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Automatic Small Intestinal Ulcer Detection in Capsule Endoscopy Images

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Abstract— In order to detect small intestinal diseases like ulcer, capsule endoscopy (CE) is widely used due to its clear visibility and non-invasive natures. But its problem lies in its reviewing process; a physician has to analyze a large number of image frames, which is very time-consuming and often leads to human error. Hence, to reduce the burden of the physician, an automatic computer aided method is necessary to detect ulcer from CE videos. In this paper, a histogram feature based ulcer detection method is developed using K-nearest Neighbor (KNN) classifiers. Most commonly used RGB color plane is utilized to extract features. Along with individual Red, green and blue plane histogram, a combination of all three color plane histograms is investigated and among them combined histogram feature provides the best detection performance. The performance of the proposed method is tested on several CE images taken from publicly available CE video database and it is found that it offers superior classification performance, in comparison to that obtained by some existing methods, in terms of accuracy, specificity, and sensitivity.

Index Terms— Capsule endoscopy, classification, feature extraction, histogram, K-nearest Neighbor (KNN), RGB color space, ulcer detection.

1 Introduction

At present, Gastrointestinal (GI) diseases like ulcer, colon cancer, tumor etc. are prominently threatening human's health. Diseases of GI tract can be cured if early detection is possible. But the main problem is that small intestine (usually considered as the main body of GI tract) cannot be visualized by traditional endoscopies. Also, other traditional medical diagnosis techniques such as ultrasound, CT scan and X-ray have been widely used to detect abnormalities of GI tract. However, the drawbacks of these technologies are: unsuitable for detecting all kind of diseases and possess side effect. Capsule endoscopy, developed by Given Imaging in 2000, can directly view the whole small intestine without pain, sedation or air insufflation, thus it draws attention among GI community. It has been reported that this innovative technology demonstration great value in assessing GI bleeding, ulcer, Crohn's disease and other diseases occurred in the digestive tract [1].

A sample of a pill-shaped capsule and CE recording system is shown in Figs 1 and 2. The capsule is small in size and an easy mouthful to the patients. Capsule consists of a CMOS camera, a battery, a radio transmitter and four light sources. When a patient swallows that capsule, it propelled by peristalsis begins to work and record images. In the meantime, images are sent out wirelessly to receiving sensor attached to the different position of abdomen and waist. This process lasts about eight hours. Finally, all the images (approx. 57,000) stored into a computer and physician can view images and diagnose different GI tract diseases. It is to be noted that reviewing process

Fig. 1: Size of Capsule endoscopy
(Source: www.swgispecialists.com)

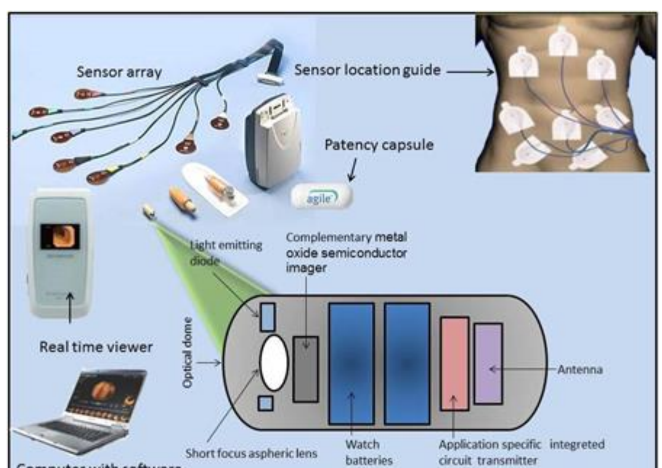

Fig. 2: Image acquiring methods of capsule endoscopy
(Source: www.intechopen.com)

of all the images is a time consuming and laborious task and often lead to human error. Moreover, there may be some anomalies that cannot be noticed by naked eyes due to their dimensions and distribution. Furthermore, different clinicians may have different judgments when they evaluate the same image. All these difficulties motivate researchers to develop

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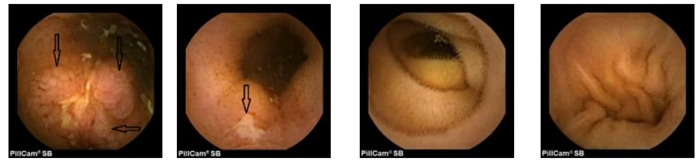
consistent and uniform assisting systems to decrease the great burden of physicians.

Due to its increasingly wide application, some researchers have initiated in direction of partially or fully automating diagnosis of CE images. The manufacturer itself offers a software tool to identify bleeding region; however, sensitivity and specificity of this system were reported to be 21.5% and 41.8%, respectively [2]. An interesting approach of selecting MPEG-7 visual descriptors as feature extractor to do diagnosis in GI tract for some main diseases such as polyp, ulcers and bleeding were advanced by Coimbra and Cunha [3]. In view of detecting bleeding and ulcer of CE data, another method [4] implies chromaticity moment which is obtained from HSI (Hue-Saturation-Intensity) color space. It is very common to use the statistical feature to detect bleeding images from CE video as proposed in [5]. Histogram obtained from an indexed image is proposed in [6] to detect bleeding frames in CE videos. In [7], a curvelet based local binary pattern is proposed as textural features to distinguish ulcer regions from normal regions. Texture and color based image segmentation and pathology detection in capsule endoscopy videos are introduced in [8]. In order to identify ulcer images of CE videos, a Color Coherence Vector (CCV) based feature is proposed in [9]. The lacunarity index of Discrete Curvelet Transform (DCT) sub-bands of the CE images is used to detect ulcer by Alexis Eid [10]. Another ulcer detection method is developed in [11] based on bag-of-words model and feature fusion technique.

In this paper, an automatic ulcer detection method is proposed using RGB histogram and KNN classifier. At first, the black portion of CE images is removed by a simple algorithm. Later on, only the intensity information of the desired pixel is processed to extract features. For the purpose of extract feature, all color planes (red, green and blue) are considered and a different number of bins are used. Apart from that, a combination of all three color plane histogram features is investigated. Finally, the K-nearest neighborhood (KNN) classifier is used to classify Ulcer and non-ulcer CE images by using the extracted features. Classification performance is tested on publicly available CE video database.

2. Properties of Ulcer Images

Two ulcer and normal (non-ulcer) CE images are presented in the Fig. 3. In Figs 3(a) and 3(b), topical ulcer images are shown where arrow mark indicates the ulcer region. From the images, it is observed that generally, an ulcer region looks like a white or pinkish-white color with arbitrary shapes. Moreover, ulcer region possesses high-intensity value with respect to its surrounding areas. On the other hand, In Figs 3(c) and 3(d), normal CE images are shown. Although normal images have white like regions (see Fig. 3(C)), it seems to have similar pixel intensity values in the entire images. Thus, to differentiate ulcer and normal images pixel intensity may play a vital role. Pixel intensity values can be represented by histogram and histogram bin values of ulcer and normal images are investigate to detect ulcer images from normal ones.



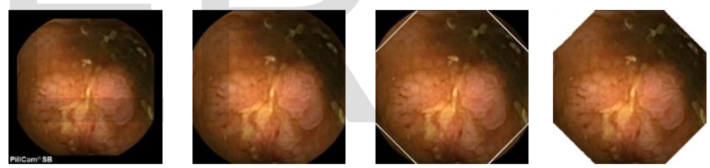
(a) (b) (c) (d)

Fig. 3: Topical capsule endoscopy images, (a) and (b) ulcer image, (c) and (d) non-ulcer image

3. Proposed Method

3.1 Removing Black Regions

Valuable information of a typical CE image is preserved in the circular or semi-octagonal center region as shown in the Fig. 4 (a). Around the central region, in the peripheral area, there exists black region which contains no useful information. If this whole image is directly used, the presence of the peripheral black pixels would degrade the performance of ulcer detection analysis. Therefore, a black region removal scheme is proposed in this paper to eradicate these black pixels. At first, the given CE image is reduced to a square shaped image considering the number of peripheral black pixels as shown in Fig. 4(b). Next, black regions around the corner zone are eliminated to attain the desired octagonal zone as demonstrated in Fig. 4(c). Because of these simple steps unwanted black regions are removed, which not only reduces computational complexity for feature extraction but also ensures better feature quality.



(a) (b) (c) (d)

Fig. 4: Illustration of black portion removal steps, (a) original CE image, (b) after removing rectangular black portion, (c) acquiring center octagonal shape, (d) final image

3.2 Histogram of CE Image

Histograms are frequently used to compare images. Examples of using histograms are observed in [12] and [13]. Its popularity stems from several factors: i) histograms are computationally efficient, ii) histograms are generally insensitive to small changes in camera position, iii) different objects often have distinctive histograms. Those properties of histogram motivate us to use it a feature to differentiate between ulcer and normal CE images.

We will assume that all images are scaled to contain the same number of pixels M. We discretize the color space of the image such that there are n distinct (discretized) colors. In the case of RGB color space, R plane is discretized into n distinct bins. Then the Histogram of R plane defines as

$$H_R = [H_1, H_2, \cdots H_n] \quad (1)$$

which each bucket H_j contains the number of pixels of color j in the image. In image based pattern recognition problems,

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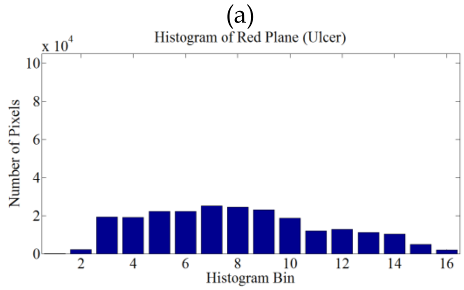
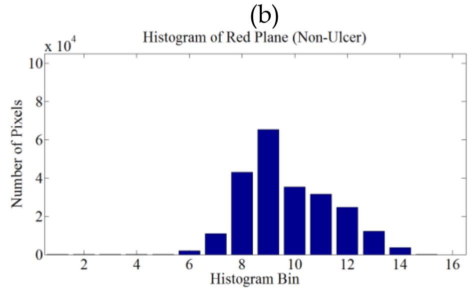
(a)

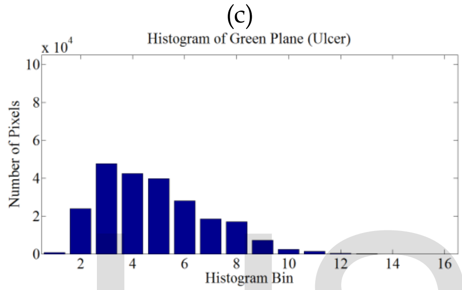
(b)



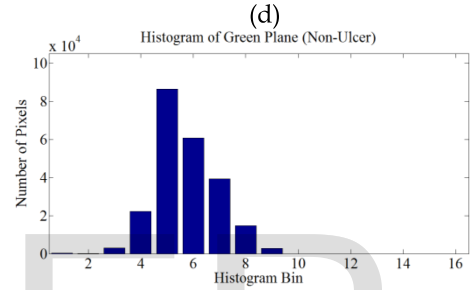
(c)



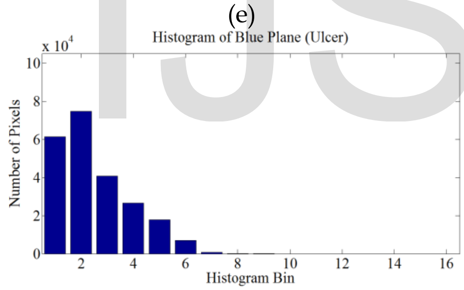
(d)



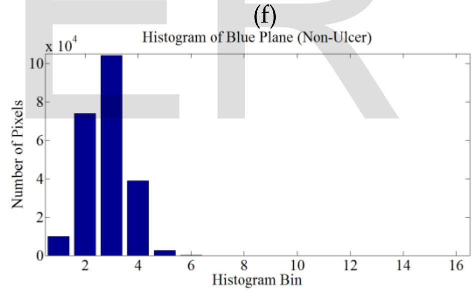
(e)



(f)



(g)



(h)

Fig. 5: Ulcer and non-ulcer image with histogram of different planes, (a) topical ulcer image, (b) topical non-ulcer image, (c) histogram of red plane (ulcer), (d) histogram of red plane (non-ulcer), (e) histogram of green plane (ulcer), (f) histogram of green plane (non-ulcer), (g) histogram of blue plane (ulcer), (h) histogram of blue plane (non-ulcer).

image histogram is widely used. In order to obtain an effective feature that can detect ulcer images from the normal ones, histograms of the red, green, and blue plane are investigated. In Fig. 5, sixteen bins histogram obtained from different color planes (red, green, and blue) of both ulcer and non-ulcer image are presented. A topical ulcer image is shown in Fig 5 (a) and the histograms obtained from different color planes of that image are illustrated in the left column. Similarly, a non-ulcer image is shown in Fig 5 (b) and its corresponding histograms are illustrated in the right column. From the histograms, it is observed that although ulcer and non-ulcer images possess overlapped regions, but histogram pattern is different from each other. According to the hypothesis, ulcer regions are white or white pinkish colored, thus it is expected that in the red, green, and blue plane it possess high-intensity values. As it is observed in the case of the red plane histogram in Figs 5 (c) and (d), for ulcer image there are higher values in the bin of 14, 15 and 16 compared to that of the non-ulcer image. In non-ulcer case, the values of that bins are nearly zero. Moreover, in the blue plane histogram, a similar phenomenon is observed in the bin number 5, 6, and 7. This phenomenon is also noticed in the green plane. It is to be noted that this type of dissimilarity does not occur in same bin numbers. As a result, in this paper, we considered all bin frequencies as a feature to detect ulcer image from CE videos. Also, the feature combination of all three color-planes is taken into consideration. All the mention color plane histograms are investigated and the best suitable feature is obtained in the result and simulation section.

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3.3 K-nearest Neighbor (KNN) Classifier

To classify the ulcer and non-ulcer CE images the K-nearest neighbor (KNN) classifier is used. Though it is one of the simplest classifiers, due to its high efficiency this nonparametric classifier is one of the most widely used classifiers in several pattern recognition algorithms. KNN classifier classifies the test data set of CE images comparing them with K neighboring train data set by considering a distance function computed between both data sets. After classification, the KNN classifier outputs a class membership. This class membership assigned to a test object is determined by votes of the majority K nearest neighbors. In the proposed method, Euclidean distance is used to classify test data set considering the class labels of K nearest image patterns. After extensive experimentation with different values of K, a suitable value is used to achieve optimum performance in the proposed method.

4. Result and Simulation

In this section, the experimental results are presented to show the efficiency of the proposed method considering 220 color images selected from 8 CE videos which are publicly available and very widely used [14]. 110 images of them show a sign of ulcer and other 110 as normal/non-ulcer. At first, for a test CE image, black areas are removed and from the resultant image histograms from red, green, blue planes are computed. Finally, histogram bin frequencies are used as a feature in KNN classifier and marked that test image as ulcer or non-ulcer. In order to obtain the performance result, 10 fold cross validation technique is implemented.

There are four cases about the detection result of ulcer image and non-ulcer images. The ulcer image will be possibly detected as a non-ulcer image which is called false non-ulcer recognition (Fnb). Similar way the non-ulcer images will be detected as ulcer images which are called false ulcer recognition (Fb). The other two cases are the true ulcer recognition (Tb) and the true non-ulcer recognition (Tnb). To assess the capability of the bleeding detection method, sensitivity and specificity [15] are ideal criterions which are calculated as following.

$$\text{Sensitivity} = \frac{\sum Tb}{\sum Tb + \sum Fnb} \tag{2}$$

$$\text{Specificity} = \frac{\sum Tnb}{\sum Tnb + \sum Fb} \tag{3}$$

$$\text{Accuracy} = \frac{\sum Tb + \sum Tnb}{\sum Tb + \sum Fnb + \sum Tnb + \sum Fb} \tag{4}$$

Among those three performance indices, sensitivity is the most important parameter due to it measures the truthfulness of ulcer image detection.

In order to investigate ulcer detection performance of different color planes, bin frequencies of the red plane histogram are used as a feature. Performance variation of different bin sizes of the red plane histogram is presented in Fig. 6. In that figure, all performance indices (accuracy, sensitivity and specificity) are illustrated. Similarly in Fig. 7 and Fig. 8, performance obtained using green and blue plane histogram features are presented. From these three figures, it is observed that histogram feature from the individual plane is not sufficient to detect ulcer images with high accuracy. But one of the interesting facts is observed that blue plane histogram provides high sensitivity value while red and green plane histograms provide high specificity. Thus, in this paper, feature cascade of all three color plane is proposed to detect ulcer images with high accuracy and sensitivity. Ulcer detection performance of cascade histogram feature is reported in Table 1.

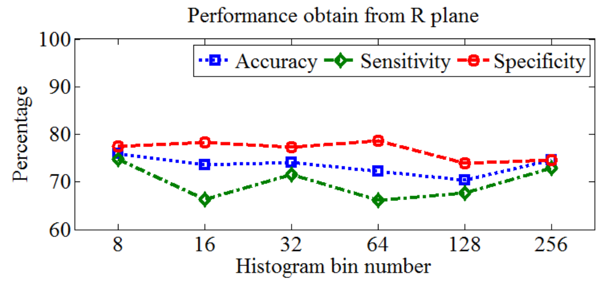

Fig. 6: Ulcer detection performance obtained from red plane histogram

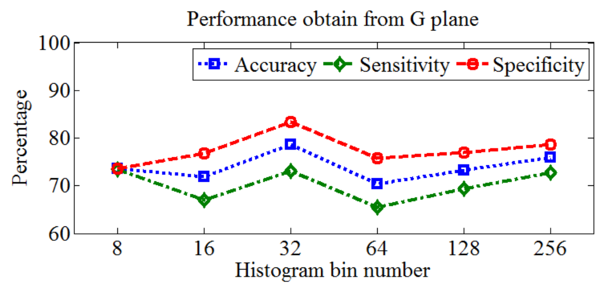

Fig. 7: Ulcer detection performance obtained from green plane histogram

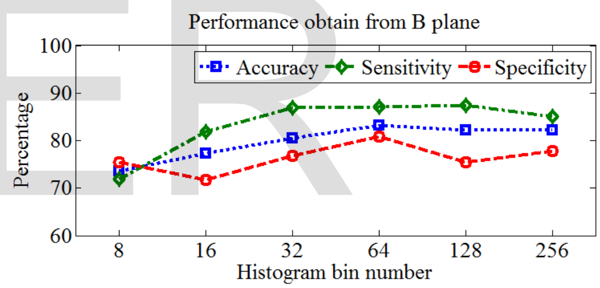

Fig. 8: Ulcer detection performance obtained from blue plane histogram

Table 1
Ulcer Detection Performance Varying Histogram Bins

Feature	Histogram bin	Accuracy (%)	Sensitivity (%)	Specificity (%)
Cascade red, green and blue histogram feature	8	82.73%	80.02%	85.94%
	16	81.82%	80.98%	83.83%
	32	**87.27%**	**88.64%**	**85.75%**
	64	83.64%	80.91%	85.80%
	128	85.91%	84.50%	88.15%
	256	85.00%	88.05%	82.23%

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From the table, it is observed that ulcer detection performance is much higher with respect to the individual color plane histogram feature. The best performance is achieved in 32 bin histogram feature, which means feature vector size is $32 \times 3 = 96$.

Moreover, ulcer detection performance is investigated of different values of 'K' in KNN classifier. Performance result varying 'K' values is illustrated in Fig. 9. It is observed that $K = 6$ provides the best performance in terms of accuracy, sensitivity, and specificity.

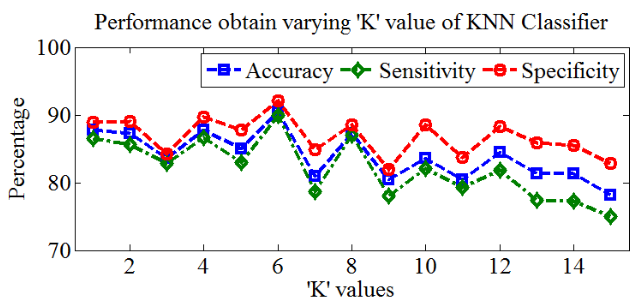

Fig. 9: Ulcer detection performance varying 'K' values of KNN classifier

Finally, to evaluate the result obtained by the proposed method, it is compared with those obtained by the methods proposed in [4], [5], and [8]. The color wavelet covariance (CWC) feature is used in [4] and the local binary pattern (LBP) feature is also used to compare in [5]. Lacunarity (LAC) obtained from discrete curvelet transform (DCT) is introduced in [8], which is also considered for comparison. Ulcer detection performance comparison result is reported in Table 2. From the table, it is observed that proposed method provides better accuracy and sensitivity with respect the others methods. It is to be noted that accuracy and sensitivity are the most important performance parameter in biological detection methods.

Table 2
ULCER DETECTION PERFORMANCE COMPARISON WITH EXISTING METHODS

Methods	Accuracy (%)	Sensitivity (%)	Specificity (%)
CWC [4]	74.35%	78.46%	70.24%
LBP [7]	83.92%	86.28%	81.56%
DCT-LAC [10]	86.54%	84.51%	88.56%
Proposed method	**87.27%**	**88.64%**	**85.75%**

5. Conclusion

In this paper, an efficient ulcer detection scheme is proposed based on RGB domain histograms of a CE image. It is observed that individual color plane histogram feature of RGB domain cannot provide satisfactory performance. While combining all three color plane histogram features of RGB domain provide much satisfactory ulcer detection performance. Feature obtained from different histogram bins are investigated and the best performance result is achieved using 32 bin histograms. Feature extract of histogram bin frequencies is simple, fast and computationally effective. For the purpose of classification, KNN classifier is employed which is considered simple and computationally less expensive. As a result, proposed method can be implemented in the real-time application. The performance of proposed features in classifying ulcer and non-ulcer images is evaluated in terms of accuracy, specificity and sensitivity, and it turns out that the proposed method outperforms other three compared methods in terms of accuracy and sensitivity.

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