Classification of Intestine Polyps *

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Abstract

In this paper, we present a method to classify hyperplastic and adenomatous polyps of large intestine semiautomatically. First, Doctors locate the contour of the original polyp images by using other software package. We determine if there are gores on the polyp by using modified Sobel operator on eliminating specular reflection pixels of original color images. We then get the polyp's texture by summing the gradient magnitude of pixels within the polyps. After detecting the actual contour of the polyps, we can determine if the polyp's contour is obvious or not (i.e. if the polyp bulges smoothly or not). We then observe whether the polyp's color is redder than or whiter than its neighbors. Finally, we classify the polyp of the intestine by applying the above steps. The flow chart of classification is as shown in Figure 1. We apply our method on 77 color images with polyps of the intestine and compare the results with a doctor's diagnosis.

1 Motivation

Colorectal cancer (CRC) [5] is one of the most common malignancies in both sexes in Taiwan, with nearly 3500 new cases and 2100 deaths each year. Currently, the majority of the pathogenesis of CRC is attributed to the adenoma-adenocarcinoma sequence. Therefore, the identification and removal of adenomatous polyps has significant clinical implications in the surveillance of CRC. Since adenomatous polyps and hyperplastic polyps account for the vast majority of colorectal polyps and the ability to differentiate these two kinds of polyps endoscopically is unreliable [1, 4], we design an image processing system to help improve the endoscopic diagnostic accuracy.

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2 Pre-Processing

Since doctors' habits of tuning hue is different, the hues of color images may be different. It is difficult for us to process the color images. So we adjust the image hue to get similar hue. We also enhance the images by taking histogram equalization for stronger contrast. We shall name the original color image as OCI. Similarly, we name the color image after adjusting image hue and enhancing image intensity as ACI (adjusted color image). The example image of OCI is shown in Figure 2.

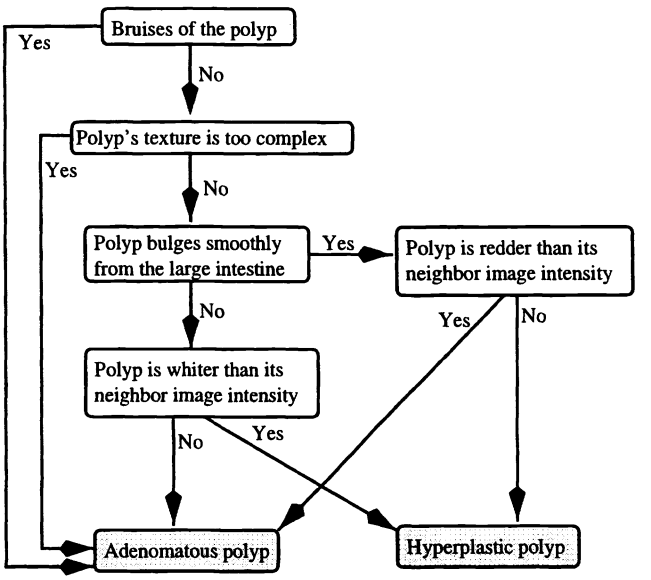

Figure 1: The flow chart of our classification.

2.1 Convert from RGB (Red, Green, Blue) to HSI (Hue, Saturation, Intensity)

Each color in OCI appears in its primary spectral components of red, green, and blue. But the RGB color model is not intimately related to the way in which human beings perceive color. Therefore we use HSI color model to adjust the color of OCI.

We convert the red, green, and blue of OCI to hue, saturation, and intensity. We use the functions defined as follows:

$$H = \cos^{-1}\left\{\frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{1/2}}\right\}$$

$$S = 1 - \frac{3}{R+G+B}[\min(R,\ G,\ B)]$$

$$I = \frac{1}{3}(R+G+B)$$

where H, S, I are the hue, saturation, and intensity respectively, and R, G, B are the red, green, and blue components.

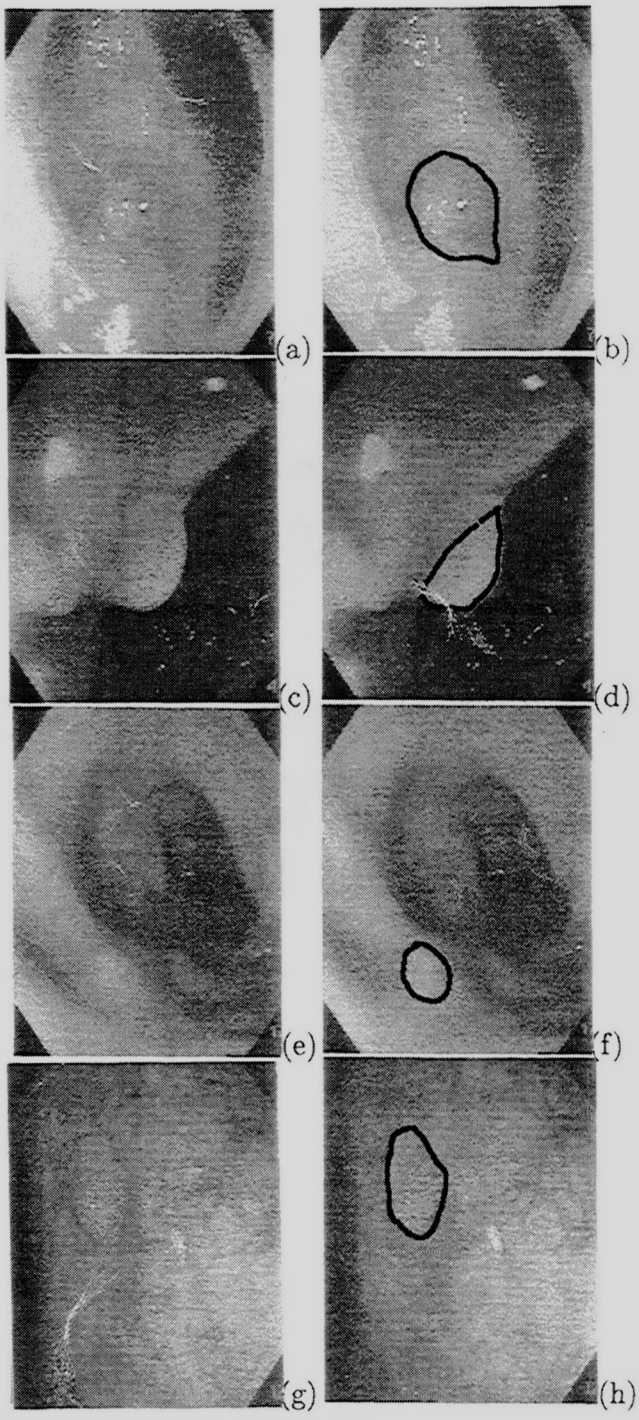

Figure 2: (a) Example 1 of original color image (OCI1). (b) OCI1 with contour located by a doctor. (c) Example 2 of original color image (OCI2). (d) OCI2 with contour located by a doctor. (e) Example 3 of original color image (OCI3). (f) OCI3 with contour located by a doctor. (g) Example 4 of original color image (OCI4). (h) OCI4 with contour located by a doctor.

2.2 Adjustment of Image Hue and Image Intensity

We transform the original image hue (OIH) to adjusted image hue (AIH).

It is convenient to analyze and process the image if the hue of each color image is similar. By observing the histogram of OIH, we find that most of the hue is distributed within an angle interval. If we move this angle interval to the red hue interval and move other hue by the same angle, we can adjust OCI to the red hue image.

We count the pixels of each angle on OIH. Then we find the angle interval which has most pixels. (We shall name the width of angle interval $ItvWidth$ as an abbreviation. $ItvWidth$ is set to 20° in our

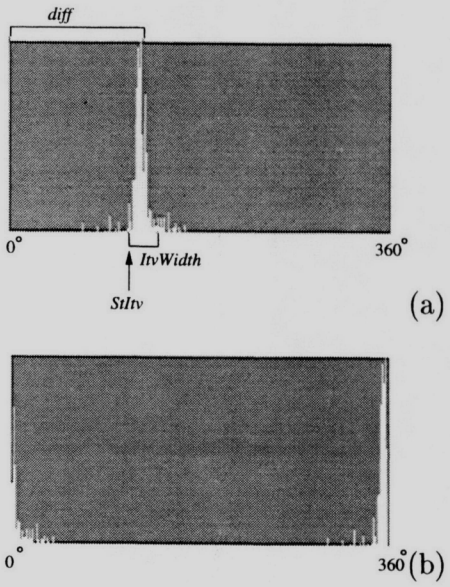

Figure 3: (a) The histogram of the original image1 hue. (b) The histogram of the adjusted image1 hue.

experiments.) We name the smallest angle of $ItvWidth$ as starting point of the interval $StItv$. The functions which we adjust the image hue is defined as follows:

$$diff = StItv + \frac{ItvWidth}{2}$$

$$\text{(The angle of AIH)} = (\text{(The angle of OIH)} - diff + 360°) \bmod 360°$$

where $StItv$ is the starting point of the interval, $ItvWidth$ is the interval width, and $diff$ is the difference angle to shift.
We then get the AIH. The histogram of OIH and AIH are as shown in Figure 3.

We also adjust the image intensity by taking histogram equalization. We shall name the adjusted intensity image IHE as an abbreviation.

2.3 Convert from HSI to RGB

We will get adjusted color image (we name it ACI) by converting AIH and IHE to adjust RGB image. The example images of ACI are shown in Figure 4.

2.4 Eliminate the Specular Reflections of Images

In order to clean the junk in patient's intestine when doctors check patient's large intestine, doctors spurt water from the blowhole of colonoscope. The water causes the bright image parts of specular reflection and it is difficult for us to detect the correct contour of polyps. Therefore we try to eliminate these specular reflections.

We adjust the image intensity by taking histogram equalization (we name it IHE as an abbreviation). Because the specular reflection pixel may be surrounded by other pixel within large intensity, we will fill the specular reflection pixels and the near surrounding pixels with the average color of the

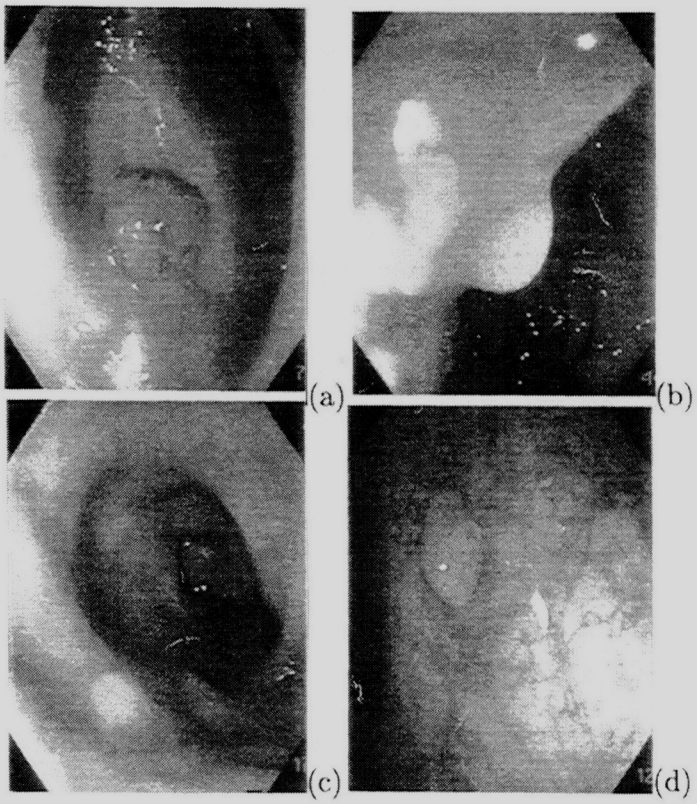

Figure 4: (a) The adjusted color image1 (ACI1). (b) The adjusted color image2 (ACI2). (c) The adjusted color image3 (ACI3). (d) The adjusted color image4 (ACI4).

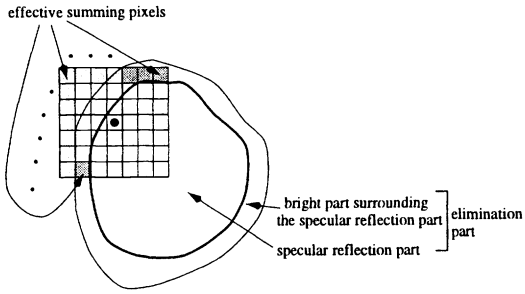

Figure 5: An explanation of using 7×7 mask to eliminate the specular reflections.

surrounding pixels. We have to fill the pixels surrounding the specular reflection pixels. The specular reflection pixels and the bright part enclosing the specular reflection pixels are named elimination pixels as shown in Figure 5.

After finding the 8-connected components of the specular reflection parts, we apply a 7×7 mask on the specular reflection pixels of each connected component. The center of the mask is the specular reflection pixel. The shadow pixels are candidate summing pixels and other pixels are elimination pixels. If the candidate summing pixel ($7 \times 4 - 4 = 24$ pixels) is not the specular reflection one, we treat it as an effective summing pixel and sum the intensity of these pixels (Figure 5). After summing every effective summing pixel of a component, we find the intensity sum and average. Finally, we fill the elimination pixels with the average red, green, and blue component intensity.

We name the images after eliminating the specular reflection parts of OCI as EROCI as shown in Figure 6.

3 Main-Processing

3.1 Judge If the Polyp Has Bruises

The polyp must be adenomatous if there are bruises on it. Thus we determine if the polyp has bruises first. Since the edge of bruises are obvious and the color contrast is apparent in ACI, we generate an edge image (gradient magnitude image) of EROCI. Since there are capillaries on the surface of large intestine, if we apply Sobel operator on ERACI, we may create edges which we do not want. Thus we apply Sobel operator on EROCI instead of ERACI.

Attempting to use Sobel edge detector [3] on intensity image is natural for us. Nevertheless, color image is different from gray scale image. Not only intensity will generate the edge, but the distinction of color can generate the edge. Thus we use modified Sobel edge detector instead of the general Sobel edge detector. The modified Sobel edge detector uses Sobel edge detector to detect the edges of R, G, and B images respectively and then generate the edge image by averaging all three edge images (Figure 7). We set a threshold to distinguish the obvious from the nonobvious edge. The threshold is set to 40 in our experiment.

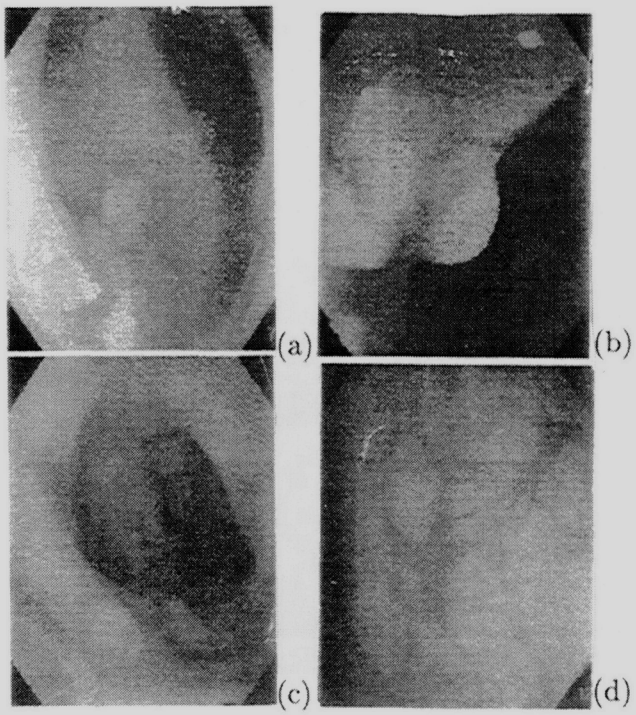

Figure 6: (a) EROCI1: image1 after eliminating the specular reflection parts of OCI1. (b) EROCI2: image2 after eliminating the specular reflection parts of OCI2. (c) EROCI3: image3 after eliminating the specular reflection parts of OCI3. (d) EROCI4: image4 after eliminating the specular reflection parts of OCI4.

We denote the intensity of red, green, and blue spectral components of ACI as $R(ACI)$, $G(ACI)$, and $B(ACI)$ respectively.

We find that if the gray scale of a pixel conforms to the following three conditions, it is a pixel on the bruise within a polyp:

1. Since the gray scale of bruises may not be too high and red spectral component of a bruise pixel is the highest, we believe the red spectral component of a bruise pixel must be smaller than 190.
2. The hue of a bruise pixel must be in the red angle interval. Thus the difference of $R(ACI)$ and the maximun of green and blue components of the bruise pixel can not be too small (larger than 80 in our experiment). For example, if $(R(ACI), G(ACI), B(ACI))$ of a pixel is (255,255,0), the color of this pixel is yellow.
3. The bruise must be magenta. If the $G(ACI)$ of a bruise pixel is greater than $B(ACI)$, the pixel will tend to be yellow. Thus $B(ACI)$ of a bruise pixel must be greater than $G(ACI)$ by at least a small amount (10 in our experiments).

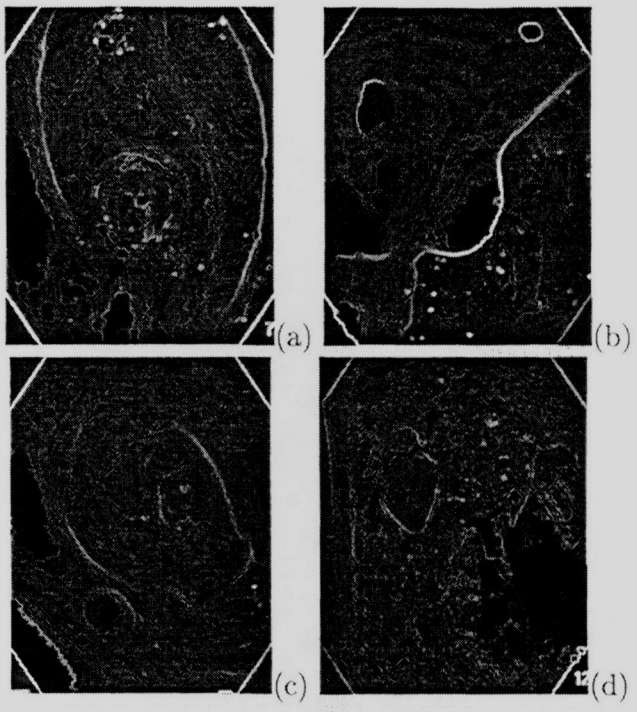

Figure 7: (a) The edge image of EROCI1 after applying modified Sobel edge detector. (b) The edge image of EROCI2 after applying modified Sobel edge detector. (c) The edge image of EROCI3 after applying modified Sobel edge detector. (d) The edge image of EROCI4 after applying modified Sobel edge detector.

These three conditions are defined as follows:

$$R(ACI) < 190$$

$$R(ACI) - \max(G(ACI), B(ACI)) > 80$$

$$B(ACI) - G(ACI) > 10$$

According to our criteria, Example1 has bruise and is correctly classified as adenomatous. Examples 2, 3, and 4 do not have bruise and need further classification.

3.2 Determine the Texture of a Polyp

If the texture of a polyp is too complex, it should be an adenomatous polyp. The sum of gradient magnitude is a good indicator of the complexity of the texture of a polyp. Instead of finding the variance of a polyp, we simply sum the gradient magnitude within a polyp to speed up determining time. If a pixel satisfies the following three conditions, we assume it is an effective texture pixel.

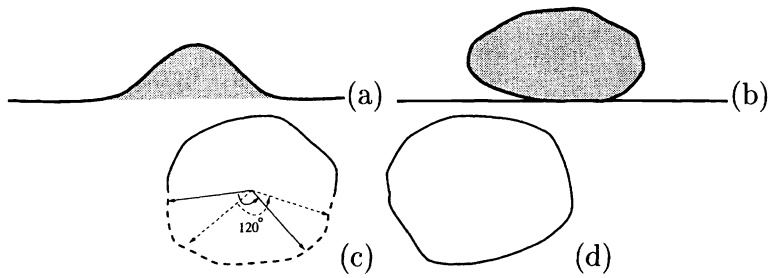

Figure 8: (a) A hyperplastic polyp bulges smoothly and is like part of large intestine. (b) A adenomatous polyp does not bulge smoothly and is like a polyp sticking to the large intestine. (c) An example contour of hyperplastic polyp in the image, where the contour covers a range of less than 240° (= 360° - 120°). (d) An example contour of adenomatous polyp in the image.

1. The pixel is on the polyp.
2. The gradient magnitude of the pixel within EROCI must be greater than zero, otherwise it is the filled specular reflection pixel.
3. The hue of the pixel (hp) must be in the red angle interval (i.e. hp $< 30°$ or hp $> 330°$).

After summing all effective texture pixels, we find the average gradient magnitude of a polyp. We need many effective texture pixels to reliably judge the complexity of polyp's texture. If the number of effective texture pixels is smaller than a threshold (set to 725 in our experiments), it might be too much specular reflection pixels (ineffective texture pixels) and lose too much information of a polyp. We only consider the average gradient magnitude if the number of effective texture pixels is greater than the threshold. If the average gradient magnitude of a polyp is larger than 30, we think it is an adenomatous polyp.

According to our criteria, Examples 2, 3, and 4 do not have complex texture, so all need further classification.

3.3 Judge If the Polyp Bulges Smoothly from the Large Intestine

We know that the hyperplastic polyp bulge smoothly and is like part of large intestine. However, the adenomatous polyp does not bulge smoothly and is like a polyp stick to the large intestine (Figure 8). If a polyp is hyperplastic, it tends to merely has obvious edge in certain direction. If a polyp is adenomatous, it tends to have obvious edge in each direction.

We create a searching fan-shaped area with angle=120° as shown in Figure 10. To allow some errors when locating the contour by doctor manually, we dilate the contour before detecting actual edge of contour. The dilation of A by B is denoted by $A \oplus B$ and is defined by:

$$A \oplus B = \{c \in E^N | \, c = a + b \text{ for } a \in A \text{ and } b \in B\}$$

where A is polyp's contour located by the doctor and the structuring element B is as shown in Figure 9.

We then find the centroid of each dilated region. In order to detect the actual contour edge, we define a searching angle θ and searching line SL. The change of θ is as Figure 10 shows (the step size is set to 2° in our experiments). The unit vector $(unit.x, unit.y)$ of each direction is defined as follows:

$$unit.x = \begin{cases} \frac{1}{\sqrt{1+\tan^2\theta}} & \text{if } \theta \bmod 2° = 0° \\ 0 & \text{otherwise} \end{cases}$$

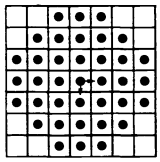

Figure 9: The 7×7 structuring element of dilation.

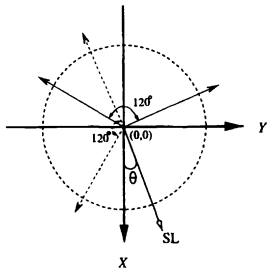

Figure 10: The searching line SL and searching angle θ. Two example searching fan-shaped areas with angle of 120°.

$$unit.y = \begin{cases} \frac{\tan\theta}{\sqrt{1+\tan\theta}} & \text{if } \theta \bmod 2° = 0° \\ 0 & \text{otherwise} \end{cases}$$

The SL radiates from the centroid of dilated contour $(cenx, ceny)$ to each direction. If the pixel is at $(cenx + unit.x, ceny + unit.y)$ of angle θ and is in the dilated contour, we consider it is a candidate edge pixel. If the polyp is on the tortuosity of large intestine, part of the polyp's contour will be obvious, no matter the actual polyp's contour is obvious or not, so that part will be ignored. Furthermore, there may be no edge in the direction of the filled specular reflection pixels, so that direction is also ignored. We assume it is an ineffective direction in the above two situations.

We first explain how to ignore the polyp's contour on the tortuosity of large intestine. We extend SL out the dilated contour in each direction to generate a ring enclosing the dilated contour. The width of ring is set to 10 pixels in our experiment. We use the intensity of the ring to judge if the polyp is at the tortuosity of large intestine (i.e. test if the polyp's neighbor is dark or not). If the intensity of a pixel within the ring is smaller than dark criterion (we set dark criterion to 70), we assume it is a dark pixel. We count the pixel number of certain direction which conforms to the above condition. We think it is an ineffective direction if the dark pixel number is greater than three because tortuosity may cause too many dark pixels.

Second, we explain how to ignore the polyp's contour in filled specular reflection parts of intestine. The filled specular reflection pixels are constant and their gradient magnitude will be 0. We then define a variable $bright_i$ as follows:

$$bright_i = \sum(\text{the gradient magnitude of all candidate edge pixels in the direction } i)$$

If $bright_i = 0$, we think it is part of area filled with the same color. Since it is a specular reflection area, we can not find the original color of it. We assume it is an ineffective direction, too.

If we select all candidate edge pixels in the profile of the contour in effective angle θ, the pixels not belonging to the actual contour edge will affect our judgement. If we just select highest gradient magnitude of candidate edge pixels, we may select false pixel. Therefore we decide to select two highest candidate edge pixels of angle θ as the effective edge pixels. After summing the effective edge pixels of each direction, we get the average gradient magnitude of the effective edge pixels within the dilated contour.

The step size of searching fan-shaped area is the same as searching angle. We observe the edge is nonobvious if the gradient magnitude is smaller than 40. For each effective edge pixel in the searching fan-shaped area, the function to judge if the polyp bulges smoothly is defined as follows:

$$nonobvious_{ij} = \begin{cases} 1 & \text{if gradient magnitude of the pixel } j \text{ in direction } i \text{ is } \leq 40 \\ 0 & \text{otherwise} \end{cases}$$

$$sample_i = \begin{cases} 1 & \text{if } i \bmod 2^\circ = 0 \\ 0 & \text{otherwise} \end{cases}$$

$$BulgeSmoothly_k = \sum_{i=(k+1^\circ) \bmod 360^\circ}^{(k+120^\circ) \bmod 360^\circ} \sum_{j=1}^{2} nonobvious_{ij} \times sample_i, \quad 0^\circ \leq k \leq 359^\circ$$

If more than three quarters of the effective edge pixels in a range of 120° are nonobvious then we assume the polyp bulges smoothly, i.e.

$$\frac{BulgeSmoothly_k}{\sum_{i=(k+1^\circ) \bmod 360^\circ}^{(k+120^\circ) \bmod 360^\circ} \sum_{j=1}^{2} sample_i} > \frac{3}{4}$$

According to our criteria, Examples 2 and 3 bulge smoothly; Example 4 does not bulge smoothly.

3.4 Judge If the Polyp is Redder Than or Whiter Than Its Neighbors

If a polyp is adenomatous, it tends to be redder than its neighbors. We define a polyp's neighbor as NBR. After counting the average hue of a polyp and its NBR respectively, we compare the hue of a polyp with its NBR. Therefore we can decide if a polyp is hyperplastic or adenomatous.

We find the eight connected components and number each component. We use a propagation technique to find the area in the contour. First, we find the centroid point as the initial propagation point. We take the centroid point as the initial propagation point. We color the point and judge its four neighbors. If a neighbor pixel is not colored and is not a contour pixel, we propagate it. Therefore we find the region within the polyp's contour (we name it INCON as an abbreviation).

If a pixel according to the following three conditions, we assume it is an effective color pixel.

1. Gray scale of the pixel in IHE < 240.
2. Gray scale of the pixel in IHE > 80.
3. The angle of AIH $< 30°$ or the angle of AIH $> 330°$.

The first condition illustrates that it is not a specular reflection pixel. The second condition illustrates that it is not a dark pixels. The third condition illustrates that this pixel is in the red angle interval. After finding the average hue of all effective color pixels within a polyp and its NBR respectively, we can judge if the polyp is redder than its neighbors.

If the hue of INCON and NBR satisfies the following condition, we assume the polyp is redder than its neighbors:

$$\mathrm{H(NBR)} - \mathrm{H(INCON)} \; > \; 3°$$

where H(NBR) denotes the angle distance between hue of NBR and angle 0°, H(INCON) denotes the angle distance between hue of INCON and angle 0°. Since the angle 0° is pure red, we believe that a pixel is redder than the other if its angle distance is closer to angle 0°.

To determine if the polyp is whiter than its neighbors, we find the average saturation of all effective color pixels within a polyp. If the saturation of INCON and NBR satisfies the following condition, we assume the polyp is whiter than its neighbor:

$$\mathrm{S(NBR)} - \mathrm{S(INCON)} \; > \; 0.04$$

where S(NBR) denotes the saturation of NBR, S(INCON) denotes the saturation of INCON. Since the saturation of a pure white pixel is 0, we set the threshold of difference of saturation between NBR and INCON in our experiment to 10.

According to our criteria, Example 2 bulges smoothly and is redder than its neighbors, so is misclassified as adenomatous. Example 3 bulges smoothly but is not redder than its neighbors, so is correctly classified as hyperplastic. Example 4 does not bulge smoothly and is not whiter than its neighbors, so is correctly classified as adenomatous.

4 Experimental Result

We apply our method on 77 color images with polyps of the intestine and compare the results with a doctor's diagnosis. The flow chart of our classification is as shown in Figure 1. Comparing the doctor's diagnosis with the computer's, we have the following table:

Class	possible diagnosis combination (doctor's, computer's)	total	rate %
Correct Detection	(adenomatous polyp, adenomatous polyp)	19	24.68
	(hyperplastic polyp, hyperplastic polyp)	43	55.84
Misdetection	(adenomatous polyp, hyperplastic polyp)	7	9.09
False Positive	(hyperplastic polyp, adenomatous polyp)	8	10.39

We can find that the correct detection rate = (24.68% + 55.84%) = 80.52%, the misdetection rate is 9.09%, and the false alarm rate = 10.39%.

5 Discussion

This experimental study was designed to determine the hyperplastic and adenomatous polyps of human large intestine. Observing the 77 results, we find that there are two major problems in classifying polyps of the large intestine. First, the correctness of detecting specular reflection parts will significantly affect our classification. Since the gray level of specular reflection parts in each image is variable, it is difficult for us to detect these parts correctly. We simply find a stricter and higher threshold (gray level 240) in our experiment and then we use a 7×7 mask to detect the specular reflection parts. It sometimes may cause misdetection and lose more information. For improving this problem, we may use Sobel operator to detect edges of images since specular reflection parts always cause the pixels with high gradient magnitude. We then find the pixels which has high intensity and is near these high gradient magnitude pixels. It might improve the correctness of detecting specular reflection parts.

Second, since the process followed by the human brain in perceiving color is a physiopsychological phenomenon that is not yet fully understood, the physical nature of color can be only expressed on a formal basis supported by experimental and theoretical results. The color models most often used for image processing are the RGB and HSI models. Nevertheless, it is hard for human beings to perceive color components. It is complicated to process the color images.

6 Conclusion

We present an original method to classify the polyps of large intestine semiautomatically. The polyp's contour of the color images are located by a doctor. We find the 8-connected component to detect the number of the polyps of an image. We then use the methods which is mentioned in this paper to classify the polyps. This algorithm is applied to 77 color images and the correct detection rate is 80.52%, misdetection rate is 9.09%, and the false alarm rate is 10.39%.

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