

A Novel Methodology for Extracting Colon's Lumen from Colonoscopic Images

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ABSTRACT

Recently, computer assisted diagnosis on colonoscopic images is getting more and more attention by many researchers in the world, while the colon's lumen is the most important feature during the process. In this paper, a novel methodology for extracting colon's lumen from colonoscopic image is presented. At first, in order to eliminate the background at the outside of colonoscopic images, an effective and easy method, which is similar to the Hough transform is used to detect the preliminary region of interest (pROI). Then the original image is segmented through two steps: relaxation process and tightening process. The relaxation process is realized by finding the all valleys from the histogram of a defined homogeneity function to produce as many homogenous regions as possible, while tightening process is subsequently employed to merge the unnecessary regions according to the color difference between them in CIE (L* a* b*) color space. After a series of postprocessing procedure, the lumen is successfully extracted. An extensive set of endoscopic images is tested to demonstrate the effectiveness of the proposed approach.

Keywords: Colonoscopic Image, Hough Transform, Relaxation and Tightening, Homogeneity, Lumen Extraction.

1. INTRODUCTION

Colon cancers have been one of the major killer diseases in the world for the past ten years [1]. Electronic video colonoscopy, due to its advantage for monitoring, documentation, and electrical manipulation of images, has been widely used for clinical and laboratorial application recently. It consists of a miniature CCD camera, which can capture the color images of the colon tract in real-time. Electronic video colonoscopy as an important form of examination and therapeutic procedure for colonic diseases raises a practical issue: how to quantitatively evaluate the exact status of colonic disease. Thus, computer-assisted diagnosis on colonoscopic images is getting more and more attention by many researchers in the world [2-5][8-9][13]. The first step in computer-assisted diagnosis is to extract the significant features of the colonoscopic images, while the most significant feature must be the lumen boundary, which is coincident to the colonoscopists' search for possible abnormalities in the colon. Usually the colonic images contain multiple patches of dark regions and furthermore the edges between the lumen and the wall of the colon are frequently diffused. The entire lumen is not homogeneous but contains reflection of light, which makes lumen sometimes appear brighter than the colonic wall [14]. All these facts cause the extraction of lumen boundary to be relatively difficult and crucial. In general, the extraction of colon's lumen from colonoscopic images can be simply regarded as a color image segmentation problem. The purpose of image segmentation is divided the original image into separate regions that are homogenous with respect to a chosen property such as brightness, color, reflectivity, texture, etc. As a whole,

segmentation methods can be classified into three groups according to the dominant features they employ: First is global knowledge about an image or its part, which is usually represented by a histogram of image features; Second is the edge-based segmentation and region-based segmentation is the third [7]. Many different characteristics may be used in edge detection or region growing, such as brightness, texture, velocity field, etc.

Color image can carry much more information than gray one, thus many researchers have focused on color image segmentation to meet different applications. At present, color image segmentation methods are mainly extended from gray level image segmentation approaches by being implemented in different color space [6]. Gray level segmentation methods are directly applied to each component of a color space, and all results are then merged into final segmentation result.

Recently, a lot of techniques for extracting the lumen of endoscopic color images have been proposed. Fuzzy logic reasoning and region growing algorithm was utilized in [3] to detect the lumen of colonoscopic image, while the seed was selected from the pseudo-center of intestinal lumen which was resulted from non-parametric multilevel hill-clustering thresholding technique. A differential region growing (DRG) technique was also used to obtain the gastrointestinal lumen by using the seed selected from the center of mass of pROI on the basis of an adaptive progressive thresholding technique. But the images segmented by region growing methods often contain too many regions (under-growing) or too few regions (over-growing) as a result of non-optimal parameter setting. In order to improve segmentation results, a variety of post-processing work had been done. Simpler post-processing decreases the number of small regions in the segmented image. More complex post-processing may combine segmentation information obtained from region growing and edge-based segmentation [7]. In addition, the region within lumen in color or gray level often seems no uniform, so region growing with only one seed often results in wrong lumen, even in failure. In 2000, [6] presented a novel hierarchical approach to color image segmentation. A newly defined homogeneity histogram including both the local information and global information was calculated in the first phase. While performing histogram thresholding, an effective peak-finding algorithm was employed to identify most significant peaks in the histogram. The valleys between the detected peaks corresponded the boundaries for the segmentation in homogeneity domain. In the second phase, histogram analysis based on color feature hue for each uniform region obtained in the first phase was performed to segment the uniform region above into more regions in the sense of color space. At last, a region merging process was employed to solve the color difference in CIE (L* a* b*) color space. [9] has also used this modified algorithm to segment the colonoscopic images successfully. But the algorithm seems require many experiential parameters to be determined in advance, and time-consuming, it is not completely applicable to segment the colonoscopic images.

In this paper, we propose a novel methodology for the colonoscopic image segmentation with several steps. An effective and easy method similar to the Hough transform is used to determine the preliminary region of interest (pROI) in order to eliminate the background of the colonoscopic images. The original image is effectively segmented through two-step processes: relaxation and tightening, which is similar to [6] to some extent but largely been modified for our application. The relaxation process is realized by finding the possible valleys of defined homogeneity function to produce as many homogenous regions as possible, while a tightening process is employed to merge the oversegmented regions based on the color difference between them in CIE ($L^* a^* b^*$) color space. In order to improve the processing speed, some measures are taken here. After some post-processing procedures, the lumen with a closed and smooth boundary is successfully extracted.

2. EXTRACTION OF pROI

A. Colonoscopic Image Pre-processing

Median filtering is a non-linear smoothing method that reduces the blurring of edges, in which the current point in the colonoscopic image is replaced by the median of the value in its neighborhood. Median filtering eliminates impulse noise quite well because the median in a predetermined window is not affected by individual noise spikes. More efficient and fast approach [10] is utilized to decrease unnecessary re-window. In our application, the median filtering is conducted in R, G, and B channel individually and 3 x 3 rectangular window is employed.



Fig. 1. An original image

B. Detecting the pROI

Fig. 1. is an original colonoscopic image. It showed that the lumen is not only near to image's left edge but also the intensity in HSI color space is very approximate to the intensity outside the pROI. In order to speed the image processing, an effective and easy method, which is near to the Hough transform, is used to extract the pROI firstly. The pROI is almost a complete circle, so an effective and easy algorithm similar to the Hough transform is adopted to detect the circle. It needs not to predetermine the size of the radius during the detecting

procedure because the radius of pROI of the colonoscopic images used in our experiment varies slightly within a range. But in order to speed the detecting procedure, some prior knowledge has been included in the algorithm, such as the range of center coordinates and radius of the desired circle. Please note that the brink of some original images is very vague in some cases.

Assume x_i, y_i ($i=1, 2, 3, \dots, n$) are the edge points of the

original image, among them some edge points x_j, y_j must be at the edge of desired circle, a and b are the center coordinates of desired circle, r is the radius of desired circle, so the analytic expression of the desired circle is:

$$(x_j - a)^2 + (y_j - b)^2 = r^2 \quad (1)$$

pROI detecting algorithm:

The pROI is detected as follows.

- Thresholding. Transform the original image into binary image by using any fast threshold-calculating techniques or a predetermined threshold by experience.
- Detect all edge points x_i, y_i ($i=1, \dots, n$) of original image by using any edge extraction techniques.
- For all edge points x_i, y_i ($i=1, \dots, n$), calculate the histogram of expression: $\sqrt{(x_i - a)^2 + (y_i - b)^2}$, which counts the frequency of occurrence of each result of the expression. The average among the results in the vicinity of the maximum value of this histogram will correspond to the desired radius r . The value of a , and b are all bounded to a specified range respectively for colonoscopic images to save calculating time.
- After the desired radius r is obtained, calculate all approximate center coordinates from the expression: $\sqrt{(x_i - a)^2 + (y_i - b)^2} - r$ when the magnitude of the expression exceeds a given threshold. Averaging all approximate centers of circles will get the position of center of desired circle. An example of the detecting the pROI is displayed in Fig. 2.

3. COLONOSCOPIC IMAGE SEGMENTATION

The extraction of colon's lumen is accomplished by colonoscopic image segmentation. Image segmentation is one of the most important steps leading to the analysis of processed

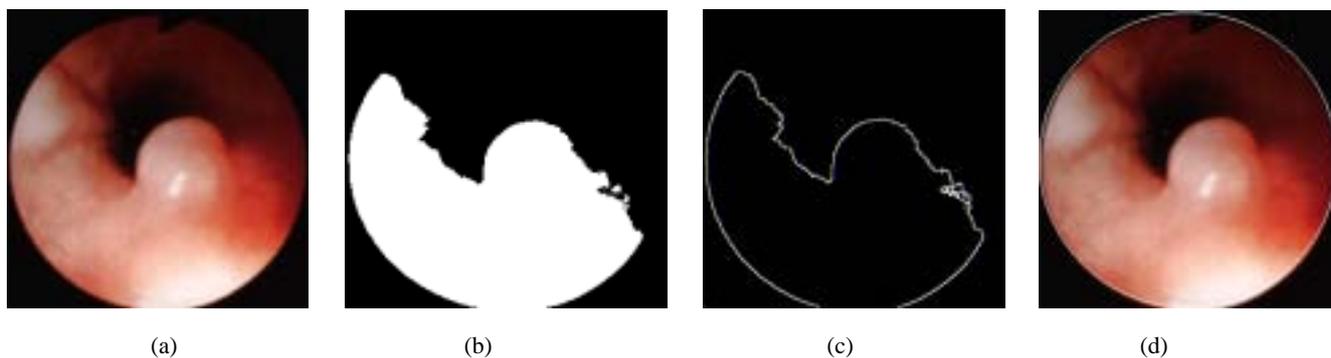


Fig. 2. Results of extraction of pROI: (a) original colonoscopic image (256x256x24bits), (b) thresholding result of (a), (c) edge extraction of (b), (d) pROI with superimposition of (a)

image data. Automatic and accurate image segmentation of colonoscopic image is different to achieve because colon is soft tissue and non-rigid bodies. Different techniques for endoscopic image segmentation have been proposed in the literature. Here we present a relaxation-tightening technique to segment the colonoscopic image. The relaxation process is realized by finding the all valleys from the histogram of user-defined homogeneity function to produce as many homogenous regions as possible, while a tightening process is subsequently employed to merge the unnecessary regions based on the color difference between them in CIE ($L^*a^*b^*$) color space.

A. Split the original colonoscopic image by relaxation process

Thresholding is the simplest segmentation process. Due to its inexpensive computation and rapid speed, thresholding can easily be done in real-time using specialized hardware [7]. Each pixel in a color digital image has its native or calculated properties such as gray, color, texture, etc. Gray-level thresholding is the method that segments the image according to each pixel's gray property. Here we consider the homogeneity property of each pixel in colonoscopic image, which is defined as a combination of two components [6]: standard deviation and discontinuity of intensities I , $I=(R+G+B)/3$. The idea of segmentation is to split the original image into different homogenous regions in the sense of the intensity of the target pixel. Standard deviation stands for the contrast within a local region, while discontinuity of intensities serves as a measure of abrupt changes in gray level and can be calculated by edge detectors.

Let I_{xy} be the intensity of a pixel at the point (x, y) in an size $L \times H$ image, w_{xy}^1 be a $m \times m$ window centered at (x, y) for computing the standard deviation, w_{xy}^2 be a $n \times n$ window centered at (x, y) for computing the discontinuity of intensities, m and n are odd integers greater than 1.

The standard deviation of pixel (x, y) is calculated below:

$$\sigma_{xy} = \frac{1}{m} \sqrt{\sum_{p=x-(m-1)/2}^{x+(m-1)/2} \sum_{q=y-(m-1)/2}^{y+(m-1)/2} (I_{pq} - u_{xy})^2} \quad (2)$$

where $0 \leq x, p \leq L-1$, $0 \leq q, y \leq H-1$, and

$$u_{xy} = \frac{1}{m^2} \sqrt{\sum_{p=x-(m-1)/2}^{x+(m-1)/2} \sum_{q=y-(m-1)/2}^{y+(m-1)/2} I_{pq}} \quad (3)$$

is the mean of intensities within the window w_{xy}^1 .

As for the calculation of discontinuity of intensities e_{xy} , we employ the edge detector---Sobel operator instead, which equals to

$$e_{xy} = \sqrt{G_h^2 + G_v^2} \quad (4)$$

where G_h and G_v are the response of horizontality and verticality of edges of Sobel operator within the window w_{xy}^2 , respectively.

Thus, the homogeneity function of any pixel in colonoscopic image is defined as below:

$$H(I_{xy}, w_{xy}^1, w_{xy}^2) = 1 - \left(\frac{e_{xy}}{e_{\max}} \right) \bullet \left(\frac{v_{xy}}{v_{\max}} \right) \quad (5)$$

where e_{\max} and v_{\max} are the maximum of e_{xy} and v_{xy} , so that we can normalized the standard deviation and discontinuity value to keep the computational consistence.

To evaluate the splitting effect of the different construction of homogeneity function and decrease the calculation of homogeneity value, the following several cases have been compared: standard deviation alone, discontinuity of intensities alone and both of standard deviation and discontinuity of intensities in (4). It was found the optimal splitting effect would be obtained by considering both of standard deviation and discontinuity of intensities. It also proves the feasibility and validity of constituting homogeneity function.

Similar to classical histogram in gray domain, the calculation of the histogram has been extended in homogeneity domain, which is defined as the frequency of occurrence of the homogeneity value in the colonoscopic image. From the homogeneity histogram, the valleys in the histogram are found in order to do segmentation. [6] had presented a new valley finding algorithm, but it is not applicable to our requirements completely. So we propose a task-oriented easy and feasible algorithm.

Suppose a histogram in homogeneity domain is represented by a function $h(i)$ where i is a integer, and $0 \leq i \leq 255$.

Valleys-Finding algorithm:

The valleys are found using algorithm as follows.

a. *Smooth the histogram:*

Use three-points fixed simple average method to smooth the histogram in order to suppress the histogram noise and lessen the impact of finding all peaks in the next step.

b. *Find all peaks:*

Find the set of points corresponding to the local maximum of the histogram

$$H_0 = \{(i, h(i) | h(i) > h(i-1) \& h(i) > h(i+1), 1 \leq i \leq 254)\} \quad (6)$$

c. *Locate the valleys between any neighboring peaks.*

The valleys are the possible desired edges of uniform regions for the segmentation in homogeneity domain.

The proposed algorithm here is easier and more tolerant than the peaks-finding algorithm in [6]. By using this algorithm, more possible valleys can be obtained. These valleys may correspond to the desired edges, especially the small and faint edges. The apparently sole shortage is getting excess edges, but it is the true purpose that this algorithm is presented. In our application, this algorithm is called as relaxation process. The excess edges will be merged by tightening process. Another advantage of this method over the hierarchical approach in [6] is that we leap over the segmentation using color feature hue, thus we can shorten the computational time.

B. Merge the color regions by tightening process

After the splitting by relaxation process, all the sub-regions with similar homogeneity have been obtained. The average color R, G, and B for each region is calculated and assigned to each pixel in the uniform region so that the segmented regions can be directly displayed in the screen.

To overcome the possible excess segmentation, which may happen when the pixels are in different homogeneity regions but possess similar colors, perceptually uniform color space is introduced in which perceived color difference recognized as

equal by the human eye would correspond to equal Euclidean distance [12].

The color difference in CIE $L^*a^*b^*$ color space is used to compare the similarity color between regions. If the color difference between any two homogenous regions is smaller than a predetermined threshold T_e , the two regions will be merged. This procedure is the so-called *tightening process*. The CIE ($L^*a^*b^*$) space is defined by the expression in the appendix, where (X_0, Y_0, Z_0) represents reference white.

Then color difference ΔE_{Lab} between two sets of $L^*a^*b^*$ coordinates (L_1^*, a_1^*, b_1^*) and (L_2^*, a_2^*, b_2^*) :

$$\Delta E_{Lab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

where $\Delta L^* = L_2^* - L_1^*$, $\Delta a^* = a_2^* - a_1^*$, $\Delta b^* = b_2^* - b_1^*$.

It is noted that color region merging in the tightening process is realized iteratively. Two regions having the smallest color difference are first found. If its color difference is smaller than T_e , the two regions will be merged. Then recalculate the merged region's average color R, G, B and $L^*a^*b^*$ values and repeat the process until no color difference between any two regions is smaller than T_e . Rather than [6], the threshold T_e is based on the experiments on more than 60 images in order to enhance the executing speed. In our experiment, we choose $T_e=15$ instead. In general, the relaxation process in our application will produce about thirty-two homogenous region, after the tightening process, about twenty-two regions will be merged. In fact, if the extraction of the lumen of colonoscopic images is solely considered, we may only consider parts of homogenous regions during the tightening process, because the lumen region often locates at the regions of relatively lower intensities so that we can produce fast merging procedure.

The main advantage of the relaxation and tightening process is that both of global information (histogram) and local information (variance and discontinuity) are considered simultaneously. In the meantime, the necessary and sufficient edge information or regions can be kept during the relaxation and tightening process, while these regions can correspond to other signs of different kinds of colonic diseases. These regions can be quantified to serve as features for doing the further classification. By the way, the idea of the relaxation and tightening process is also a bit similar to that of conventional split-merge algorithm.

4. EXTRACTION OF COLON'S LUMEN

About ten homogenous regions, both in intensity and perceptual uniform color have been created after the segmentation of colonoscopic image. The next step is to extract the colon's lumen. The extraction of colon's lumen is rather a trivial process.

A. Identify the corresponding regions of colon's lumen

Approximate ten regions have been produced during the segmentation process, and then which region or how many regions among them should correspond to the lumen's region? By using a training set of colonoscopic images and considering the universalities and particularities of colonoscopic images, we define the following general and comprehensive criterions.

Suppose $l(l=1,2,3,\dots,n)$ is the index of segmented regions with its value proportional to the intensity value, n is the number of segmented regions, ΔE_{Lab} is the color difference

between two neighboring regions, I_l and I_{max} represent the intensity of l^{th} region and the maximal intensity among all regions.

Criterion 1: Colon's lumen often locates at the dark regions of a colonoscopic image, usually l is smaller or equal to 4 in our experiment.

Criterion 2: The color difference between the lumen region and non-lumen region is much greater than the one between the non-lumen regions. Here we select ΔE_{Lab} as 78.0.

Criterion 3: As a whole, in comparison with the maximal value of intensity at the region of colonoscopic image, the intensity of lumen region is smaller, that is to say, the ratio of the maximal value of intensity to the intensity of lumen region must be in a predetermined threshold. In our application, we choose the threshold as 9.2.

It is noted that the third criterion is not a republication of the first one, because sometime there is no lumen region existing in the colonoscopic image. By using three combined criteria listed above, it is not very difficult for us to identify the corresponding regions of colon's lumen.

B. Regions labeling

By using the criteria defined above, the colon's lumen regions are easily isolated. But due to position of light delivered and possible pathological changes and non-rigid nature of colon, there are some other small regions that have the same characteristics as lumen. They have to be eliminated. All regions are labeled with different unique (integer) numbers based on the above criteria. Meanwhile, the areas of different regions are calculated. The region with maximal area usually corresponds to the lumen's region.

Mathematical morphology based on the algebra of non-linear operators has got more and more application in image processing. After lumen's region is extracted, the closing operator is used to smooth the lumen's outline by filling up narrow gulfs. That is to say,

$$X \bullet S = (X \oplus S) \ominus S \quad (8)$$

where X is the image subject to closing operation, S is the structure element.

C. Boundary tracing

The boundary of the lumen can be obtained using boundary tracing algorithm, and at the same time can quantify some

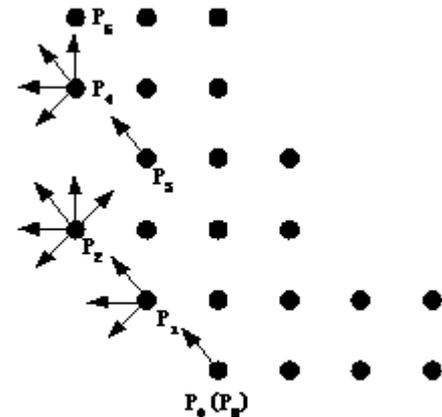


Fig. 3. The Sketch map of boundary tracing

parameter of lumen, such as perimeter, enclosed boundary area, form factor [3], etc. But due to mucosal reflection, the lumen

often consists of small sub-regions having relatively higher intensities and lower saturation, which form white pockets embedded in the main lumen region in the segmented image, so [13] adopted the combined method of boundary thinning and boundary connecting, but sometimes it may lead to wrong connecting track. Therefore a practical and feasible tracing algorithm to solve this problem in another way is proposed. Suppose the lumen's boundary point is a black point (its gray level equals 0) and the number of boundary point is N , we define the boundary tracing algorithm as follows.

Boundary tracing algorithm:

- a. Find the first boundary point P_0 by searching the pixels in colonoscopic image from left to right and from bottom to top, so the first boundary point found must be utmost boundary point located in the bottom-left direction.
- b. Start from the boundary point $P_n (n = 0, 1, 2, 3 \dots N - 1)$ and define the initial searching direction as top-left. If the point in its top-left direction is a black point, then the point is just a boundary point $P_n (n = 1, 2, 3 \dots N)$ and go to step d.
- c. The searching direction rotates 45 degree clockwise continuously until the black point, i.e., boundary point $P_n (n = 1, 2, 3 \dots N)$ is found.
- d. $P_n (n = 1, 2, 3 \dots N - 1)$ is regarded as a new point, rotates 90 degree counter-clockwise on the basis of current searching direction. If the point found, it considered as boundary point, and go to step b, otherwise go to step c.
- e. Repeat step b- step d until the boundary point found is the point P_0 .

The Skew map of boundary tracing is in Fig. 3. The proposed approach can be described by a flowchart as shown in Fig. 4.

5. RESULTS AND DISCUSSION

More than sixty colonoscopic images are employed in our application. Some experimental results are shown in Fig. 5-7. The original colonoscopic images are stored in RGB format and all are 256x256 size with each primitive component (R, G, B) 8 bits and its intensity from 0 to 255.

Fig. 5-7 are the demonstration of the results of the proposed method. The results are the combination of original image and lumen's boundary. It can be found that the lumen boundary is detected successfully. The original colonoscopic image in Fig. 5 is highly contrast and very clear, so the extraction of lumen boundary is realized easily and correctly. But the lumen boundaries of images in Fig. 6 and Fig. 7 is very vague and slowly dim, due to the relaxation process of our proposed approach, the lumen boundaries are also successfully extracted. Other smoothing algorithms may also further smooth the lumen boundary extraction.

A large number of clinical images will be employed to verify the effectiveness and feasibility of our proposed approach. In view of the fact that a good segmentation technique is able to locate the object boundary that coincides with the true boundary [14], the comparison between the lumen boundary extracted by our proposed algorithm and the one delineated by the colonoscopist will be also made in the near future. Certainly, our ultimate and long-term objective is to develop a computer-assisted diagnosis system on clinical colonoscopic images, although we will have to do much further work, such as efficient feature extraction, pattern recognition and large clinical experiments.

6. CONCLUSIONS

In this paper, a novel approach for extracting colon's lumen from endoscopic image analysis is presented. The preliminary region of interest (pROI) is effectively and easily detected and the original colonoscopic image was segmented with two sequential steps: relaxation process and tightening process. It was shown from the testing using more than sixty clinical endoscopic images that the lumen is successfully extracted using the proposed method. These results verified the effectiveness of the proposed approach. As a key and important step, the proposed approach extracted lumen boundary of endoscopic images automatically, and offer valuable assistance in the diagnosis of malignant and benign colon tumors in the future.

7. ACKNOWLEDGEMENT

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APPENDIX

The color transformation from RGB color space to CIE L*a*b* color space as follows.

$$L^* = 116f\left(\frac{Y}{Y_0}\right) - 16$$

$$a^* = 500\left[f\left(\frac{X}{X_0}\right) - f\left(\frac{Y}{Y_0}\right)\right]$$

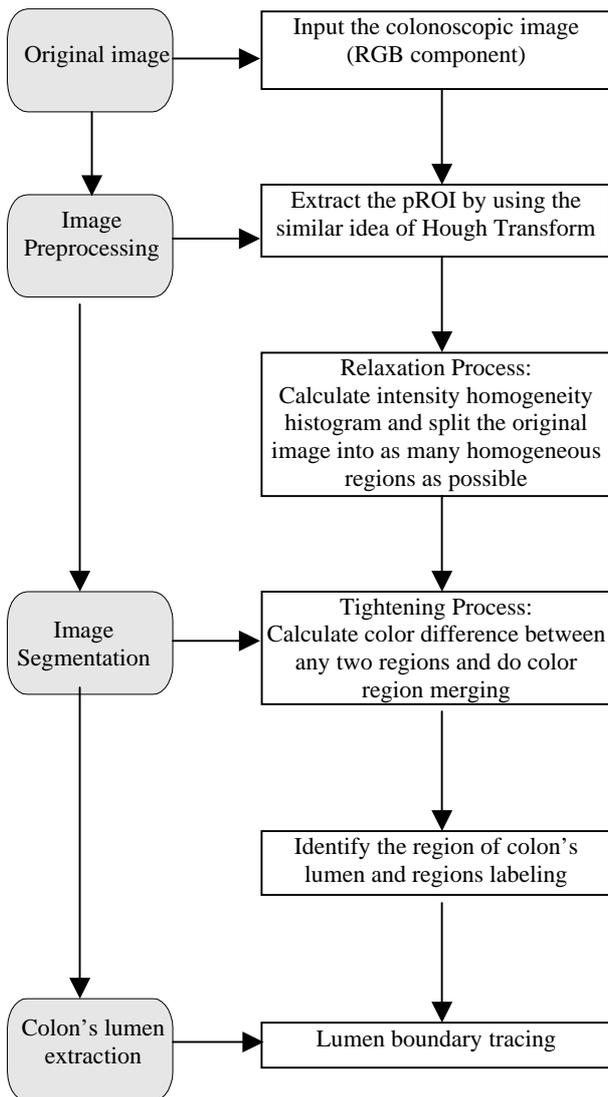


Fig. 4. Flowchart of the proposed approach

$$b^* = 200\left[f\left(\frac{Y}{Y_0}\right) - f\left(\frac{Z}{Z_0}\right)\right]$$

where

$$f(x) = \begin{cases} x^{1/3} & x > 0.008856 \\ 7.787x + \frac{16}{116} & \text{otherwise} \end{cases}$$

and

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.607 & 0.174 & 0.200 \\ 0.299 & 0.587 & 0.114 \\ 0.000 & 0.066 & 1.116 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

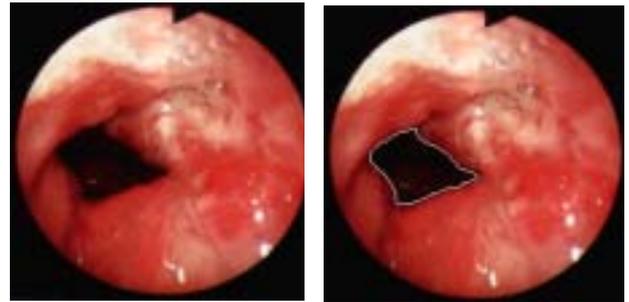


Fig. 5. (a) Original Image, (b) Display of Lumen Extraction on the Original Image

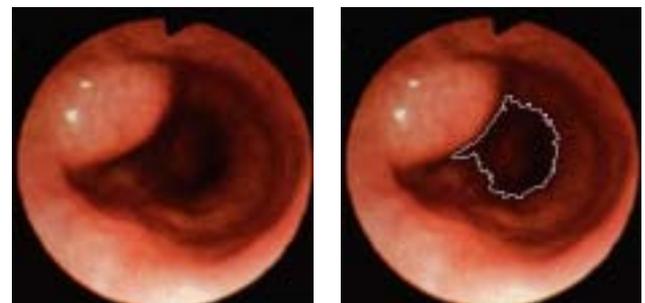


Fig. 6. (a) Original Image, (b) Display of Lumen Extraction on the Original Image

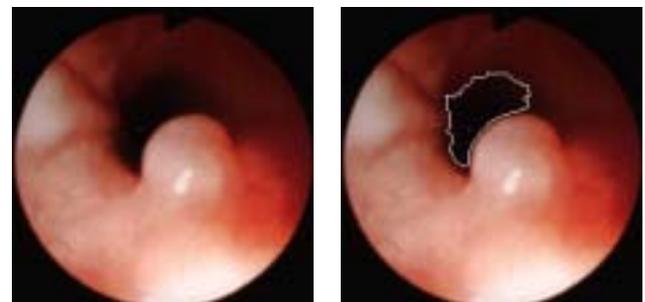


Fig. 7. (a) Original Image, (b) Display of Lumen Extraction on the Original Image