

Potential of hybrid adaptive filtering in inflammatory lesion detection from capsule endoscopy images

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Dear Science Editor Yuan Qi,

This submission is the revised version of the previously submitted manuscript no. 28764. We greatly appreciate the comments of you and the ones from reviewers contributing to the enchainment of our manuscript. We have addressed the raised comments towards their resolution, as described in the detailed response that follows.

Thank you again for your guidance.

Yours sincerely,

Prof. Leontios Hadjileontiadis

Response to the reviewers' comments.

Reviewer #1

Dear authors, in this paper entitled “The potential of hybrid adaptive filtering in inflammatory lesion detection from capsule endoscopy images”. The authors developed a new algorithm to detect mucosal inflammation in Crohn’s disease. This is an interesting work to reduce reading time of the video capsule endoscopy. Major comments.

- Comment 1

Please describe by comparing the difference between the existing software such as blood indicator, automatic mode which can reduce the total number of images by combining similar images, FICE, and blue mode.

Response

The following text has been added to the revised manuscript, at the end of section RELATED WORK:

In the direction of reducing the reading time of WCE images, apart from the research efforts reported in the literature, there are some existing software solutions that have been implemented within the WCE image reviewing software by the manufacturing companies of the wireless capsules. The first software module designed towards reading time reduction was the Suspected Blood Indicator^[25]. This software module analyses WCE images with respect to color and selects the frames that contain a large number of red pixels, detecting, in this way, blood or other lesions characterized by the red color. The notion behind this software module is the same as the ones presented above (and the one proposed in this work), i.e., automatic detection of a specific disorder. However, the performance is substandard in terms of sensitivity (40.9%) and specificity (70.7%)^[25] and, thus, cannot be reliably used in clinical practice. Another software tool aiming at

reading time reduction is Automatic Mode^[26], that groups images with similar semantics based on color, shape and texture features and projects only one representative frame. No automatic detection of disorders, however, takes place. In this context, the physician saves time (up to 47%^[26]) by reviewing less images. Nevertheless, lesions that only appear in few images and small-sized lesions that do not cause significant shifts of the image features are often missed. Consequently, this tool is suggested to be used when diffuse or large lesions are expected to be found^[26]. Last but not least, two software tools targeting data enhancement have been incorporated in WCE images reading software, namely Blue Mode^[27] and Fuji Intelligent Colour Enhancement (FICE)^[27]. Blue Mode enhances the images by applying color shifting in the short wavelength range of visible light (around the wavelength of blue color). On the other hand, FICE, based on Spectral Estimation Technology^[28], analyses an image, estimates spectra at various wavelengths and produces an enhanced image of a given wavelength of light (most often to narrowed blue and green). Both techniques do not provide direct automatic lesion detection, but reduce WCE reading time in an indirect way. By improving image quality and intestinal surface structure representation, the doctors, theoretically, can more easily identify pathologic changes and, thus, review the whole sequence faster. Although such tools seem to improve the detection accuracy of lesions^[27], the significance of WCE data reading time reduction in clinical practice has not been studied yet.

25 **Signorelli C**, Villa F, Rondonotti E, Abbiati C, Beccari G, De Franchis R. Sensitivity and specificity of the suspected blood identification system in video capsule enteroscopy. *Endoscopy* 2005; 37: 1170-1173 [PMID: 16329012 DOI: 10.1055/s-2005-870410]

26 **Kyriakos N**, Karagiannis S, Galanis P, Liatsos C, Zouboulis-Vafiadis I, Georgiou E, Mavrogiannis C. Evaluation of four time-saving methods of reading capsule endoscopy videos. *Eur J Gastroenterol Hepatol* 2012; 24: 1276-1280 [PMID: 22825645 DOI: 10.1097/MEG.0b013e32835718d2]

27 **Krystallis C**, Koulaouzidis A, Douglas S, Plevris JN. Chromoendoscopy in small bowel capsule endoscopy: Blue mode or Fuji Intelligent Colour Enhancement? *Dig Liver Dis* 2011; 43: 953-957 [PMID: 21893436 DOI: 10.1016/j.dld.2011.07.018]

28 **Haneishi H**, Hasegawa T, Hosoi A, Yokoyama Y, Tsumura N, Miyake Y. System design for accurately estimating the spectral reflectance of art paintings. *Appl Opt* 2000; 39: 6621-6632 [PMID: 18354676 DOI: 10.1364/AO.39.006621]

Reviewer #2

I read this interesting article with great effort. In this article the authors aimed to improve the detection of CD based lesions with a novel procedure. This procedure may decrease the reading time of WCE. However, I have some suggestions about the article.

- Comment 1

The article is very long and hard to understand. I recommend that, the authors may put the technical details as supplementary part after the article, and focus on the aim and results of the study.

Response

In order to reduce the complexity of the manuscript, the section MATHEMATICAL BACKGROUND has been shifted to the supplementary part.

- Comment 2

Abstract should contain some briefings such as the number of patients, images, results.

Response

The abstract of the revised manuscript has been updated so as to give more details about patients and results. More specifically, the corresponding part of the updated abstract is:

“... For the training and testing of HAF-DLac, an 800-image database was used, acquired from 13 patients who undertook WCE examinations, where the abnormal cases were grouped into mild and severe, according to the severity of the depicted lesion, for a more extensive evaluation of the performance. Experimental results, along with comparison with other related efforts, have shown that the HAF-DLac approach evidently outperforms them in the field of WCE image analysis for automated lesion detection, providing higher classification results, up to 93.8% (accuracy), 95.2% (sensitivity), 92.4% (specificity) and 92.6% (precision). The promising performance ...”

- Comment 3

Too many abbreviations, it is very confusing. Authors may make an abbreviation part after the abstract part.

Response

In order to help the reader keep track of the abbreviations and facilitate the reading of the document, a Nomenclature section with the list of abbreviations used has been added after the abstract. The Nomenclature section is the following:

Nomenclature

| Abbreviation | | Definition |
|------------------|-----|---|
| \overline{ACC} | ... | Average accuracy |
| AR | ... | Autoregressive model |
| CaEn | ... | CapsuleEndoscopy.org database |
| CD | ... | Crohn's Disease |
| CT | ... | Curvelet transform |
| CurvLac | ... | Methodology based on CT and Lac ^[6] |
| CurvLBP | ... | Methodology based on CT and LBP ^[8] |
| DLac | ... | Differential lacunarity |
| ECT | ... | Methodology based on edge, color and texture features ^[17] |
| EFF | ... | Energy-based fitness function |

| | | |
|-------------------|-----|--|
| FICE | ... | Fuji Intelligent Chromo Endoscopy |
| FF | ... | Fitness function |
| FFT | ... | Fast Fourier transform |
| FV | ... | Feature vector |
| GA | ... | Genetic algorithm |
| GBA | ... | Gliding box algorithm |
| GI | ... | Gastrointestinal |
| Grad | ... | Gradient-based features |
| GT | ... | Gastrointestinal tract |
| HAF | ... | Hybrid adaptive filtering |
| Hist | ... | Histogram-based features |
| HSV | ... | Hue-Saturation-Value |
| IP | ... | Initial population |
| Lac | ... | Lacunarity |
| LBP | ... | Local binary patterns |
| LFF | ... | Lacunarity curve gradient fitness function |
| NR | ... | No reconstruction |
| \overline{PREC} | ... | Average precision |
| R | ... | Reconstruction |
| RGB | ... | Red-Green-Blue |
| riuLBP | ... | Rotation invariant uniform local binary patterns |
| RLM | ... | Run-length-matrix |
| ROI | ... | Region of interest |
| SB | ... | Small bowel |
| \overline{SENS} | ... | Average sensitivity |
| SIFT | ... | Scale invariant feature transform |
| \overline{SPEC} | ... | Average specificity |
| SVM | ... | Support vector machines |
| WCE | ... | Wireless capsule endoscopy |
| WT | ... | Wavelet transform |

Other alterations

The title of the manuscript has been changed from “The potential of hybrid adaptive filtering in inflammatory lesion detection from capsule endoscopy images” to “Potential of hybrid adaptive filtering in inflammatory lesion detection from capsule endoscopy images” and an Acknowledgements section has been added.