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Feature-Based Texture Display for Detection of Polyps on Flattened Colon Volume

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Abstract-This paper presents a volume-based algorithm to flatten the colon. Based on the flattened colon volume, three different display schemes are adapted to transfer the three-dimensional (3D) flattened colon volume into a 2D image. One display scheme is surface-based rendering, one is volume-based rendering, and the third one is feature-based texture display. These three displays generate not only a traditional flattened-colon surface image, but also a feature-based texture image which can be utilized to characterize and detect the colonic polyps, resulting in a new way to visualize the entire colon.

Keywords: Colon Flattening, Colonic Polyps, Detection, Feature, Texture

1. INTRODUCTION

Colon cancer is the third most common human malignancy and the second leading cause of cancer-related deaths in the United States in 2004. It is estimated more than 130,000 new cases and 56,000 deaths each year. More than 90% colon cancer is developed from adenomatous polyps, which take five to 15 years for malignant transformation. Early detection and removal of the polyps will dramatically reduce the risk of the death. Computed tomography colonography (CTC) is becoming an increasingly important technique for detection of the polyps. It utilizes advanced medical imaging and computer technologies to mimic the fly-through procedure of fiber optic colonoscopy (OC), looking for polyps by navigating through a virtual colon model which is constructed from the patient abdominal CT image [1].

Besides the CTC navigation through a virtual colon, flattening and unraveling the colon-wall surface has also been explored by many researchers [2]. This latter technique allows the physicians to view the whole colon surface quickly. A straightforward flattening method starts with a centerline of the colon. Along the centerline curve, a sequence of cross-sectional images is generated orthogonal to the centerline. By a 360-degree radial sampling of a cross-sectional image, a corresponding radial or flattened image is obtained, in which the colon boundary enclosure in the cross-sectional image becomes a curve along the x-axis if the sampled radii are placed along the y-axis. Piling all these flattened images along the centerline, a flattened volume is obtained for image rendering. This flattening method can actually transform the whole three-dimensional (3D) colon wall of a pipe shape into a single 2D slice image. However it encounters a major problem in a high curvature section on the centerline. To overcome this shortcoming, several approaches have been proposed. For example, Wang, *et al.* [2] utilized an artificial electrical field to unravel the colon surface. Paik, *et al.* [3] proposed a visualization technique which uses the cylindrical and planar mapping to project the whole colon wall on to a cylinder-likely plan. Hacker, *et al.* [4] employed a conformal texture mapping algorithm to unravel the whole colon surface onto a 2D plane. Bartrol, *et al.* [5] presented an unfolding method for the colon surface in which a nonlinear ray tracing and 2D scaling technique are used to parameterize the whole surface into a 2D grid. All these flattening methods perform satisfactorily on unraveling the colon surface. However, they overlook the internal image intensity information for a potential improvement in detection of the polyps using the flattened dataset.

In this paper, we propose a new flattening and display method to enhance the detection of the polyps. Firstly, a volume-based flattening algorithm is presented. This algorithm combines the centerline-based distance map and the boundary-based distance map to parameterize the whole colon surface without double sampling. Then a flattened volume is generated by the constrained sampling along the boundary-based distance map. Comparing to the previous flattening methods, this new algorithm focuses mostly on the neighborhood relation in the final flattened volume. It remains both the shape and intensity information. Based on the flattened volume, three different display schemes are introduced. By these three display schemes, not only the traditional surface image but also the intensity feature image can be created for detection of the polyps.

The content of this paper is organized as follows. Section 2 presents the new flattening algorithm and the three display schemes. Some experimental results are reported in Section 3, followed by discussion and conclusion in Section 4.

2. METHODS

2.1. Volume-Based Colon Flattening Algorithm

Given an acquired CT image of the colon V, we can obtain the colon-wall mucosa surface B and its corresponding centerline curve C. Based on the surface and the centerline curve, we create two different distance maps: a centerline-based distance map and a boundary-based distance map. For each voxel in the centerline-based distance map, a value is assigned that indicates the minimum distance from its position to the centerline. Correspondingly, this value also indicates the nearest distance to the colon wall boundary in the boundary-based distance map.

Along the whole centerline curve C, a series of sample point $\{C_u\}$ are defined with a fixed interval. At each sample point C_u, a constant number of rays are emitted from this point. Initially all these rays are emitted evenly on the plane orthogonal to C by a constant angular interval. For a given

initial ray $r_{u,v}$, a new sampling starts to move along the direction defined by the gradient of the centerline-based distance map until it reaches the colon wall surface. Thereafter the new sampling crosses the colon wall surface and moves further forward along the direction defined by the gradient of the boundary-based distance map. Along this newly-sampled path, a series of intensity values $s_{u,v,w}$ are obtained with a fixed distance interval. Collecting all these sampled intensity values into a regular grid, a new volume $\{s_{u,v,w}\}$ is then generated.

Different from the previous surface-based flattening methods, this volume-based flattening algorithm generates a 3D flattened volume instead of a 2D flattened surface. Comparing to a 2D flattened surface, a flattened volume preserves more shape and intensity information of the colon. It is expected that the preserved information would generate more accurate features for detection of the polyps. As described in [5], the centerline-based distance map will "push" the rays to be perpendicular to the centerline curve as much as possible. The nature of the distance gradient map can also avoid the intersection of any two rays except on the surface so that a double appearance of a polyp will not occur in the newly-flattened volume. At the same time, the boundary-based distance map will guarantee that any two adjacent samples along a ray have a closet-distance connection so that the flattened volume will retain the original intensity neighborhood information as much as possible.

2.2. Feature-Based Texture Display of Flattened Volume

After the flattened volume is generated, display of the volume will play a crucial role for detection of the colonic polyps. Three different display schemes are presented.

One of the display schemes is based on a traditional surface rendering. Using the lighting model [4, 5], the whole colon wall surface can be extracted from the volume and rendered into a 2D texture image. This display scheme can simulate the real flattening result and provide a realistic rendering image. A typical polyp can be detected by the shape and lighting/shadow information using the lighting display scheme. The lighting scheme has been widely utilized in the previous colon flattening researches [4, 5].

Another display scheme is based on intensity-mapping rendering. In this scheme, each voxel is assigned a specific color and opaque values according to its CT intensity. Then the whole 3D volume is transformed into a 2D texture image using the volume-based rendering technology. This display scheme does not provide the pure surface information, instead it provides the intensity distribution information along each ray, which is hidden behind the surface.

The observations of our previous research [6] as well as other researchers' reveal that the CT density values within a polyp are not uniform. Furthermore, the variation of the density values shows a specific pattern, which can be utilized as an indicator for polyp identification. Based on this feature, a new display scheme is proposed to show the intensity

variation pattern for polyp detection. Given a voxel v in the volume, three engivalues from its Hessian matrix can be obtained. Without loss of generality, we suppose the three engivalues are λ_1, λ_2, and λ_3 (with $|\lambda_1| \geq |\lambda_2| \geq |\lambda_3|$). For each pair of the engivalues (λ_i, λ_j), we calculate the corresponding pattern parameters $PA_{i,j}$ by:

$$PA_{i,j} = -\frac{2}{\pi}\arctan\left(\frac{\lambda_i + \lambda_j}{|\lambda_i - \lambda_j|}\right), \quad (i,j|i,j \in \{1,2,3\}, i \neq j) \quad (1)$$

The minimum parameter value in the triple-element vector $<PA_{1,2}, PA_{1,3}, PA_{2,3}>$ is defined as the growth indicator for the corresponding voxel. This growth indicator is sensitive to some specific intensity variation pattern which reflects a typical pattern of the polyp voxles. By mapping the growth indicators into different color and opaque values, a feature-based flattening image can be generated using the volume-based rendering technology. Similar to the intensity-mapping display scheme, this scheme can also provide the intensity information behind the colon wall. Since the polyps show different intensity variation pattern than the colon fold and residual material do, this feature-based texture-display scheme can improve detection of the polyps.

3. RESULTS

Three patient CT datasets were used to verify the new flattening algorithm and the three different display schemes. These datasets were acquired from patients who followed a gentler bowel preparation with low-residue diet and oral contrast tagging of the colonic material. A single-slice spiral CT scanner was used with clinically available protocols to cover the entire abdominal volume during a single breath-holding acquisition time period. Each patient study included both supine and prone scans. The detector collimation was 5mm and the images were reconstructed as 1mm thickness of 512×512 arrays.

Figure 1 shows the three different display images of one flattened colon volume. In this colon, there is a polyp whose size is 6mm in diameter. The shape of the polyps is clearly seen in the flattened image with the traditional lighting display. Some specific color pattern in the flattened image with the intensity mapping display can be observed, even this special pattern is somewhat difficult to identify. In the flatten image with the feature-based texture display, the polyp shows its special color pattern that is different to its neighborhood pattern and, therefore, can be identified easily.

In the second dataset, there is a polyp whose size is 10mm in diameter. However this polyp was pressed by its surrounding colon wall and its shape deformed by some degree during the CT scan. On the flattened image with the lighting display scheme, this polyp does not show the traditional shape. However, some specific color pattern still occurs in the intensity-mapping display image and the feature- based texture display image, see Figure 2. A different texture feature is clearly seen in the feature-based display.
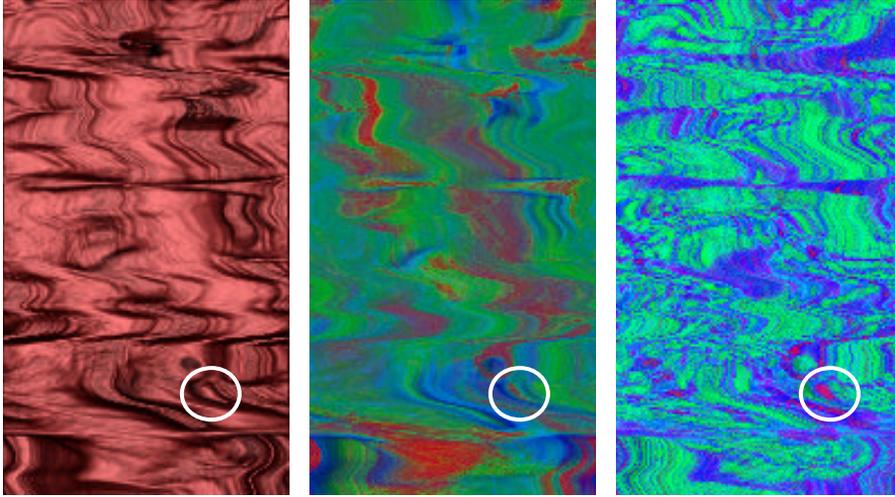
Figure 1. The three different display images of a flattened volume (part). Left picture shows the traditional lighting display. The polyp is indicated by the white circle. Middle picture is the intensity-mapping display. Right picture is the feature-based display, where the polyp feature is clearly seen.
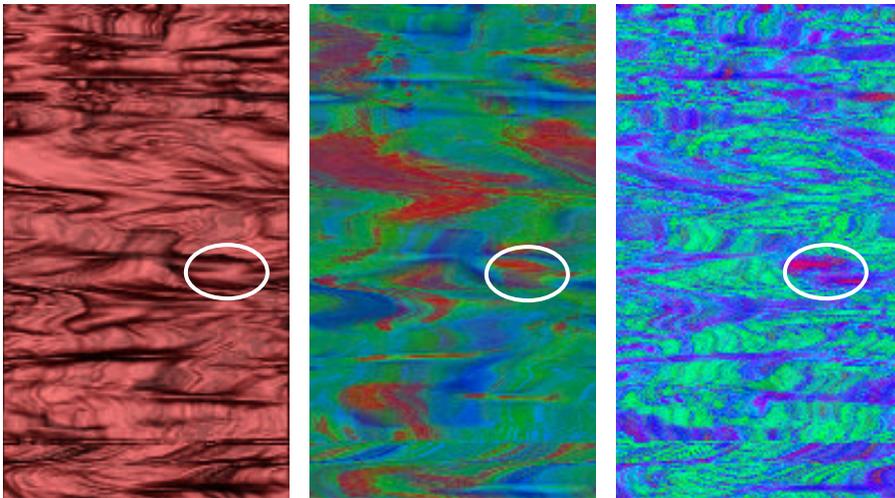
Figure 2. The three different display images of another flattened volume (part). Left picture shows the traditional lighting display. The polyp indicated by the white circle is deformed and compressed by its adjacent colon fold. Middle picture is the intensity-mapping display. Right picture is the feature-based texture display, where a different texture feature is clearly seen.
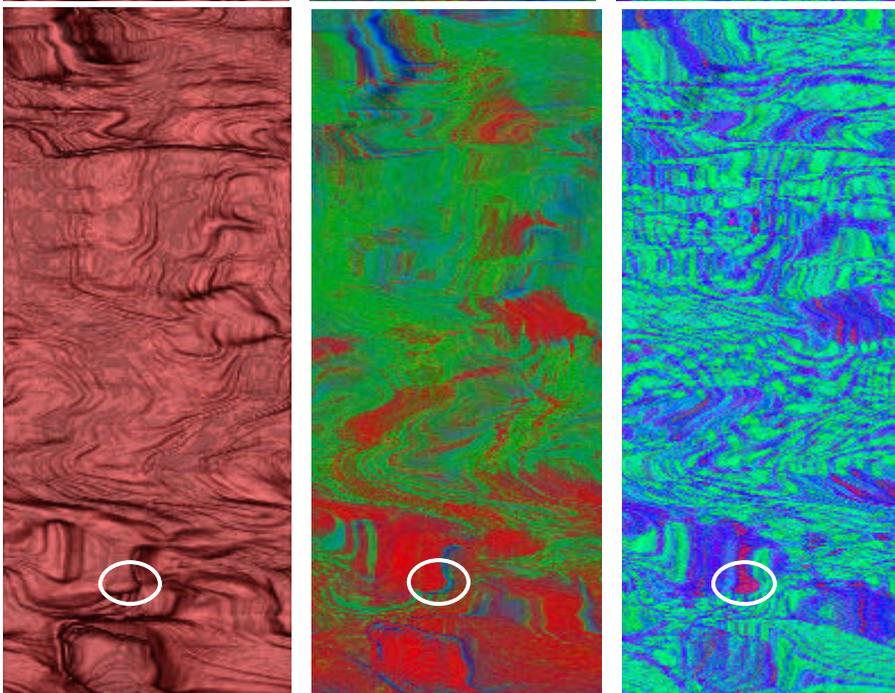
Figure 3. The three different display images of the third flattened volume (part). Left picture shows the traditional lighting display. The polyp is indicated by the white circle. Middle picture is the intensity-mapping display. Due to the intensity change, it is impossible to identify the polyp from this image. Right picture is the feature-based texture display. The polyp can be seen clearly.
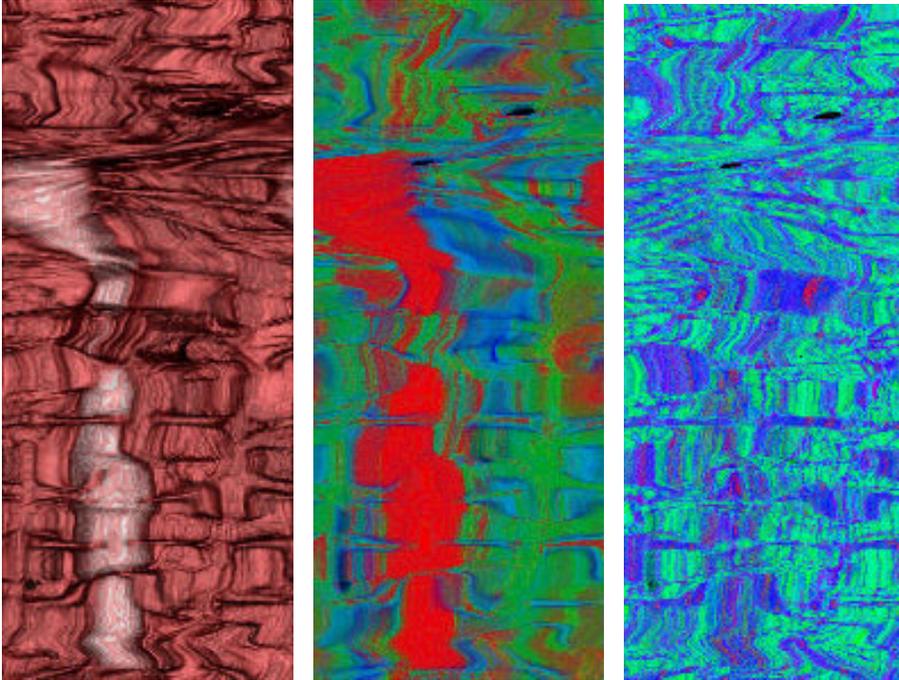
Figure 4. The three different display images of the third flattened volume (another part). Left picture is the traditional lighting display. There is some residual fluid left in the flattened volume (indicated by the white color). The residual fluid affects the shape of the colon wall (from convex to concave). Middle picture shows the intensity-mapping display. Due to the intensity change, the residual fluid is marked by the same color pattern of the polyp. Right picture is the feature-based texture display. There is no significant change in this texture-display image.

The third dataset contains a polyp with 6mm size in diameter. For this dataset, both the lighting display and the featured-based display show good information for polyp detection, see Figure 3. However the intensity-mapping display can not provide useful information. There is some retained residual fluid in the colon of this dataset. This fluid is "flattened" by the flattening algorithm. From the image of the lighting display, see Figure 4(left), the residual fluid affects the shape of the colon wall and makes the real colon wall invisible in the image. At the same time, the residual fluid also affects the intensity of the normal colon wall. The intensity-mapping display image can not provide useful information on the colon wall, see Figure 4(middle). Fortunately, the growth indicator can overlook this side effect from residual fluid. There is no misleading information from the residual fluid as shown in Figure 4(right).

4. DISCUSSION AND CONCLUSION

In this paper, a volume-based colon flattening algorithm was presented. Based on the flattened volume dataset, three different display schemes were investigated to show useful information for detection of colonic polyps on a 2D slice image. Research findings show that the flattened slice image can provide a faster way and clearer view to identify the polyps than the endoscopic view in CTC. Comparing to the previous surface-based flattening methods, the volume-based flattening algorithm can retain more information in the flattened volume. For example, using the flattened volume, the surface-based flattening result can be simulated using the lighting display scheme. Furthermore, more information can be provided using the intensity-mapping display and feature-based texture display. The intensity-mapping display is sensitive to the intensity change. Without the effect of the residual material, it is possible to distinguish the real polyps from the normal tissues using the intensity-mapping display. Comparing to the intensity-mapping display, the growth feature is more robust to the residual and other effects. Furthermore, it is sensitive to some typical intensity variation pattern associated with polyps. It shows potential to improve the polyp detection on the flattened colon dataset. Combining all these three display schemes, the polyps can be identified quickly and correctly.

Although the improvement using different display schemes on the flattened colon volume dataset is observed, our research still stays at the initial stage. Further improvement on the non-distorting flattening algorithm, alternative combination of the three display schemes, and more investigation on the features are currently under progress.

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