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Detection of small bowel tumor based on multi-scale curvelet analysis and fractal technology in capsule endoscopy

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ABSTRACT

Wireless capsule endoscopy (WCE) has been a revolutionary technique to noninvasively inspect gastrointestinal (GI) tract diseases, especially small bowel tumor. However, it is a tedious task for physicians to examine captured images. To develop a computer-aid diagnosis tool for relieving the huge burden of physicians, the intestinal video data from 89 clinical patients with the indications of potential tumors was analyzed. Out of the 89 patients, 15(16.8%) were diagnosed with small bowel tumor. A novel set of textural features that integrate multi-scale curvelet and fractal technology were proposed to distinguish normal images from tumor images. The second order textural descriptors as well as higher order moments between different color channels were computed from images synthesized by the inverse curvelet transform of the selected scales. Then, a classification approach based on support vector machine (SVM) and genetic algorithm (GA) was further employed to select the optimal feature set and classify the real small bowel images. Extensive comparison experiments validate that the proposed automatic diagnosis scheme achieves a promising tumor classification performance of 97.8% sensitivity and 96.7% specificity in the selected images from our clinical data.

1. Introduction

Small bowel tumors are an uncommon and heterogeneous group of diseases, accounting for 3–6% of all GI tract tumors and 1–3% of cancers [1–4]. Histologists have identified almost 40 different types of small bowel tumors. However, due to nonspecific or absent symptoms and inaccessibility of the small bowel, the diagnosis of small bowel tumors is often delayed, which results in poor survival prognosis for patients with malignant lesions [5]. In fact, conventional diagnostic modalities present some crucial limitations in the diagnosis of GI diseases, such as incomplete exploring depth, invasive exam procedure and poor performance in diagnostic yield [6–13]. The above problems promote the development of effective non-invasive monitoring systems like several types of wireless image capsule endoscopy (WI-CE) from different manufacturers and the wireless video capsule endoscopy system (WV-CES) that we designed in a previous work [14]. It has been discovered that WI-CEs are superior in finding Crohn's disease, obscure bleeding and suspected polyps of small bowel [15,16]. However, the image resolution and frame rate of WI-CEs are relatively poor. WV-CES can continuously collect videos of human GI tract under normal physiological conditions, analyze video data and evaluate GI state. Patients do not need to be narcotized before the examination and can walk freely during the test. WV-CES provides much more frames per second and high image resolution. In this manuscript, the GI video data is obtained by means of using WV-CES.

Based on the information of GI images, researchers have made a variety of efforts to automatically recognize small bowel tumors and help physicians to make decisions. Baopu Li et al. [17] proposed novel textural features which combined wavelet with local binary pattern for the detection of tumors in WCE images. Then, they proved their advanced performance by comparing them with several other traditional texture features [18], including curvelet based local binary pattern (CLBP) [19], color wavelet covariance (CWC) [20] and texture spectrum histogram (TSH) [21]. SVM-based feature selection methods can be used to further improve detection accuracy [22]. However, the wavelet owns low directional sensitivity and the texture patterns usually appear to be complex in a medical image. In [23], Daniel J C B et al. put forward different feature sets based on discrete curvelet transform (DCT) and statistical texture descriptors to recognize the WCE images of tumors. With the covariances of texture descriptors in different angles, this scheme showed promising classification results with SVM in real WCE image data. However, the method they proposed had poor robustness to illumination variation of different WCE

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images and the covariances were only calculated from a given curvelet scale. Daniel C B and Dalila B R [24] introduced a multi-scale analysis method based on the second and third order moments of statistical features taken from two reconstructed images. The images were obtained by the inverse wavelet transform of selected wavelet bands. The dimensionality of the feature set was reduced by using principal component analysis (PCA). However, the feature reduction method using PCA was not improved in classification performance.

In the current work, a computerized detection system for small bowel tumors is developed to exploit multi-scale textural features and a feature selection method based on SVM. To achieve this goal, a clinical study was conducted, covering 105 patients with different indications of potential tumors. The high prevalence rate found in the study proves the advancement of WV-CES we designed. Novel features for the selected small bowel images, which characterize multi-direction texture patterns and are robust to illumination variation of the images, are extracted by combining discrete curvelet transform with fractal technology. To find the optimal features which yield the greatest classification performance, a feature selection approach and genetic algorithm based on SVM (GA–SVM) are used to refine the proposed feature set. Comparison experiments with different feature sets and other methods of selected WV-CES images validate that the proposed method achieves an encouraging recognition rate for small bowel tumors.

2. Material

2.1. System description

The small bowel video data was obtained by the WV-CES that we developed. The WV-CES consists of three parts including a wireless capsule, a portable recorder and a workstation as shown in Fig. 1. The capsule incorporates a miniaturized camera, four light sources, a radio transmitter, a battery and a low-power application-specific integrated circuit (ASIC). The little device is propelled by peristalsis, capturing the image videos of entire GI tract with a resolution of 400×400 and at a frame rate of 24 f/s. Meanwhile, the video data of images is wirelessly transmitted outside the patients' bodies. The portable recorder can receive the data transmitted from the capsule in real time and store them on the multimedia card (MMC). Then, the video data can be downloaded to a computer and processed at the workstation after the examination. The process includes playing back the video, image pre-processing, extracting characteristic textural features, recognizing abnormal images and providing a preliminary diagnosis.

To extend the work time of the capsule and increase the frame rate, a low-power controlling and processing ASIC is designed and made up of a three-stage clock management, a power management unit and a power efficient image compression module [25]. In addition, a novel RF transmitter with an on-off keying (OOK) modulation rate of 20 Mb/s is applied in the capsule. Benefiting from these key designs, the capsule can work for more than 14 h with specially-designed batteries.

In order to reduce the volume of the capsule, all components with the small package are integrated onto three PCBs of 0.5 mm thickness and 10 mm diameter [14]. The performance parameters of the developed capsule system compared with some commercially available WI-CEs are shown in Table 1.

2.2. Patients

From August 2013 to March 2015, a total of 105 patients (46 females; mean age 47.8 years old; range from 31 to 67 years old) were chosen as candidates of the WCE procedure at the Gastroenterology Unit of Pudong New Area People's Hospital. Information consent of all patients was obtained and the study was in accordance with the ethical guidelines related to human experiments.

The main indications for the WCE procedure include obscure GI bleeding, chronic diarrhea associated with flushing syndrome, abdominal pain and weight loss. The mean duration of symptoms before diagnosis is 8 months. Prior to the WCE procedure, 105 patients had undergone 442 previous diagnostic procedures (average 4.2 per patient) which included 164 colonoscopies, 151 upper endoscopies, 41 CT scans, 34 enteroscopies, 26 enteroclysis, 18 CT enterographies, 6 MRI enterographies as well as 2 angiographies.

The aim of this study is to obtain complete videos of the small bowel in order to develop a computer-aid diagnostic system and automatically recognize tumor images. Thus, the following three categories of patients were excluded.

1) Patients ($n=8$) with acute gastroenteritis, severe ischemic diseases and radioactive colonitis (active bacterial dysentery and ulcerative colitis) were excluded from this study.
2) Rondontti et al. found that small bowel obstruction or strictures had a high risk of capsule retention [26]. In addition, patients with other implanted electromedical devices could influence the examination procedure of WCE. Therefore, patients with

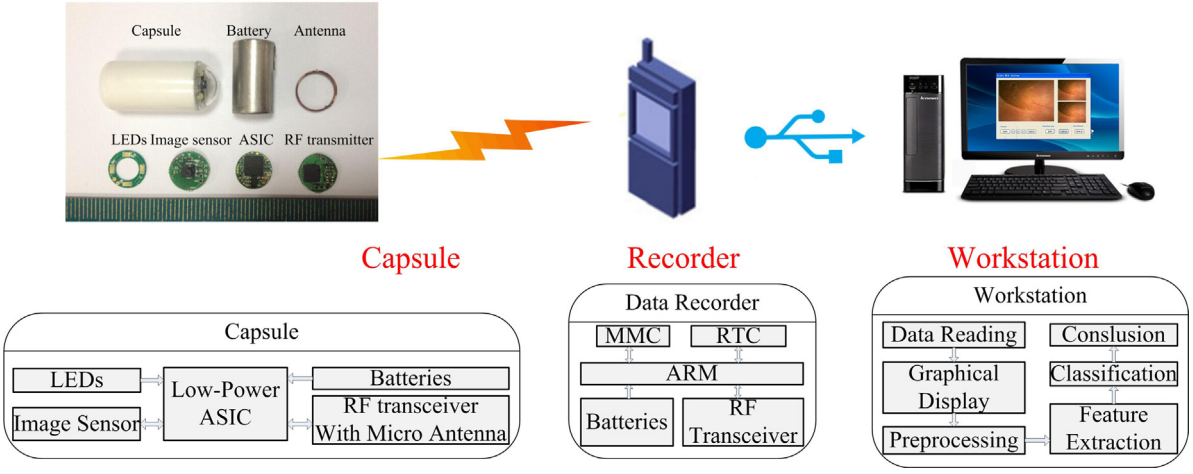

Fig. 1. Wireless video capsule endoscopy system.