Computers in Biology and Medicine 72 (2016) 138–150

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Edge density based automatic detection of inflammation in colonoscopy videos

I. Ševo [a], A. Avramović [a,b,*], I. Balasingham [c,d], O.J. Elle [c,e], J. Bergsland [c], L. Aabakken [f]

[a] Faculty of Electrical Engineering, University of Banja Luka, Patre 5, 78000 Banja Luka, Bosnia and Herzegovina
[b] School of Electrical Engineering, University of Belgrade, Bulevar Kralja Aleksandra 73, 11000 Belgrade, Serbia
[c] The Intervention Centre, Oslo University Hospital, N-0027 Oslo, Norway
[d] Department of Electronics and Telecommunications, Norwegian University of Science and Technology, N-7491 Trondheim, Norway
[e] Department of Informatics, University of Oslo, Oslo, Norway
[f] Rikshospitalet University Hospital, 0027 Oslo, Norway

ARTICLE INFO

Article history:
Received 11 December 2015
Received in revised form
21 March 2016
Accepted 22 March 2016

Keywords:
Colonoscopy
Inflammation
Texture
Automatic detection

ABSTRACT

Colon cancer is one of the deadliest diseases where early detection can prolong life and can increase the survival rates. The early stage disease is typically associated with polyps and mucosa inflammation. The often used diagnostic tools rely on high quality videos obtained from colonoscopy or capsule endoscope. The state-of-the-art image processing techniques of video analysis for automatic detection of anomalies use statistical and neural network methods. In this paper, we investigated a simple alternative model-based approach using texture analysis. The method can easily be implemented in parallel processing mode for real-time applications. A characteristic texture of inflamed tissue is used to distinguish between inflammatory and healthy tissues, where an appropriate filter kernel was proposed and implemented to efficiently detect this specific texture. The basic method is further improved to eliminate the effect of blood vessels present in the lower part of the descending colon. Both approaches of the proposed method were described in detail and tested in two different computer experiments. Our results show that the inflammatory region can be detected in real-time with an accuracy of over 84%. Furthermore, the experimental study showed that it is possible to detect certain segments of video frames containing inflammations with the detection accuracy above 90%.

1. Introduction

Colon cancer is recognized as one of the most common malignant diseases, thus regular examination of colon gains importance, especially for high risk populations [1]. Prevention of colon cancer is related to the detection of polyps, since untreated polyps can develop into cancer [2]. Inflammatory bowel diseases (most commonly Crohns disease and ulcerative colitis) are chronic diseases that include inflammation in the gastrointestinal tract. Early stage detection of inflammatory diseases is very important as it allows the patient to be provided with dietary advice and precaution. Polyps and inflammation can be detected during various medical procedures which include analysis of high-length videos, implying the necessity of computer-aided diagnostics of the gastrointestinal tract and its discussion within the scientific community.

The most effective colon screening method is colonoscopy, which is a bowel examination procedure that uses a camera and a flexible tube. Colonoscopy provides high resolution video, suitable for easy visual detection of pathological inflammation and colon diseases. Although colonoscopy can provide high quality videos and efficient ways to visually detect anomalies and ability to collect tissue samples in vivo, it is invasive and often uncomfortable [3] and gives view to colon only. One alternative medical approach for examination of the digestive tract is the so-called virtual colonoscopy, which includes the analysis of computer tomography (CT) scans. This method irradiates the patient. In the last decade, capsule endoscopy (CE) treatment has gained popularity. It is a minimally invasive screening approach which allows viewing the complete digestive tract without sedation, radiation or air-inflation. Capsule endoscopy uses a smart pill equipped with a camera and a radio transmitter that sends images to a recorder attached to the patient's waist. Smart pill can record over an eight hour long period, providing thousands of images. An overview and manual annotation of the complete dataset from one examination is time

* Corresponding author at: Faculty of Electrical Engineering, University of Banja Luka, Patre 5, 78000 Banja Luka, Bosnia and Herzegovina.
E-mail addresses: igor.sevo@etfbl.net (I. Ševo), aleksej@etfbl.net (A. Avramović), ilangko.balasingham@iet.ntnu.no (I. Balasingham), oelle@ous-hf.no (O.J. Elle), jacob.bergsland@ous-hf.no (J. Bergsland), lars.aabakken@medisin.uio.no (L. Aabakken).

http://dx.doi.org/10.1016/j.compbiomed.2016.03.017
0010-4825/

consuming. It would be helpful to automatically select images showing anomalies, such as internal bleeding, polyps and inflammation. If a physician is focused on images with higher priority, diagnosis requires less time. The main advantage of CE is the possibility of image acquisition throughout the whole digestive tract.

Even though physicians are able to observe live video during the colonoscopy examination, during which visual overview is usually sufficient to detect anomalies, additional real-time processing may be helpful for pinpointing the exact location of anomalies and faster visual detection. Another motivation for real-time processing of colonoscopy videos can be supported by the study showing that accuracy of real-time optical small polyp (less than 1 cm) detection made by gastroenterologists, is approximately 76% [4]. Therefore, real-time processing of high definition video can be useful to provide the gastroenterologist with a decision making tool to improve the human performance. Nevertheless, it is hard to implement real-time processing, especially if complex algorithms need to be included. On the other hand, parallel implementation can provide fast processing and less time consumption.

Two main starting goals of this research were enabling fast video processing and achieving a high detection rate of inflammatory tissue. The algorithm proposed in this paper relies on neither computationally expensive feature extraction nor statistical learning. We took advantage of new technological developments in video acquisition, which can provide high quality video data. We used videos obtained by the Olympus probe [5] which delivers images with increased brightness and contrast, enabling close mucosal observation. The probe has an optical system with depth of field from 2 to 100 mm. Observing from closer distance can reveal fine texture of mucous when it is either healthy or inflamed. The first contribution of this research is a proposal of a simple and fast texture analysis based on edge density estimation, which is used for automatic inflammation detection. The second contribution is the fact that parallel implementation of the proposed algorithm based on General Purpose computing on Graphics Processing Units (GPGPU) using OpenCL and C♯proved that colonoscopy videos can be automatically annotated in real time.

The rest of the paper is organized as follows. Section 2 gives a brief overview of the related literature, Section 3 describes the data used, while Section 4 describes the proposed algorithm in details. Section 5 describes the experimental setup and discusses the experimental results. Section 6 is a conclusion.

2. Related work

As it was briefly described in the previous section, recent technology improvements enabled acquisition of high resolution colonoscopy videos as well as large amounts of capsule endoscopy images. For automatic polyp detection in colonoscopy videos two major approaches are block-based classification and model-based detection. In [6] analysis of frames extracted from colonoscopy video footage is used for automatic polyp detection based on simple spatial-color features, Support Vector Machines (SVM) and previously manually labeled polyp regions. The authors divided every available frame into blocks of size 40×40 pixels. One specific block is considered to contain polyp only if a certain number of block's pixels overlap with manually labeled polyp mask. Ameling et al. used local texture features in [7] to automatically detect polyps in high resolution colonoscopy videos in a block-based approach similar to [6]. Häfner et al. in [8] used multi-scale local color patterns to automatically classify endoscopy images according to a pit pattern classification scheme. The authors used the local color vector pattern and k-Nearest Neighbors (kNN) classifier to classify 716 colonoscopy color images into pit pattern types. Although they emphasized on the speed and computational simplicity of multispectral image processing, they were able to achieve the classification accuracy over 85%. Bernal et al. in [9] proposed a model based polyp detection approach. In their research, a robust model of polyp appearance was developed to extract adaptive descriptors used for automatic detection of polyp regions in 380 colonoscopy images.

Li and Meng used local textural features for automatic detection of various bowel diseases in [10–13]. They reported the classification accuracy over 93% when features based upon wavelet transformation and local binary pattern were used in order to detect small bowel tumor [10,13] and the classification accuracy over 92% when feature based upon curvelet transformation and local binary pattern were used in order to detect ulcer [11]. They also suggested the usage of chromaticity moments for bleeding and ucelar detection [12]. Furthermore, various color and texture features were used for bleeding detection [14], informative frame detection [15] and analysis optimization [16]. In [17] a method based upon analysis of morphological and texture information of the colon wall, was used to detect polyps, while Tu et al. in [18] used a probabilistic model for object detection in order to detect polyps in CT scans. An improved model for polyp segmentation presented in [19] increased the accuracy of CT-based polyp detection. Authors reported the detection rate over 98% for polyps larger than 3 mm. The overview of diagnostic methods, their properties and achieved accuracies is given in Table 1.

Based on the literature review, we can notice that there are proposed and discussed algorithms for detection of various anomalies in the digestive tract. However, automatic inflammation detection remains undiscussed in the existing literature. To the best of our knowledge this is the first research on automatic inflammation detection within colonoscopy videos. Anomalies in images of the digestive tract are usually detected with a block-based approach, relying on the advantages of SVM or kNN classifier. Training of classifier is done offline, using a previously manually labeled dataset of CT scans, CE images or frames extracted from colonoscopy videos. In other words, no real-time processing was discussed in details. We concluded that a model-based approach is more suitable for real-time video annotation, compared to an approach based on statistical learning. Robust models could be developed for every targeted anomaly. Motivated by the research presented in [9] and the fact that various probes provide images with different details, magnification and colormap,

Table 1
Overview of the diagnostic methods with their most important properties and reported detection accuracies.

Diagnostic method	Properties	Accuracy
Colonoscopy	Invasive method, visual detection in real-time, provide high-resolution video, enable tissue sample collection, uncomfortable for the patient, real-time and off-line automatic data analysis	≈ 94% for pit pattern classification
Capsule endoscopy	Minimally invasive method, off-line visual and automatic detection, captures info from the whole digestive tract	≈ 93% for small bowel tumor classification and ≈ 92% for ulcer classification
Virtual colonoscopy	Indirect method which includes radiation with CT scan, inefficient for small size polyps	≈ 98% for polyps larger than 3 mm