COMPUTER METHODS AND PROGRAMS IN BIOMEDICINE 107 (2012) 61–74

journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Capsule endoscopy image analysis using texture information from various colour models

Vasileios S. Charisis[a], *Leontios J. Hadjileontiadis*[a,*], *Christos N. Liatsos*[b,c], *Christos C. Mavrogiannis*[c], *George D. Sergiadis*[a]

[a] *Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, GR 541 24 Thessaloniki, Greece*
[b] *Department of International Medicine and Gastroenterology Unit, 401 Army General Hospital of Athens, GR 115 25 Athens, Greece*
[c] *Academic Department of Gastroenterology, Athens University, GR 115 27 Athens, Greece*

ARTICLE INFO

Article history:
Received 20 February 2011
Received in revised form
25 August 2011
Accepted 12 October 2011

Keywords:
Wireless capsule endoscopy
Ulcer
Colour–texture
Lacunarity
RGB HSV CIE *Lab*

ABSTRACT

Wireless capsule endoscopy (WCE) is a novel imaging technique that is gradually gaining ground as it enables the non-invasive and efficacious visualization of the digestive track, and especially the entire small bowel including its middle part. However, the task of reviewing the vast amount of images produced by a WCE examination is a burden for the physicians. To tackle this major drawback, an innovative scheme for discriminating endoscopic images related to one of the most common intestinal diseases, ulceration, is presented here. This new approach focuses on colour–texture features in order to investigate how the structure information of healthy and abnormal tissue is distributed on RGB, HSV and CIE *Lab* colour spaces. The WCE images are pre-processed using bidimensional ensemble empirical mode decomposition so as to facilitate differential lacunarity analysis to extract the texture patterns of normal and ulcerous regions. Experimental results demonstrated promising classification performance (mean accuracy > 95%), exhibiting a high potential towards automatic WCE image analysis.

1. Introduction

The anatomy of the human body renders the diagnosis of gastrointestinal (GI) diseases very hard for both the clinician and the patient. Traditional endoscopy techniques, by their nature, are highly invasive causing discomfort to the patients. This is also the reason why preventive examinations are not carried out, leading to delayed diagnosis of serious and lethal diseases. The visualization of the upper and lower part of the GI track (esophagus, stomach, duodenum, terminal ileum and colon) has been achieved by the use of conventional endoscopic techniques. However, the visual inspection of the entire small bowel has posed a challenge to the gastroenterologists due to its physical inaccessibility. The 7 m length and the numerous windings make it extremely painful, burdensome and not always possible to examine in total, as there is a dead space in the middle, the alleged last frontier of enteroscopy. Some techniques used for the inspection of the small bowel are enteroclisis, double balloon and push enteroscopy, although they are deeply inconvenient to undergo and dangerous for patients with cardiovascular issues.

In 2000 the researchers of Given Imaging drew the attention of GI community unveiling what is now called endoscopic capsule. Wireless capsule endoscopy (WCE) [1] is a revolutionary

* *Corresponding author at*: Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Faculty of Engineering, University Campus, GR 541 24 Thessaloniki, Greece. Tel.: +30 2310 99 63 40; fax: +30 2310 99 63 12.
E-mail addresses: vcharisis@ee.auth.gr (V.S. Charisis), leontios@auth.gr (L.J. Hadjileontiadis), cliatsos@yahoo.com (C.N. Liatsos), crismav@otenet.gr (C.C. Mavrogiannis), sergiadi@auth.gr (G.D. Sergiadis).
0169-2607/$ – see front matter © 2011 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.cmpb.2011.10.004

form of endoscopy that has enabled, for the first time, a non-invasive, painless and effective diagnosis inside the digestive track. A WCE system consists of the capsule endoscope, a data recorder system and computer software for WCE data processing. The capsule endoscope is a disposable, pill-shaped device which consists of a CMOS camera, four light sources, two batteries and a radio transmitter. The patient shallows the capsule which captures images of the GI track at a speed of two frames per second (fps). These images are compressed with JPEG algorithm and transmitted wirelessly to a special recorder attached to the patient's waist. The entire process lasts approximately 8 h until the batteries exhaust. Finally, the images stored in the recorder, are downloaded to a computer and the physicians, with the aid of the special software, can review the images and analyze potential sources of various GI diseases. The capsule travels along the digestive track with the physical peristalsis, without the need for air insufflation and sedation. Thus, the examination of the entire small intestine has become the most comfortable endoscopic examination for the patient to undergo. In this way WCE is suitable even for children and elderly.

WCE is especially indicated for the exploration of the small bowel which constitutes 75% of the digestive track. WCE has proven invaluable in evaluating various diseases of the small intestine, such as obscure bleeding, polyps, Crohn's disease, celiac disease and mucosal ulcers [2]. Ulcer is one of the most common lesions of the digestive track that affects small intestine (especially duodenum) and stomach. Ulcer is defined as chronic inflammatory erosion on the internal mucous membranes and is caused by *Helicobacter pylori* bacteria and non-steroidal anti-inflammatory drugs (NSAID). Although ulcer by itself is not lethal, it is connected with some serious diseases, such as Crohn's disease and ulcerative colitis, whose complications may cause death. Consequently, early diagnosis and treatment is essential. On the contrary, WCE exhibits poor diagnostic efficacy for the examination of colon. The main reason is the limited power supply that causes the image capturing to cease before the capsule crosses the entire GI track. It is even possible that transmission stops before the end of ileum, in case of extended residence in stomach.

No matter how advantageous and revolutionary WCE is over the traditional techniques, there are challenging issues to deal with. One of the most crucial drawbacks that prevent WCE from wide use is the time-consuming, and consequently expensive, task of inspecting the images produced. The endoscopic capsule captures approximately 57,000 images (2 fps $\times$ 8 h approximately) during its trip inside the human body and it takes more than 2 h for the clinician to review and analyze the data [3]. This procedure is a burden since the clinician has to stay focused and undistracted for such a long period. Moreover, it is usual that abnormal findings are visible in only one or two frames and considering a reviewing rate of 5–10 fps, they are easily missed. Last but not least, the size, colour and texture of the abnormal regions may mislead the clinician to wrong diagnosis. Thus, automatic inspection and analysis of the WCE data is of immediate need in order to reduce the labour of the clinician, the cost of the examination, and eliminate the omission of lesions due to the clinician's non-concentration.

Many efforts and computational approaches towards WCE image analysis have been reported in the literature concerning malignant tissue and bleeding detection. To cope with bleeding detection a common idea is to occupy colour information since colour is a strong feature of medical images depicting bleeding regions. More specifically, blood detection was performed with the exploitation of chromaticity moments [4], colour spectrum transformation [5] and colour-adaptation carried out by cone-response transform [6]. On the other hand, to achieve abnormal pattern detection, texture information is utilized either in chromatic or achromatic domain. In particular, co-occurrence matrices [7], discrete wavelet transform with the aid of second-order statistics [8,9] and local binary patterns [10] in conjunction with *G*-statistic [11] contributed to polyp and tumor identification. Detection of abnormal patterns is also realized by employing texture unit number and texture spectrum [12–15], local colour features [16], *L*–*G* graphs and image registration [17] along with segmentation techniques [18]. Regarding ulcer recognition, the related research is quite limited, no matter how common and important this disease is. The techniques proposed include texture spectrum [14], texture-feature extraction from the histogram of a curvelet-based uniform local binary pattern [11,19], chromaticity moments calculated with the aid of Chebyshev polynomials [20], MPEG-7 descriptors [21] and RGB pixel values evaluation [22].

In the current work, an alternative approach is presented. Colour information is a primary property of the WCE intestinal images that a clinician examines and analyzes in order to draw a conclusion. As illustrated in Fig. 1, the ulcer regions show variations in colour compared to the healthy tissue. However, this information alone is insufficient and misleading for a successful ulcer detection scheme since colour is highly

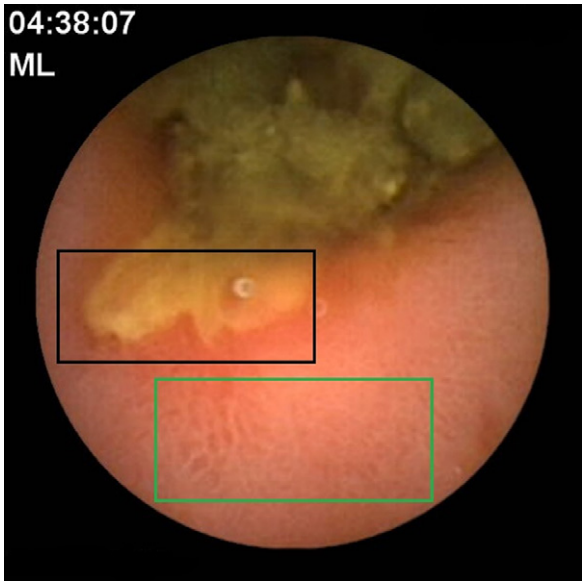

Fig. 1 – Image captured from a WCE system (PillCam SB, Given Imaging). The black box designates the ulcer region of interest while the green box encloses part of the normal tissue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)