

Electronic Colon Cleansing Using Segmentation Rays for Virtual Colonoscopy

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ABSTRACT

We present an electronic colon cleansing algorithm using a new segmentation technique based on segmentation rays. These rays are specially designed to analyze the intensity profile as they traverse through the dataset. When this intensity profile matches any of the pre-defined profiles, the rays perform certain task of reconstruction. We use these rays to detect the intersection between air and residual fluid, and between residual fluid and soft-tissue. One of the most important advantages of segmentation rays over other segmentation techniques is the detection of partial volume regions. Segmentation rays can accurately detect partial volume regions and remove them if needed. Once partial volume is eliminated, removal of other unwanted regions (e.g., tagged fluid) is relatively easy. This approach to electronic cleansing is extremely fast as it requires minimal computation.

Keywords: Virtual colonoscopy, electronic cleansing, segmentation rays, cancer diagnosis, 3D medical imaging

1. INTRODUCTION

Cancer of the colon has been reported to be the second leading cause of death from cancer in the United States. This mortality could be reduced if cancerous colon polyps were detected and removed in the early stages of their malignancy¹. Various health organizations like the American Cancer Society, the American College of Physicians and the World Health Organization have thus recommended a colon exam every 3 years after the age of 50, for the detection of these polyps. Unfortunately, most patients do not follow their physician's advice to undergo such a procedure because of the pain, risk, discomfort and high cost associated with the current optical colonoscopy techniques. Consequently, a non-invasive, low-cost, accurate and comfortable alternative to the existing techniques would be extremely valuable.

The State University of New York (SUNY) at Stony Brook has pioneered the development of one such system, called *Virtual Colonoscopy*²³⁴⁵, which uses advanced computer graphics and visualization techniques. The current system roughly involves four steps. First, the patient's colon is cleansed and inflated with CO_2 in a way similar to that of optical colonoscopy. Second, a helical CT scan of the patient's abdomen is taken such that it covers the entire colon. This takes about 30-40 seconds and can be done in a single breath hold. The scan produces several hundred slices of 512x512 resolution. In the third step, these slices are reconstructed into a 3D volume of 100-250 MB. This volumetric data then undergoes a series of pre-processing stages which are required for the virtual navigation. The most important of these stages is the accurate segmentation of the colon lumen, which is the interior of the colon, from the original CT images. In the final step, we use accurate volume rendering for virtual navigation through the inside of the colon, to detect polyps.

All current colonoscopy techniques, including the virtual colonoscopy, require a clean colon lumen for accurate detection of the polyps. Residual materials inside the colon could be falsely interpreted as part of the colon. Thus, as the preparation for colonoscopy, the patient undergoes a physical bowel cleansing. This includes washing the colon with large amounts of liquids and administering medications and enemas to induce bowel movements. This bowel preparation is often more uncomfortable and unpleasant than the examination itself. An alternative technique which does not require this uncomfortable cleansing would be a boon to the patients. As a result, a new bowel preparation scheme has been developed at SUNY Stony Brook⁶⁷. This would lead to a more comfortable colonoscopy procedure for the patients.

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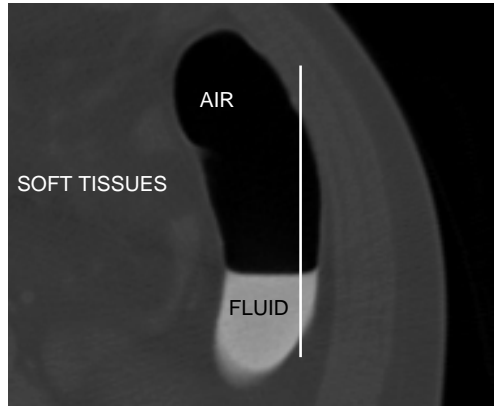


Figure 1: A traverse slice showing a part of the colon.

The basic idea of the new bowel preparation scheme is to enhance the intensity of stool and fluid so that they can be digitally removed from the dataset. The patient is asked to remain on a soft-food diet (yogurt, cereals, mashed potatoes etc.) for an entire day. Three bottles of a density-enhancing fluid is taken by the patient with each meal. Some additional solutions are also taken by the patient for the purpose of liquidizing and enhancing the stool. The colon is then distended with carbon dioxide (CO_2 gas of approximately 1000cc) via a rectal tube.

A CT scan of the patient's abdomen is then taken and reconstructed into a 3D dataset. The dataset is then passed through the segmentation process to clean the colon lumen, making it devoid of all residual materials for a virtual screening. Accurate segmentation of the colon lumen, is thus as critical as accurate rendering for detection of malignant polyps.

In the next section we present the problems faced in segmenting the dataset generated from the new bowel preparation. We also show why contemporary segmentation approaches are not good enough for accurate results. We then describe our new approach.

2. NEED FOR A SOPHISTICATED SEGMENTATION

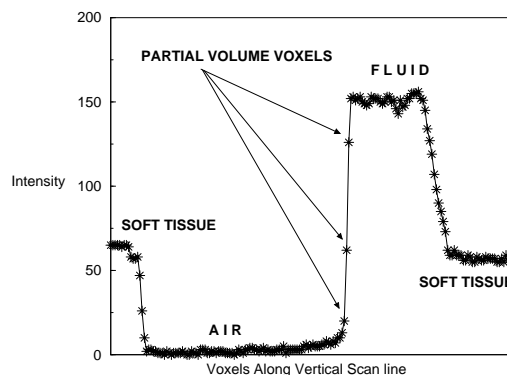


Figure 2: Intensity profile at the boundary of air and fluid.

The CT data obtained after the new bowel preparation is much more complex than the one obtained from a pre-cleansed bowel. The complexity arises because of the large amount fluid and stool residing inside the colon (Figure 1). Although these unwanted residues have been enhanced, they do not have a clear boundary due to partial volume effect. The situation is even worsened by the finite resolution and low contrast of the CT scanner. We now discuss the unusability of naive segmentation approaches.

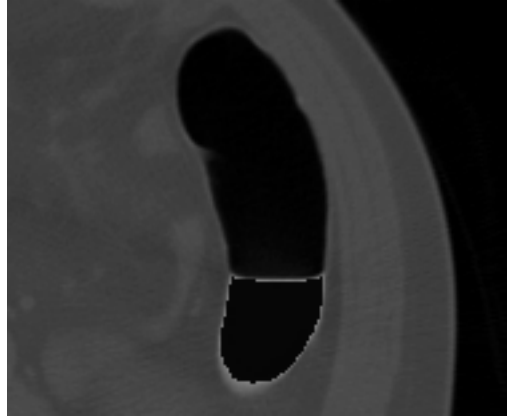


Figure 3: Result of segmentation by thresholding.

2.1. Segmentation by thresholding

The simplest segmentation approach is thresholding. The human abdomen consists mainly of three distinct density regions: air, soft-tissues, and high density materials (which include the bone). A CT scan assigns different intensities to these materials and we classify them based on these intensities. Our previous virtual colonoscopy system, which needed physical colon cleansing in the bowel preparation stage, successfully used thresholding to segment the colon lumen³⁴. However, with our new bowel preparation scheme, bones are not the only high density material present in the abdomen. Residual fluid and stool, which were enhanced, also have CT image intensities similar to those of bone, thus complicating the segmentation. Although thresholding gives the fastest results, it has many disadvantages which we list below.

First, thresholding does not remove partial volume voxels. Figure 2 shows the intensity profile along a vertical line from top to bottom as shown in Figure 1. We observe that, at the boundary of two regions with different intensities lie voxels, whose intensities do not match either of the two regions. We name these voxels the *Partial Volume Effect (PVE)* voxels. These voxels are undesirable since they are incorrectly classified when thresholding is used. For example, in Figure 2, the voxels between the fluid and the air lie in the soft-tissue range. Hence, they are marked as soft-tissue voxels and would not be removed. The adverse effect on segmentation is immediately evident and is shown in Figure 3. Although the high density fluid/stool has been removed, a thin soft-tissue-like boundary still exists, which is not present in reality.

Second, the threshold for each range of intensities are very sensitive. A slight change to these thresholds could lead to a change in the outcome of the segmentation, especially the contour of the inner surface of the colon.

Third, thresholding also gives rise to aliasing effects at the inner colon boundary. It is immediately evident when we take a closer look at the segmented volume (Figure 4). The intensity values move sharply from soft-tissue range to air-range. This is undesirable from the point of view of the volume rendering. A sharp boundary also means the absence of thin colonic mucosa that is present on the inner surface of the colon. Colonic mucosa is key to the detection of the polyps and hence its removal is undesirable. For comparison, we also show an example interior surface of the colon (the mucosa) where no stool was attached to it (Figure 5).

2.2. Segmentation by morphological operations

A succession of morphological operations such as dilates and erodes could be used for segmentation⁸. For example, we could perform a flood-fill on all the fluid and stool regions, and then use a sequence of dilates and erodes to remove the *PVE* voxels. However it is well known that dilates followed by erodes can fill in holes and erodes followed by dilates can remove noise⁸. Thus, they could affect the inner contour of the colon as it is highly twisted and has a very rough surface.

This method would also require seed points to be placed in each and every region filled with fluid or stool for performing the flood-fill. This could be a cumbersome task considering the large number of such regions. In addition, it may require a lot of human intervention. This could also slow down the entire process of segmentation and may result in some fluid/stool regions being neglected.

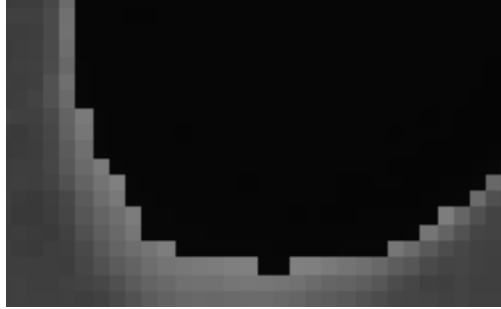


Figure 4: Aliasing effects of segmentation by thresholding.

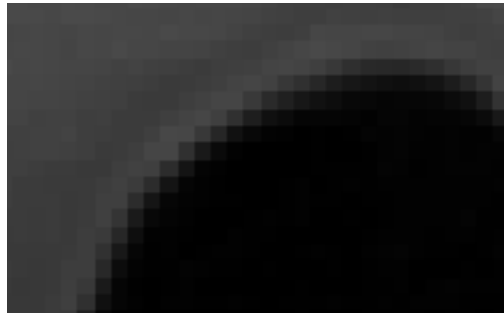


Figure 5: A normal colonic mucosal surface without fluid or stool attached to it.

3. SEGMENTATION USING SEGMENTATION RAYS

The basic idea behind our approach is that the intersection of two distinct-density regions possesses a unique property. This property is the unique intensity profile at each intersection as we move in a direction normal to the intersection. While doing so, we pass through the *PVE* voxels present at the intersection before reaching the other region. We can thus identify these *PVE* voxels accurately and remove them.

The unique intensity profiles for different intersections are studied and stored beforehand. These were found to be the characteristic of the intersection of the two regions and they do not depend on the CT scanning protocol.

The next step of our algorithm aims at detecting the intersections based on its characteristic properties. This is done by casting rays through the volume and comparing the intensity profile graphs along the ray to the intensity profiles of different intersections. If there is a match, the ray has successfully detected the intersection. We call these rays the *Segmentation Rays*⁹ as they assist in the segmentation.

We further optimize our algorithm so that we do not cast rays where we know for sure that there is no intersection. Here we exploit the fact that the interior of colon is filled with air. Applying region growing on the air voxels from a seed point inside the colon gives a rough contour of the colonic interior. We then cast *segmentation rays* outwards from the boundary of this air region. We are thus casting rays only at the intersection of air with other regions.

Once a ray detects an intersection, a certain task is performed. This primarily involves removing the *PVE* voxels present at the intersection by either classifying the voxels or altering their intensity values for reconstructing the mucosa. By the end of this, we have detected and eliminated most of the *PVE* voxels.

For the remaining *PVE* voxels, which are at the intersection of fluid and soft tissues, we use *Volumetric Contrast Enhancement* which is a volumetric extension to the *contrast enhancement* used in image processing. This results in the reconstruction of mucosa, which was completely lost due to the high density fluid. The step also removes the remainder of fluid from the colon.

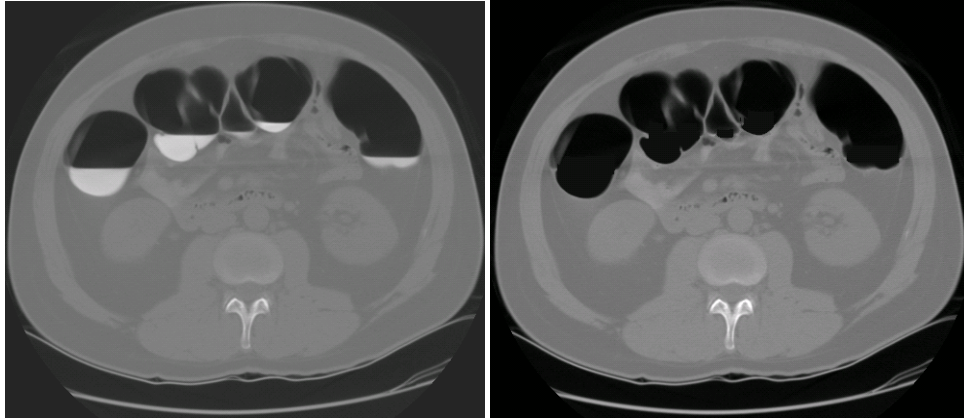


Figure 6: A traverse slice before (left) and after (right) electronic cleansing.

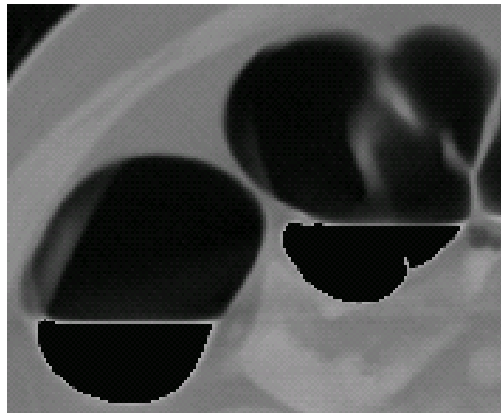


Figure 7: Result of segmentation by thresholding.

4. RESULTS

Our fully automatic segmentation method was tested on a variety of CT datasets obtained with the new bowel preparation. We use one of our case study datasets of size 512x512x411 to show the results here. Since the patient did not undergo any colon-cleansing prior to the scan, there was a significant amount of residual fluid inside the colon. A thin layer of stool was found to be attached to the colonic mucosa in many places.

Our algorithm removed all the fluid and stool voxels accurately (Figure 6). Our method was able to detect and remove stool deposits as thin as one voxel thick which is about 0.7 mm. We were also able to unearth all the mucosa voxels lying below the fluid at the intersection of fluid with colon wall. We also compare our results (Figure 9) with thresholding (Figure 7) and vector quantization (Figure 8).

The average time taken for electronic cleansing (for datasets with about 400 slices of 512x512 resolution each) was 1 min on a Linux workstation (900MHz AMD).

5. CONCLUSION

We presented an electronic colon cleansing technology based on segmentation rays. The advantage of segmentation rays over other segmentation approaches is in the detection of partial volume regions. Segmentation rays can accurately detect partial volume regions and remove them if needed. Once partial volume is eliminated, removal of other unwanted regions (e.g., tagged fluid) is straight-forward (e.g., by using thresholding). This approach to electronic cleansing is extremely fast as it requires minimal computation.

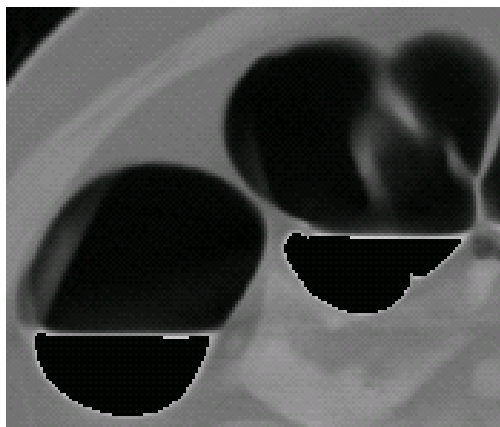


Figure 8: Result of segmentation by vector quantization.

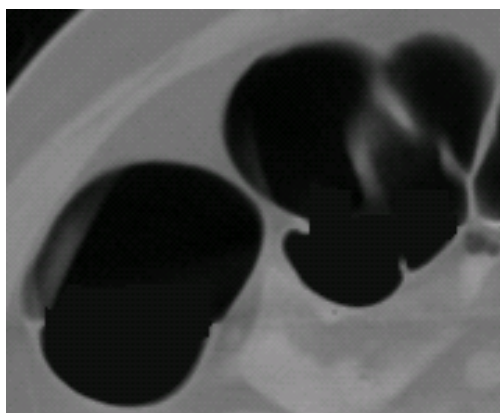


Figure 9: Result of electronic cleansing using segmentation rays.

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REFERENCES

1. J. Mandel, J. Bond, J. Church, and D. Snover, "Reducing Mortality from Colon Cancer Control Study," *New England Journal of Medicine* **328**, pp. 1365–1371, 1993.
2. W. Lorensen, F. Jolesz, and R. Kikinis, "The Exploration of Cross-Sectional Data with a Virtual Endoscope," *Interactive Technology and the New Medical Paradigm for Health Care*, eds. R. Satava and K. Morgan, pp. 221–230, 1995.
3. L. Hong, A. Kaufman, Y. Wei, A. Viswambharn, M. Wax, and Z. Liang, "3D Virtual Colonoscopy," in *Proc. Symposium on Biomedical Visualization*, pp. 22–32, 1995.
4. L. Hong, S. Muraki, A. Kaufman, D. Bartz, and T. He, "Virtual Voyage: Interactive Navigation in the Human Colon," in *Proc. SIGGRAPH*, pp. 27–34, 1997.
5. M. Wan, Q. Tang, A. Kaufman, Z. Liang, and M. Wax, "Volume Rendering Based Interactive Navigation Within The Human Colon," in *Proc. IEEE Visualization*, pp. 397–400, 1999.

6. Z. Liang, F. Yang, M. Wax, J. Li, J. You, A. Kaufman, L. Hong, H. Li, and A. Viswambharan, "Inclusion of *A Priori* Information in Segmentation of Colon Lumen for Virtual Colonoscopy," in *Conf Record IEEE NSSS-MIC, CD-ROM*, 1997.
7. M. Wax, Z. Liang, D. Chen, B. Li, R. Chiou, A. Kaufman, and A. Viswambharan, "Electronic Colon Cleansing for Virtual Colonoscopy," in *1st Intl Conference on Virtual Colonoscopy*, (Boston, MA), Oct. 1998.
8. K. H. Hohne and W. Hanson, "Interactive 3D Segmentation of MRI and CT Volumes using Morphological Operations," *Journal of Computer Assisted Tomography* **16**, pp. 285–294, Mar. 1992.
9. S. Lakare, M. Wan, M. Sato, and A. Kaufman, "3D Digital Cleansing Using Segmentation Rays," in *IEEE Visualization*, pp. 37–44, 2000.