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Original Research Article

Formulation and statistical evaluation of an automated algorithm for locating small bowel tumours in wireless capsule endoscopy

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ABSTRACT

Wireless capsule endoscopy (WCE) is an imaging modality which is highly reliable in the diagnosis of small bowel tumors. But locating the frames carrying tumors manually from the lengthy WCE is cumbersome and time consuming. A simple algorithm for the automated detection of tumorous frames from WCE is proposed in this work. In the proposed algorithm, local binary pattern (LBP) of the contrast enhanced green channel is used as the textural descriptor of the WCE frames. The features employed to differentiate tumorous and non-tumorous frames are skewness (S) and kurtosis (K) of the LBP histogram. The threshold value of the features which offers the trade-off between sensitivity and specificity is identified through Receiver Operating Characteristic (ROC) curve analysis. At the optimum threshold, both the features exhibited a sensitivity of 100% and specificity of 90%. The skewness and kurtosis of the LBP computed from the enhanced green channel of tumorous and non-tumorous frames differ significantly ($p \ll 0.05$) with a p-value of 2.2×10^{-16}. The proposed method is helpful to reduce the time spent by the doctors for reviewing WCE.

1. Introduction

Small bowel tumor (SBT) is one of the common clinical complications in gastroenterology. SBTs are usually diagnosed late as they present non-specific symptoms. The lack of an imaging modality which can directly visualize the internal walls of small bowel is another reason for this late diagnosis. By the time, benign lesions may turn to be malignant [1]. Only indirect methods like Barium follow-through, CT enterography and CT/MR enteroclysis were previously available for examining small bowel lesions. Barium studies have serious limitations such as, they exhibit limited diagnostic significance in ileus and extra-luminal diseases, not adequate when perforations or abrupt small-bowel obstruction are suspected and not appreciable for frequent examination of the small bowel in young, especially when the radiation dose is not 'low dose' or 'no dose' [2,3]. Whereas, discomfort associated with naso-enteric tube placement is the major demerit of CT enteroclysis

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[4]. Sub-optimal bowel distention and overlapping bowel loops make CT enteroclysis challenging [5]. Moreover, CT enteroclysis produces false-positive results in patients with neuro-endocrine tumors (NET) of small bowel [6]. Another indirect modality, MR enterography (MRE) offers quality images only if the subject remains stationary, even against respiratory movements, do not have metallic implants and is able to fully receive the intravenous gadolinium contrast [7].

The conventional upper gastro intestinal (GI) endoscopy reaches only till the duodenum, while lower GI endoscopy has access till terminal ileum. Wireless capsule endoscopy (WCE) is an imaging modality meant for the examination of the midway regions of the GI tract, particularly the small bowel, which are beyond the access of the conventional endoscopy and colonoscopy. Unlike MRE, WCE do not require any intravenous contrast andit allows visualization and characterization of subtle mucosal lesions, missed by MRE [8]. Multiple studies [9,10] have unanimously agreed that WCE is superior in the detection of mucosal disorders like angiodysplasias, ulcersand polyps. In WCE, the subject is allowed to swallow an ingestible 'Pillcam' which continuously transmits images of the internal surface of the GI tract to the external receiver which is known as Pillcam recorder, during its passage through the tract.

The Pillcam takes 7–8 h to transit through the GI tract yielding almost 55,000–80,000 video frames. The clinicians have to spend approximately 80–120 min to review this lengthy WCE video [11] and Adler & Gostout [12] also have reported that the review of WCE takes 2 h, typically. When WCE is employed for investigating the presence of tumors in small bowel, it is incommodious and strenuous for the clinician to identify the frames carrying tumors from the lengthy WCE, as only few WCE frames may have tumors on it. There is a probability that the clinician may even miss the tumors during the review. In this scenario, automated software can assist the clinician and resolve this issue to a great extent. But, development of software which enables automated identification of tumorous frames from the lengthy WCE is not trivial as SBTs completely differ in their appearance, do not share any common pattern or do not exhibit close similarity in terms of intensity, textural and geometric features.

Few automated methods [13–18] are available in literature for screening the tumorous and non-tumorous frames from WCE. Liu et al. [13] introduced a method to detect tumorous WCE frames in which second order textural descriptors and higher order moments between the inverse curvelet transform (ICT) of few selected scales of the curvelet transform of the colour channels were employed as feature input to SVM and genetic algorithm (GA) classifiers. For the same objective, Li and Meng [14] adopted another strategy in which the uniform local binary pattern (LBP) of the wavelet sub-bands, obtained from two-level decomposition of the colour channels of the WCE frame was computed first. The LBP histograms of the sub-bands of each colour channel were concatenated to form LBP histogram of that colour channel. Eventually, LBP histograms of all the colour channels themselves were super imposed to form a feature vector. The dimensionality of the feature vector was further minimized by employing two techniques, based on support vector machine (SVM), which are recursive feature elimination and sequential forward floating selection.

Energy, entropy, mean, standard deviation, skewness and kurtosis of the histogram of uniform LBP of the middle level wavelet sub-bands, obtained via three level decomposition of the colour channels were used as the feature vector by Li et al. [15]. An ensemble classifier which is a combination of SVM, multilayer perceptron neural network (MLP) and k-nearest neighbour (kNN), built from six ensemble rules, majority voting, maximumproduct rule, median rule, minimum product rule and fuzzy integral, were employed in this literature. Li and Meng [16] used the histogram of the uniform LBP of the detailed wavelet sub-bands, HL, HH and LH, obtained via the three-level decomposition of the colour channels, as the feature input to the SVM classifier. In literature [17], entropy, correlation, inverse difference moment andangular second momentof the co-occurrence matrices of images formed from the inverse wavelet transform (IWT) of the selected scales of wavelet transform (WT) of red, green and blue channels, after dimensionality reduction with principal component analysis (PCA) were used as the input of artificial neural network (ANN) classifier.

Karargyris and Bourbakis [18] extracted the binary map of the boundaries of the structures present in the WCE frame by combining the outcomes of a log Gabor filter bank and Smallest Univalue Segment Assimilating Nucleus (SUSAN) edge detector. Then, the centres of curvature of the boundary pixels with local curvature above a threshold were computed. Each curvature centre was assigned to the corresponding cluster with the help of a simple two-threshold sequential clustering. A level-set model was allowed to expand an active contour on the grayscale version of the WCE frame, starting from each cluster centre, until it grows and reaches the boundary pixels of the cluster. The percentage of boundary pixels reached and the eccentricity was considered as the features which can indicate the presence of polyps in the frame. The percentage of boundary pixels reached during the contour expansion above 85% and eccentricity above 0.70 were the indications used for identifying the presence of the polyps in the WCE frame. The first condition was meant to evaluatewhether the identified region have well defined boundaries and the second one was to assess whether the region is of oval geometry. It also hadbeen admitted in this literature itself that the SUSAN edge detector and the computation of curvature centres impose intolerable computational burden and make this method impractical in real time application.

The skew and kurtosis of LBP were used by Li et al. [13] to characterize the symmetry and 'peakedness' of the LBP histogram. Unlike the procedure followed in literature [13], these statistics have to be extracted from the LBP rather than from the LBP histogram. Selecting all the three colour channels towards feature extraction and discarding few sub-bands after wavelet decomposition as done in [14–18] is not appreciable as it may cause information loss. Instead, LBP of most significant channel can be extracted directly. This will reduce the computational burden also. The selection of the sub-bands and the level of decomposition were done arbitrarily in literature [13–17]. Instead, the information content in the sub-bands and the colour channels has to be considered before selecting them for feature extraction. Simultaneous proces-

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