Colonic Polyp Characterization and Detection based on Both Morphological and Texture Features

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ABSTRACT

In this paper, a method is presented for detection of colonic polyps using both morphological and texture features of the colon wall from the abdominal computed tomography (CT) images. This method consists of two steps. In the first step, suspicious patches of the colon wall are quickly identified by utilizing special local and global geometrical information of the segmented inner-wall mucosa layer. In the second step, a special mapping strategy is employed to identify the growing region of each suspected polyp. Then its internal CT density textures are extracted and quantitatively analyzed based on an assumed ellipsoid polyp model. Finally, both the extracted texture and morphological information are applied to eliminate the false positives from the identified suspicious patches. With all the extracted geometrical, morphological and texture features, this presented computer-aided detection (CAD) method has demonstrated a significant improvement in detection of the colonic polyps over the previously-reported geometry-based CAD methods for CT-based virtual colonoscopy.

Keywords: Density texture, Morphology, Geometry, Computer-aided Detection, Colonic Polyps

1. Introduction

Colonic polyps have a high probability of greater than 90% developing into colon cancer, which is the second leading cause of the cancer death in United States. Both the routine optical colonoscopy (OC) and the newly developed virtual colonoscopy (VC) [6, 7, 15] can provide a similar procedure of high accuracy for detection of clinically significant colonic polyps. VC could be a screening modality with follow-up biopsy on positive findings by OC. However, the anticipated large amount of VC screening procedures demands a computer-aided detection (CAD) scheme. A CAD scheme that automatically detects polyps has the potential to substantially reduce radiologists' interpretation time and increase radiologists' diagnostic performance by reducing false positive and false negative results. Up to now, there have been several CAD methods reported in the literatures with variable success for polyp detection. For example, Paik *et al*. [3] applied the normal information of the colon wall surface to find some geometrical features of the colonic polyps. Yoshida *et al*. [4, 5] employed the shape index and curvedness techniques to distinguish the polyps from the normal colon tissues. Summers *et al*. [12, 13] used some more features, such as the mean of the curvature, the maximum curvature, the minimum curvature and *etc*, to identify the colonic polyps. Gorturk *et al*. [14] proposed a pattern recognition method to detect the polyps. This method utilized some orthogonal triple planes to extract some feature vectors from the polyp candidates, and then used a three-dimensional (3D) pattern recognition strategy to make the final decision.

Although all these proposed CAD methods performed relatively well for most types of the colonic polyps, the false positive rates were relatively high. One main reason is because most of them only take advantages of the geometrical feature of colon wall, such as the shape change caused by the polyps, for detection purpose. Since the polyps have many different sizes and shapes, and the colon-wall folds may mimic their sizes and shapes, it is impossible to distinguish the polyps from other normal tissues or stools by the geometrical information of the colon wall surface only. In this paper, we propose a new CAD method for

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detection of colonic polyps. Different from most of previously reported CAD methods, our new method utilizes the geometrical, morphological and texture information for differentiation of false positives, where the initial finding of polyp suspects is performed by the use of both local and global geometrical information.

The content of this paper is organized as follows. In section 2, we present three different types of the features, which are utilized in our proposed CAD method. These features are geometrical features, morphological features and texture features. The details of these features are introduced in sections 2.1, 2.2, and 2.3 respectively. In section 3, we present our CAD scheme. Some experimental examples of polyp detection and conclusions will be shown in section 4.

2. Feature Extraction

Research findings show that a clinically significant colonic polyp can change not only the shape of the colon wall, but also the shape of its adjacent tissues due to its growth. Furthermore, the texture information in CT images may also provide very useful information for identification of the colonic polyps. Only after combining all these information, it is possible to detect all colonic polyps with low false-positive rate.

2.1. Geometrical Features of Colon Wall

Usually a colonic polyp has a regular shape which can be described as "elliptic curvature of the peak subtype". Through the shape analysis of the colon wall, some suspected regions of the colon wall can be figured out. All these sections have some kinds of "elliptical" shapes which are the typical shape of the true polyps and have a high probability to be the real colonic polyps.

Geometrical feature is crucial feature for the detection of colonic polyps. Most of the recent CAD methods [3-5, 12] took advantage of this geometrical feature for detection purpose. Some quantitative measures, such as the curvature and curvature-based shape measures, were utilized to describe the shape feature of the colon wall. In our proposed method, the local curvature and global curvature, which can provide general shape description of the colon wall [17], was utilized for the detection.

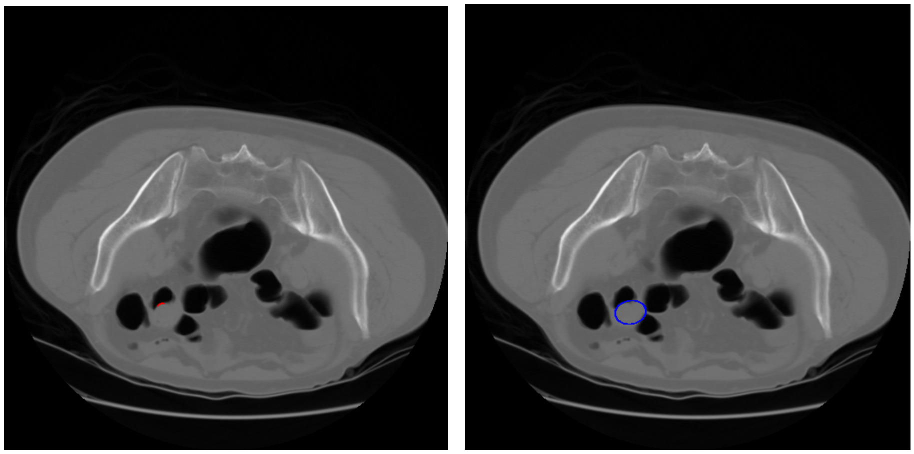
2.2. Morphological Features of Ellipsoid ROI

Previous research findings of ours as well as others have revealed that most colonic polyps have some "elliptical" shapes, and especially the true polyps (or malignant polyps) are growing along every direction outward from their center points. This morphological feature can provide more helpful information for the identification of the true polyps. However, this morphological feature is hard to be detected through optical or virtual colonoscopy. To analyze the morphological feature for each candidate, the relation between the candidates and its neighbors should be figured out. That means we have to "dig out" the whole region of interest (ROI) from the surrounding tissues of a suspected region, especially along the direction of outward the lumen.

Since most of colonic polyps have some "elliptical" shape, we utilized a 3D ellipsoid to simulate the whole polyps region or the similar suspected region (see Figure 1 below) in our proposed method. Through the ellipsoid ROI, some morphological features of this suspected region, such as the volume of the ellipsoid, the ratio among the length of three axes of the ellipsoid, the mean, standard variance, maximum, minimum of the CT value and so on, can be achieved. These morphological features can provide a global as well as detailed understanding of the ROI, which can be utilized to differentiate a polyp from the initial candidates and, therefore, reduce the false-positive rate of the previous geometry-based CAD methods.

The border of the ROI plays an important role in the analysis of the shape change caused by the growth. In clinical cases, most polyps do not have a smooth surface. So the surface of simulated ellipsoid can not be utilized to represent the border of the ROI directly. A mapping technique is developed in our proposed method to solve this problem. At first, we constructed the outer and inner layers of the ellipsoid. Then all voxels between these two layers were mapped onto the surface of the ellipsoid according to some criteria.

Finally, we obtained an elliptical mapping texture image of this polyp (see Figure 2 below). By analyzing the mapped image, we extracted two more morphological features. One is the "Coverage Rate", which calculates the ratio of area of mapped region to the area of the whole surface. Another measure is the "Distribution Rate", which describes the distribution of the mapped region along the whole surface. All these two measures can reflect if the polyps are growing and if this candidate really has an elliptical shape.



(a) (b)

Figure 1: The construction of ellipsoid ROI. (a) The initial candidates. (b) The final ellipsoid using the original voxels and the added edge points.

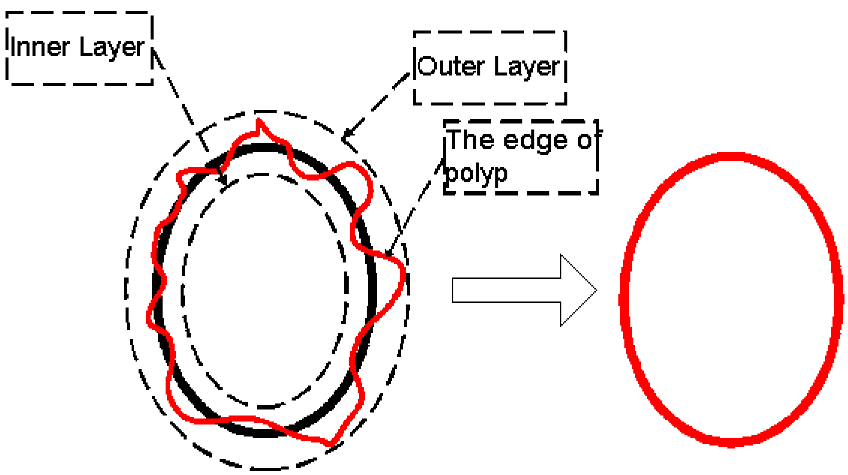


Figure 2: Illustration of the mapping procedure.

2.3. 3D Intensity Texture Features of Ellipsoid ROI

Besides the morphological features as mentioned above, other important feature used in our proposed method is the intensity texture feature. By analyzing more than ten polyp samples, we observed that the intensity values of the voxels inside the polyps are not uniform, and the variance of the intensity shows some special patterns. These observations can be depicted by 3D/2D texture information. In this work, we presented a new 3D texture measure for detection of this special growth pattern of a polyp.

For each voxel p in 3D volume dataset, let $\lambda 1$, $\lambda 2$, $\lambda 3$ be the three eigenvalues of the Hessian matrix and $\lambda 1 > \lambda 2 > \lambda 3$. We define three pattern parameters $TP1$, $TP2$, $TP3$ which can be calculated by:

$$TP1 = -\frac{1}{\pi} \arctan \frac{\lambda 1 + \lambda 2}{\lambda 1 - \lambda 2}$$

$$TP2 = -\frac{1}{\pi} \arctan \frac{\lambda 2 + \lambda 3}{\lambda 2 - \lambda 3}$$

$$TP3 = -\frac{1}{\pi} \arctan \frac{\lambda 1 + \lambda 3}{\lambda 1 - \lambda 3}$$

In Figurer 3, the difference of the relations among the pattern parameters between the polyps and their surrounding normal tissues are showed. From the figure, we can see that the distribution of the pattern parameters is different between sample points of the polyps and of the normal tissues. Thus the triple pattern parameters (*TP*1, *TP*2, *TP*3) can be used as a 3D texture feature for detection of the polyps.

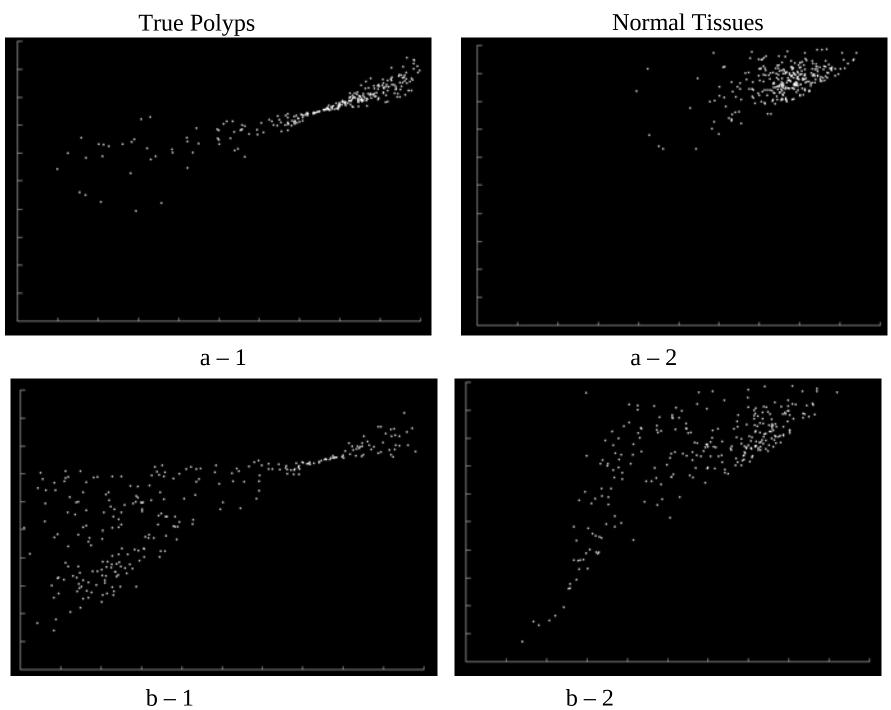


Figure 3: Comparison of the texture attributes between the polyps and the normal tissues. The sample points are selected randomly from 10 positive polyps and their surrounding tissues. a-1 and b-1 show the plots of texture attributes of the sample points from the polyps. In the plots, each sample point is represented as a 2D points located at (*TP*1, *TP*2) or (*TP2*, *TP3*). a-2 and b-2 show the plots of texture attributes of the sample points from the normal tissues.

3. Detection of the Colonic Polyps

Different from most of previously reported CAD methods for colonic polyps, our new method uses both geometrical, morphological and texture information to detect the polyps. At first, the 3D geometrical (both local and global) features of the colon wall were utilized, as described in our previous published global shape-based CAD method [17], for the detection of the “polyps-likely” abnormal sections. All these abnormal sections have some kinds of “elliptical” shape which is the typical shape of the true polyps. They are called as initial candidates. Due to the complexity of colon wall and residue colonic materials, there are many small folds or residue materials whose shapes are also “elliptical” like. It is extremely challenging to distinguish all these false candidates from the true polyps by only analyzing the shape information of the colon wall. More information is necessary to reduce the false-positive rate.

The initial candidates, which are generated using the shape change analysis of the colon wall, are some suspected regions of the colon wall. These sections are frequently too small to provide enough description information for the generation of ellipsoid ROI (Figure 1a). From the initial candidate location, a ray-tracing edge detection method is utilized to detect the border points between the suspected region and its adjacent tissues. Those border points provide sufficient information to generate the ellipsoid ROI for each candidate. Then all 3D morphological features are extracted from the ROI to differentiate the false positives.

In addition to morphological features, the 3D texture features are calculated for each ellipsoid ROI too. After the above ROI extraction and analysis stages, we obtained more than twenty morphological and texture features of the ROI for detection of the colonic polyps from the initial candidates. It is expected that not all features are useful for the final decision. Some features may even provide misleading information. A feature selection should be performed to choose the useful features for the CAD on the initial candidates. After the feature selection, each remaining feature was given different weight according to its importance for the final decision to achieve the CAD goal of low false-positive rate and no false negative.

4. Experiment and Discussion

Ten patients' CT datasets were used to evaluate the efficiency of our method. In the experiment, two different methods are performed and compared. One is our previously reported shape-based CAD method, which uses only the geometrical (local and global) information of colon wall for the detection. The other is this presented method, which uses the geometrical, morphological and texture information of the colon. In the experiment, we used 3 morphological features (minimum axis length, maximum length axis, and ratio of the maximum to minimum axis length) and one texture feature (radiation rate). The final decision is the threshold selection. From the experimental results, both methods have achieved the same high sensitivity. However, the false-positive rate of our new method is ten times less than that of the shape-based method.

There are two breakthrough points in our method. One is the combination of both shape information of the colon wall and the other tissues behind the colon wall. With both outer and inner shape information, improved detection of colonic polyps is expected. The other breakthrough work is the introduction of the texture information into the detection of the colonic polyps. With the texture information, we will be able go beyond the shape information and let the computer to do more work for the physicians. For true colonic polyps, especially the malignant (growing) polyps, the texture features are different from the texture features of normal tissues. Our method takes advantage of both texture and geometrical information to detect the colonic polyp and was shown to provide more accurate detection results.

Acknowledgement

This work was partly supported by NIH grant # CA82402 of National Cancer Institute and grant #HL51466 of National Heart, Lung, and Blood Institute. We would like to thank Viatronix Inc. for providing the virtual colonoscopy software for visualization of the colon data.

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