the future, we hope to explore advanced visualization uses of the shape preserving flattened colon meshes. Doctors are currently more used to viewing the endoluminal view than a flattened view, but we are interested in discovering just how useful the flattened view can be and whether doctors would be more likely to make use of it if further enhancements are introduced to tie it into the VC system.

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References

1. Hong, L., Muraki, S., Kaufman, A., Bartz, D., He, T.: Virtual Voyage: Interactive Navigation in the Human Colon. In: Proc. of SIGGRAPH, pp. 27--34 (1997)
2. Vilanova Bartroli, A., Wegenkittl, R., König, A., Gröller, E., Sorantin, E.: Virtual Colon Flattening. In: Proc. of VisSym '01 Joint Eurographics – IEEE TCVG Symposium on Visualization, pp. 127--136 (2001)
3. Umemoto, Y., Oda, M., Kitasaka, T., Mori, K., Hayashi, Y., Suenaga, Y., Takayama, T., Natori, H.: Extraction of Taeniae Coli from CT Volumes for Assisting Virtual Colonoscopy. In: Proc. of SPIE Medical Imaging, pp. 69160D (2008)
4. Haker, S., Angenent, S., Tannenbaum, A., Kikinis, R.: Nondistorting Flattening Maps and the 3-D Visualization of Colon CT Images. *IEEE Trans. on Medical Imaging.* 19(7), 665--670 (2000)
5. Hong, W., Gu, X., Qiu, F., Jin, M., Kaufman, A.: Conformal Virtual Colon Flattening. In: Proc. of ACM Symposium on Solid and Physical Modeling, pp. 85--93 (2006)
6. Bitter, I., Kaufman, A.E., Sato, M.: Penalized-Distance Volumetric Skeleton Algorithm. *IEEE Trans. on Visualization and Computer Graphics.* 7(3), 195--206 (2001)
7. Wan, M., Dachille, F., Kreeger, K., Lakare, S., Sato, M., Kaufman, A., Wax, M., Liang, J.: Interactive Electronic Biopsy for 3D Virtual Colonoscopy. In: Proc. of SPIE Medical Imaging, pp. 483--488 (2001)