Principal Curvature-Based Colonic Polyp Detection

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Abstract. An automatic polyp detection framework is presented based on surface curvatures, and a new color coding scheme is used to highlight the detected polyps which enhances the visualization. An accurate estimate for the surface curvature together with three geometric features is used to detect the polyps. We place the detected polyps inside a polygonal dataset with exactly the same topology and geometry properties as the mesh surface of real colon dataset, and assign different colors to the two separated datasets, in order to highlight the polyps. This approach is shown to detect polyps of size above 5 mm and reduces false positives. The algorithm is validated on simulated data sets as well as real CT colonoscopy data.

Keywords: computer aid diagnosis, geometric feature, principal curvatures, colonic polyp detection, and color coding

1. Introduction

Colorectal cancer is the second leading cause of cancer-related death and the third most common form of cancer in the United States [1]. Since colorectal cancer is largely preventable, early detection and removal of colonic polyps can substantially reduce the risk of cancer occurrence. Computer tomographic colonoscopy (CTC) is a rapidly evolving diagnostic tool for the location, detection and identification of benign polyps on the colon wall in the early stage before their malignant transformation.

As shown in Figure 1, colonic polyps generally grow from the colonic mucosa, and appear as dome-like structure with small curvature. The haustral folds appear like shape ridges, which have large curvature values. The colon walls have nearly flat or cup structures with small curvatures.

Different geometric feature descriptors have been used for colonic polyp detection [2-5]. In CTC examination, image display formats can affect the performance of the radiologists. Index color coding is one of the important methods to improve the visualization effect of data. However, the lookup table is sensitive to the hue, saturation, value, and alpha opacity (HSVA). Since it is not easy to know how the lookup table works and how to balance HSVA values, it is hard to understand all the associated parameters.

In this paper, we propose a general framework for colonic polyp detection using three geometric features: shape index, curvedness and sphericity ratio. We also include our newly developed color coding approach to enhance the visualization [6]. This paper extends that concept and tests the overall framework on real dataset.

2. Curvature Based Polyp Detection

Let \( p = (x, y, z) \) denote a voxel on the 3D surface \( S \), if we know the Gaussian curvature and mean curvature, two principal curvatures can be computed as:

\[
\kappa_1 = H + \sqrt{H^2 - K} \quad \text{and} \quad \kappa_2 = H - \sqrt{H^2 - K} \quad (1)
\]

The main difficulties associated with computing the principal curvatures are the following: 1) under discrete cases, \( H^2 - K \) in Eq. 1 is not always guaranteed to be greater...
Fig. 1. Three different tissues, (i) polyp: dome-like structure, (ii) folds: ridge-like structure, and (iii) colon wall: near flat or small cup-like structure.

Fig. 2. Shape index scales of different 3D geometric shapes ranging from 0 to 1.

than or equal to zero; 2) $\kappa_1$ and $\kappa_2$ computed in this way can not provide any direction information; and 3) large neighborhood for the high accuracy of principal curvatures, increases the computational complexity. To solve these problems, we employed the curvature estimation of Taubin, 1995 [7], which showed a good performance with respect to various uncertainties. We propose three geometric features for colonic polyp detection which are based on curvature: shape index (SI), curvedness (CV) and sphericity ratio (SP). They are defined in terms of the principal curvatures as:

$$SI = \frac{1}{2} - \frac{1}{\pi} \arctan \left( \frac{\kappa_1 + \kappa_2}{\kappa_1 - \kappa_2} \right), \quad CV = \sqrt{\left( \frac{\kappa_1^2 + \kappa_2^2}{2} \right)} \quad \text{and} \quad SP = \left| \frac{\kappa_1 - \kappa_2}{H} \right| \quad (2)$$

From the shape index scale as shown in Fig. 2 and curvedness, we can easily set thresholds of shape index $th_{SI}$ and curvedness $th_{CV}$ to detect colonic polyps. In this paper, we combine the three features for colonic polyp detection. The detected results can be computed as $\phi_{detect} = \phi_{SI} \cap \phi_{CV} \cap \phi_{SP}$, where, $\phi_{detect}$, $\phi_{SI}$, $\phi_{CV}$ and $\phi_{SP}$ denote the numbers of final detection, detected by SI, CV, and SP, respectively.

3. Color Coding for Visualizing Polyps

In order to facilitate the visual detection of polyps, we propose a new color coding scheme, which is shown in Fig. 3.

The following steps describe the overall polyp detection and visualization algorithm:

1. Reconstructing 3D colon object.
2. Computing continuous curve skeleton of the 3D volumetric colon object.
3. Creating isosurface of 3D colon using the standard marching cubes algorithm.
4. Generating the first polygonal dataset of triangle mesh on the isosurface.
5. Creating the second polygonal dataset with exactly the same topology and geometry properties with the one in Step 3 but void at each point address.

6. During navigation, checking each triangle vertex of the first dataset.
   a) If it is a polyp candidate, insert its scalar values and all neighboring vertices at the same location in the second polygonal dataset.
   b) If not, keep the vertex at the same location in the second polygonal dataset void.
   c) Repeat, until the entire points in the first dataset are finished.

7. Assigning background color to the first colon polygonal dataset (containing colon inner wall and haustral folds) and foreground color to the second polygonal dataset (only containing polyp candidates).

Compared with other methods (e.g., [3]), our algorithm differs in Steps 5 and 6. It creates a new polygonal dataset with the same geometric and topology structures with the original 3D CT colon object, then associates polyp and non-polyp candidates with different datasets, finally assigns foreground color to the polyp candidates, and background color to the non-polyp tissues for easy visualization of polyps.

4. Results

In experiment I, three sessile sphere-like polyps with different sizes of 8mm, 10mm and 12mm are generated. Before polyp detection, both of polyps and colonic lumen are assigned same color. In experiment II, two sphere-like polyps with sizes of 10mm and 15mm, and one ellipse-like polyp with size of 12mm are generated. All the polyps are totally detected and visualized by assigning red color. In experiment III, five thick spherical folds with diameters ranging from 15mm to 60mm are simulated in a colonic lumen. Five sessile sphere-like polyps with sizes of 7mm, 9mm, 12mm, 15mm and 20mm, are created and inserted as shown in Fig. 4. All the polyps as shown in Fig. 4(a) are totally detected as shown in Fig.4(b) to Fig.4(f), although the phantom is more complicated than those in the experiment I and II.

![Fig.4. Results of the colon phantom in experiment III](image)

In experiment IV, we use a clinical colon dataset to validate the proposed framework. We select five boundary points as the centers, where the five polyps with efficient sizes of 7.5mm, 9mm, 12mm, 15mm, and 18mm are placed. All the positions of these polyps

![Fig.5. Polyp 4 inserted in real colon dataset. (a) detected polyp, (b) its positions, (c) detected by mean curvature and colored by the lookup approach, and (d) detected by the proposed detection framework and colored by the lookup table approach](image)
are clearly indicated by the arrows at the 3D real colon object as shown in the column (b) of Fig. 5. For comparison, the five synthetic polyps are detected by mean curvature and visualized by the index color coding as shown in the column (c) of Fig. 5. We also visualize the polyps using the conventional color coding after detecting them using the proposed detection framework in the column (d) of Fig. 5. We find that the proposed color coding scheme provides better results than the conventional one.

To demonstrate the effectiveness of the proposed method, we have tested it on four clinical colon datasets acquired by Siemens Sensation CT scanner. All the datasets have been examined under optical colonoscopy by an expert radiologist and total 8 polyps with diameter no less than 5 mm have been found. The algorithm has achieved sensitivity for the real polyps of 75% (6 of 8 polyps) for the four real clinical colon datasets. The results of polyp detection and color coding in the real clinical colon datasets are shown in Fig. 6. The two polyps as shown in Fig. 6 (c) and (d) are missed by the proposed algorithm, since they have small sizes and irregular shapes.

5. Conclusion

In this paper, we proposed an automatic polyp detection framework based on three geometric features. All the detected polyps were placed separately and are visualized in different color by the proposed new color coding method. Finally, the polyp detection framework is validated by the synthetic polyps with different shapes and sizes. Regarding the future work, we are planning to incorporate new curvature-based features for reducing false positive. More clinical colon dataset will be used for test the accuracy of the proposed algorithm.

References