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Computer-aided small bowel tumor detection for capsule endoscopy

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ABSTRACT

Objective: Capsule endoscopy is useful in the diagnosis of small bowel diseases. However, the large number of images produced in each test is a tedious task for physicians. To relieve burden of physicians, a new computer-aided detection scheme is developed in this study, which aims to detect small bowel tumors for capsule endoscopy.
Methods and materials: A novel textural feature based on multi-scale local binary pattern is proposed to discriminate tumor images from normal images. Since tumor in small bowel exhibit great diversities in appearance, multiple classifiers are employed to improve detection accuracy. 1200 capsule endoscopy images chosen from 10 patients' data constitute test data in our experiment.
Results: Multiple classifiers based on k-nearest neighbor, multilayer perceptron neural network and support vector machine, which are built from six different ensemble rules, are experimented in three different color spaces. The results demonstrate an encouraging detection accuracy of 90.50%, together with a sensitivity of 92.33% and a specificity of 88.67%.
Conclusion: The proposed scheme using color texture features and classifier ensemble is promising for small bowel tumor detection in capsule endoscopy images.

1. Introduction

Malignant neoplasms of the small bowel are uncommon tumors, accounting for only 2% of all gastrointestinal tract cancers [1]. These tumors are often diagnosed late as the long convoluted small bowel is beyond the reach of conventional endoscopes from both the oral and anal route. The advent of capsule endoscopy (CE) enables physicians to visualize the inside of the entire small intestine. It is well tolerated by most patients and therefore extensively used in patients with suspected small bowel diseases. When compared to other imaging modalities such as small bowel series and computed tomography (CT) enteroclysis, CE remains superior in the diagnosis of mucosal and intraluminal masses.

As shown in Fig. 1, CE is a pill-shaped device, which consists of a specific camera, light source, battery, radio transmitter and some other miniature components. A CE propelled by peristalsis starts to take images while moving forward along the digestive tract after it is swallowed by a patient. Meanwhile, images recorded by a camera are sent out wirelessly to a recorder attached to the waist. This process lasts for about 8 h until CE battery ends. Finally, all the image data are downloaded to a computer, and physicians view and interpret images as a video sequence. CE was approved by U.S. Food and Drug Administration in 2001, and it has been shown to be accurate in diagnosing small bowel bleeding, Crohn's disease, tumor and other small bowel diseases [2].

The examination of CE produces a large number of images. It is time consuming and often tedious for clinicians to view and interpret these images. Approximately 50,000 images are produced in one examination, and the average time cost by an experienced clinician to review and analyze all the video data is between 45 min and 1 h and 15 min [2]. In addition, there may be some abnormalities that cannot be detected by naked eyes. Such problems inspire researchers to develop computer-aided detection (CAD) system to reduce burden on physicians. However, it should be admitted that this goal is challenging because true features associated with diseases are not exactly known or well defined. In addition, different diseases may have totally different symptoms in the digestive tract, and the same disease may even show great diversities in color and shape.

Some efforts have been made for CE image analysis. The manufacturer itself provides a software tool to identify bleeding region, however, accuracy of this system was reported to be low [3]. A method using color distribution to discriminate stomach, intestine and colon tissue in CE images was proposed by Mackiewicz et al. [4]. In [5], the authors employed two cues, i.e., lumen and illumination highlight, for navigation of active endoscopic capsule. Recently, Bejakovic et al. [6] put forward a scheme using color, texture and edge features to analyze the Crohn's disease lesion for CE images. We have investigated bleeding and ulcer region detection for CE images in our previous works [7–9], which mainly concen-

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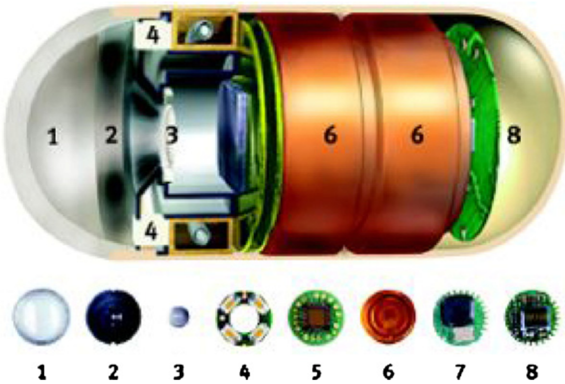

Fig. 1. CE (1) optical dome; (2) lens holder; (3) lens; (4) illuminating sources; (5) image sensor; (6) battery; (7) transmitter; and (8) antenna.

trate on features that are suitable to describe bleeding and ulcer in CE images.

In this study, we aim to develop a computer aided system to diagnose small bowel tumors. To this end, we propose a new textural feature that is built upon wavelet and local binary pattern. Concerning classifier, we exploit an integration of k-nearest-neighbor (KNN), multilayer perceptron (MLP) neural network and support vector machine (SVM) to tackle great variations of tumor in CE images. Comparative experimental results on our present CE image data show that this new scheme achieves a promising performance for small bowel tumor detection.

The structure of this paper is designed as follows. The proposed textural feature is described in detail in the following section, followed by classifier ensemble introduction in Section 3. In Section 4, experiments verifying performances of the proposed scheme are presented. Discussions about CE and the whole work reported in this paper are made in Section 5, followed by some conclusions drawn in Section 6.

2. Textural features

Normal CE images and tumor CE images can be differentiated using textural features as texture information is one of the primary features analyzed by clinicians. As illustrated in Figs. 2 and 3, respectively, the normal CE images and CE images with tumor show

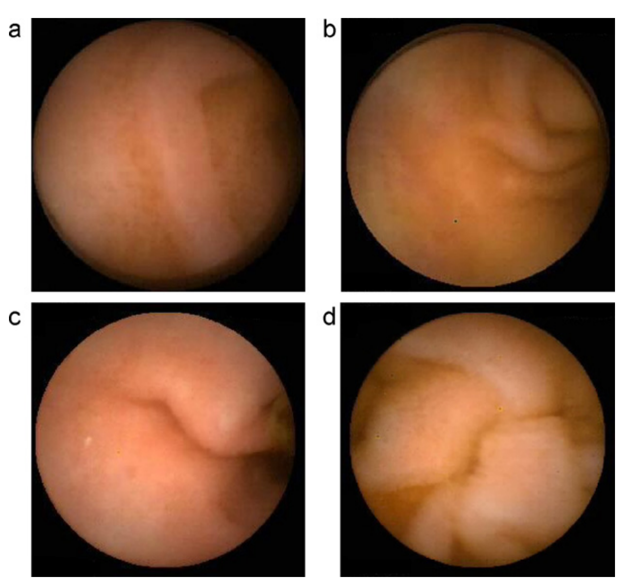

Fig. 2. Some normal CE images.

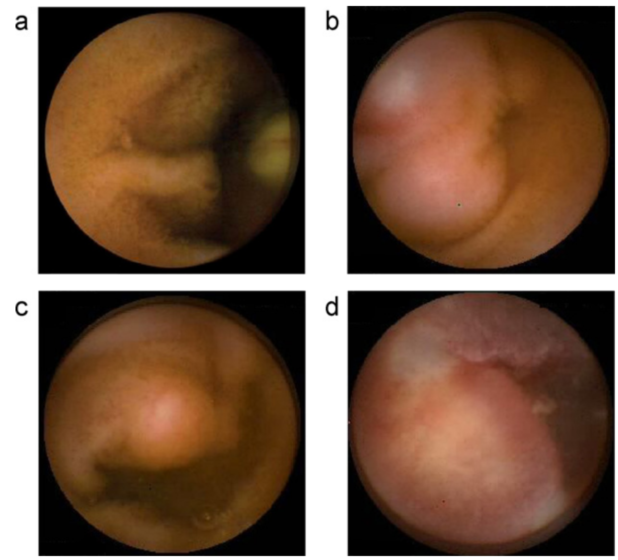

Fig. 3. Some CE images with tumor.

different textural characteristics on its mucosa surface. This property motivates us to investigate color texture features of these images. However, it should be emphasized that tumor in the GI tract exhibits great variations in appearances [10], as can be observed from Fig. 3, which pose a great challenge to a CAD system design since one feature may not be powerful enough to describe such a great variation. Moreover, image resolution of CE images used in our experiments is only 256×256, which may make this task more difficult to handle as traditional commercial endoscopy images have a higher resolution such as 720×480 or even higher [11]. To overcome the above problems, we design in this section a new texture feature for gray images and extend it to color space since CE images are color images.

Ojala et al. [12] advanced the local binary pattern (LBP) texture operator, in which image pixels are first labeled by thresholding the difference between central pixel and its neighbors using the step function. Then values of pixels in the thresholded neighborhood are multiplied by binomial weights assigned to the corresponding pixels. Finally, values of products are summed up to obtain an LBP number of this neighborhood. The LBP of a 3×3 neighborhood produces up to $2^8 = 256$ local texture patterns, and a 256-bin occurrence LBP histogram computed over a region is then used for texture description. They further introduced a simple yet efficient approach based on LBP in a subsequent paper [13], where they found that some LBPs are fundamental and are called 'uniform' pattern. The uniform patterns have circular structures that contain few transitions from 0 to 1. In order to formally define 'uniform' patterns, a uniformity measure U is introduced, which corresponds to the number of spatial transitions (bitwise 0/1 changes) in a pattern. For example, both pattern 00000000 and pattern 11111111 have U values of 0, and patterns that have U values of at most 2 are designated as 'uniform'. Based on the above discussions, a novel operator is introduced:

$$\mathrm{LBP}_{P,R}^{u2} = \begin{cases} \displaystyle\sum_{p=0}^{P-1} s(g_p - g_c) & \text{if } U(\mathrm{LBP}_{P,R}) \le 2 \\ P+1 & \text{otherwise} \end{cases} \tag{1}$$

where $U(\mathrm{LBP}_{P,R}) = \left|s(g_{P-1} - g_c) - s(g_0 - g_c)\right| + \sum_{p=1}^{P-1} \left|s(g_p - g_c) - s(g_{p-1} - g_c)\right|$ and $s(x)$ is the *sign* function, P and R is the number of neighbor set and radius of a circle. More details about this algorithm can be found in [13]. This operator is a useful measure of