Computer Aided Polyp Detection with Texture Analysis

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Abstract. We present a novel pipeline for computer-aided detection (CAD) of colonic polyps by integrating texture analysis with volume rendering and conformal colon flattening. Using our method, the 3D polyp automatic detection problem is converted into a 2D image analysis problem. The colon surface is first segmented and extracted from the CT data set of the abdomen, which is then mapped to a 2D rectangle using conformal mapping. This flattened colon is rendered using a direct volume rendering technique with a translucent electronic biopsy transfer function. The polyps are detected by a 2D clustering method on the flattened image. The false positives are further reduced by analyzing the volumetric shape features of suspicious regions. Compared with shape based methods, our method is more efficient without the need of computing curvature and other shape parameters for the whole colon wall.

1 Introduction

The anticipated large amount of interpretation effort associated with the virtual colonoscopy screening procedure suggests a computer-aided detection (CAD) scheme. A CAD scheme that automatically detects the locations of the potential polyp candidates could substantially reduce the radiologists' interpretation time and increase their diagnostic performance with higher accuracy. However, the automatic detection of colonic polyps is a very challenging task because the polyps can have various sizes and shapes. Moreover, there are numerous colon folds and residual colonic materials on the colon wall that mimic polyps and could result in false positives (FPs). A CAD scheme should have the ability to identify the true polyps and eliminate the FPs.

Wan et al. [1] have observed that the internal tissues of polyps have a slightly higher density and different texture than healthy tissues. These high density areas are beneath the colon wall and cannot be seen during an optical colonoscopy. However, the internal structure of a polyp can be revealed through volume rendering with a translucent transfer function, called electronic biopsy. Fig. 1 shows the electronic biopsy images of four different kinds of objects. Although polyps and normal tissues may have similar shapes, it is observed that adenomatous polyps have a higher density and a different texture beneath the surface. Retained stool, however, has a uniform high density inside the whole object with sharp boundaries due to the colonic material tagging, while a hyperplastic polyp does not have any high density voxels. Adenomas and tubulovillous adenomas have high density voxels gradually transferring to normal tissues with an irregular structure. The tubulovillous adenomas may have high densities hidden behind normal tissue, which does not have an abnormal shape or the usual bulb shape of

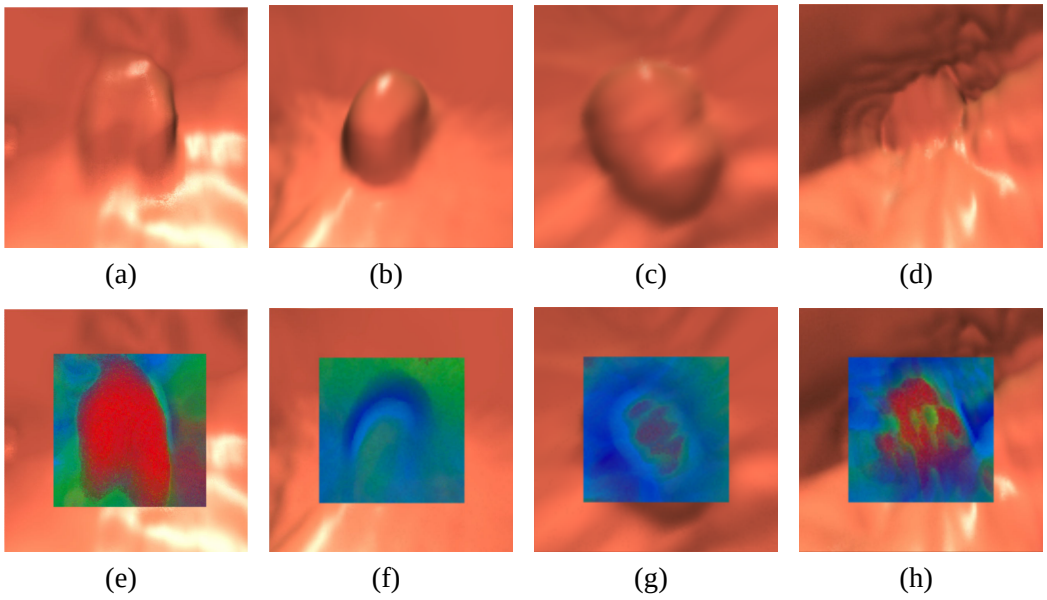


Fig. 1. (a)-(d) surface rendering results of (a) retained stool, (b) a hyperplastic polyp, (c) an adenoma, and (d) a tubulovillous adenoma. The small square images in (e)-(h) are the electronic biopsy rendering results of the respective objects in (a)-(d), all with the same transfer function. In the electronic biopsy images, the red color represents the highest densities and blue represents the lowest densities. Green represents tissues of medium densities. Normal tissues have low to medium densities.

polyps. These observations suggest that polyps can be detected by analyzing the electronic biopsy image of the whole colon. However, due to the haustral folds and complex shape of the colon, it is very hard to cover the entire colon surface with one electronic biopsy image. Although we can render multiple biopsy images for full coverage during navigation, this approach increases the computation burden and complicates the algorithm due to the overlapping among multiple images. Therefore, we first conformally map the colon surface to a 2D rectangle for electronic biopsy image rendering, which simplifies the polyp detection problem from a 3D volume to a single 2D image.

2 CAD Pipeline

Fig. 2 shows the overview of our texture analysis based CAD pipeline. Digital cleansing aims to segment the colon lumen from a patient's abdominal data set acquired using an oral contrast agent for colonic material tagging, and to cleanse the colon lumen of all tagged material, so that a virtual colon model can be constructed. An iterative partial volume segmentation algorithm [2] is used to classify the voxels in the colon lumen as air, mixture of air with tissue, mixture of air with tagged materials, or mixture of tissue with tagged materials. Then, the CT density values of the colon surface tissue are recovered.

In the colon surface extraction step, the simple point concept is incorporated with a region growing based algorithm to extract a topologically simple segmentation of the

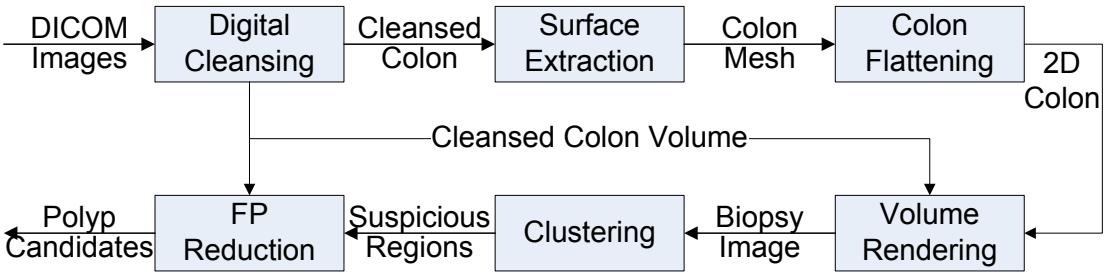


Fig. 2. Texture analysis based CAD pipeline.

colon lumen. The algorithm detects whether adding or removing a point from the colon lumen will change the topology [3]. Then, an enhanced dual contour method [4] extracts a simplified smooth colon surface while preserving the topology of the finest resolution colon surface.

We have developed the algorithm [5] to compute the conformal map between the colon surface and a 2D rectangle. The conformal mapping is an angle preserving method, which means that the shape information of the colon surface is preserved. This conformal mapping simplifies our polyp detection problem from 3D to 2D. Geometric features and texture features can be computed in 3D and mapped to 2D.

The electronic biopsy technique uses a volume rendering algorithm to present the information inside the colon wall on a 2D image. It uses a pseudo-color transfer function to assign color and opaque values to CT intensities. Then, the 3D volume is transformed into a 2D texture image based on our flattened colon using a volume rendering technique. This 2D texture image provides the density distribution information along each ray, which is hidden behind the colon surface.

It is observed that similar color features appear in a contiguous area in several regions of the 2D electronic biopsy image. It is reasonable to classify these features within a certain range in the 2D image. The RGB values of the given pixel and its twelve neighboring pixels form a 39-dimensional local feature vector.

Consequently, a high resolution flattened electronic biopsy image is used in our CAD system, where each pixel has a 39-dimensional local feature vector. It requires intensive computational effort to manipulate such a large quantity of vectors. To reduce the computing burden, a feature analysis of the local vector series is necessary. Principal component analysis (PCA) is applied to the local vector series to determine the dimension of the feature vectors and the associated orthogonal transformation matrix (i.e., the K-L transformation matrix). The PCA on the training data sets shows that a reasonable dimension of the feature vectors is 7, where the summation of the first 7 principal components variances is more than 96.5% of the total variance.

The K-L transformation matrix is applied to the local vector series belonging to hand segmented polyps on the 2D flattened electronic biopsy images. In the K-L domain, the feature vectors are formed by the first 7 principal components from the transformed vector series. The mean vector of these feature vectors is computed and used as the representative vector V of the feature vectors belonging to polyps. The square root

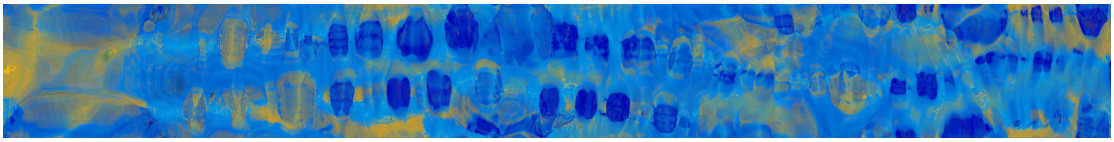
of the variance of these feature vectors is also computed and used as a threshold T for vector similarity in the clustering.

For a given testing data set, we use the representative vector V and similarity threshold T to classify the feature vectors in the K-L domain. If the Euclidean distance between a feature vector and V is less than T, the corresponding pixel is classified as belonging to a polyp. A 2D image is generated where the pixels classified as belonging to a polyp are shown in red. The red regions in this 2D image are highly suspicious of being polyps, indicating that the physicians should examine these areas in the 3D view very carefully.

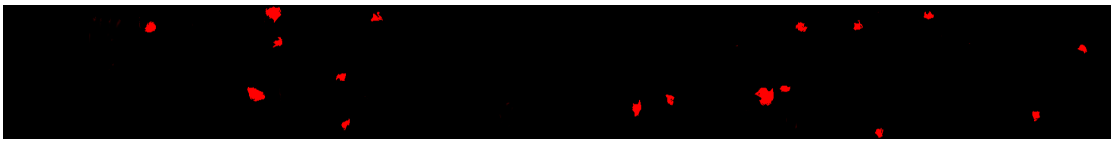
After the clustering algorithm, the pixels classified as belonging to a polyp are marked. We first use a labeling algorithm to extract the connected components on the 2D image. Since we only consider polyps with a diameter larger than 5 mm, a smaller component is classified as a false-positive finding. Consequently, many small components are removed.

The false positive findings are further reduced by analyzing the shape features, i.e., the shape index and curvedness [6]. In our pipeline, we compute these features as in existing shape based methods. However, the critical difference is that we only compute these features on several suspicious areas for FP reduction, rather than for the entire colon.

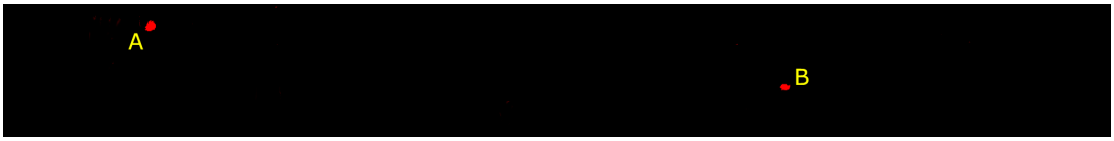
3 Results



(a) The electronic biopsy image generated using our conformal colon flattening and ray casting.



(b) Suspicious regions detected by our clustering algorithm.



(c) Polyp candidates obtained after FP reduction using shape analysis and 3D texture analysis.

Fig. 3. Results for a partial segment of a colon data set.

Our texture analysis based polyp detection algorithm has been tested with 52 NIH data sets and 46 Stony Brook University Hospital (SBUH) data sets. Fig. 3 shows the biopsy image, the suspicious regions detected in the clustering, and the polyp candidates

obtained after FP reduction for a partial segment of a colon data set. Virtual colonoscopy and optical colonoscopy reports have been used to evaluate the performance of our algorithm. Ten NIH data sets have been used for training the algorithm. Our experimental results showed that our pipeline found all the 58 polyps in the NIH data sets and the 65 polyps in the SBUH data sets. Consequently, our system is 100% sensitive to polyps and yielded an average of 3.0 FPs per data set (average of 3.1 in the NIH and 2.9 in the SBUH data sets).

4 Ongoing Work

Different from previous shape based methods, the presented system first detects polyps on 2D electronic biopsy images rendered from conformally flattened colons. Then, the expensive shape analysis and 3D texture analysis are applied on suspicious areas to reduce false positives. The volume rendering technique transforms the information from 3D to 2D, which significantly reduces the computation burden and data size. However, volume rendering also loses information due to compositing. Moreover, it may cause over and under sampling at some regions. Also, the ray termination is controlled by the accumulated alpha value or by a rough estimation of the colon thickness. Therefore, we have developed and been implementing a new pipeline of texture analysis. We have used a level set based method to segment the volumetric colon (the volume bounded by the inner and outer wall of the colon). Then, the tetrahedral mesh of the volumetric colon is conformally flattened to a thin cuboid, in which the top and bottom surfaces correspond to the inner and outer colon wall. Finally, 3D image analysis methods are used to detect the polyps in the cuboid. Hexagonal and face-centered cubic (FCC) lattices may be used for better angular invariance.

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References

1. Wan, M., Dachille, F., Kreeger, K., Lakare, S., Sato, M., Kaufman, A., Wax, M., Liang, J.: Interactive electronic biopsy for 3D virtual colonoscopy. SPIE Medical Imaging **4321** (2001) 483–488
2. Wang, Z., Liang, Z., Li, X., Li, L., Eremina, D., Lu, H.: An improved electronic colon cleansing method for detection of colonic polyps by virtual colonoscopy. IEEE Transactions on Biomedical Engineering **53** (2006) 1635–1646
3. Hong, W., Qiu, F., Kaufman, A.: A pipeline for computer aided polyp detection. IEEE Transactions on Visualization and Computer Graphics **12**(5) (2006) 861–868
4. Zhang, N., Hong, W., Kaufman, A.: Dual contouring with topology-preserving simplification using enhanced cell representation. IEEE Visualization (2004) 505–512
5. Hong, W., Gu, X., Qiu, F., Jin, M., Kaufman, A.: Conformal virtual colon flattening. ACM Symposium on Solid and Physical Modeling (2006) 85–94
6. Yoshida, H., Näppi, J.: Three-dimensional computer-aided diagnosis scheme for detection of colonic polyps. IEEE Transactions on Medical Imaging **20**(12) (2001) 1261–1274