METHODS OF DIAGNOSIS OF INTESTINAL POLYPS WITH SOFTWARE APPLICATIONS IN WIRELESS CAPSULE ENDOSCOPY

Mihaela Ionescu[1], Adriana Florentina Constantinescu[1], Alin Gabriel Ionescu[1], Costin Teodor Streba[1], Angela Simona Apostol [2], Otilia Constantina Rogoveanu[1], Marius Eugen Ciurea[1], Cristin Constantin Vere[1]

[1] University of Medicine and Pharmacy of Craiova
[2] "Tibiscus" University of Timisoara

Corresponding author: Alin Gabriel Ionescu, alinionescu81@yahoo.com

ABSTRACT: Wireless capsule endoscopy is a modern imaging technique used for the overall investigation of the gastrointestinal tract, indicated for the detection of occult gastrointestinal bleeding, polyps, Chron's disease, tumours or other lesions. Among those, polyps represent a category of lesions difficult to discriminate from the normal mucosa. Most of the algorithms proposed for automatic polyp detection relay on retrieving geometric details, followed by a textural analysis of the detected region, most of the times combined with the corresponding colour analysis (with a smaller weight), and a subsequent classification either on particular regions or the entire image. Usually, all image descriptors are involved in the decision making, for which several learning / decision algorithms are employed. The entire process is developed according to the human analysis process, but it takes into account the powerful computation capabilities of nowadays computers and processing algorithms.
KEYWORDS: wireless capsule endoscopy, polyps, software applications

1. INTRODUCTION

Wireless capsule endoscopy (WCE) is a modern technique often employed for the investigation of various gastrointestinal diseases [V+08, Ron08, P+10]. Its outcome is represented by a set of more than 50000 individual snapshots of the patient's digestive tract. Given this impressive number of images to be viewed, the time spent for this process may be reduced using automatic image analysis that would indicate specific sections that contain potential lesions, as well as their classification with a certain probability.

Even though upper and lower gastrointestinal endoscopy represent the gold standard examination in the diagnosis of gastrointestinal diseases, wireless capsule endoscopy is a good alternative to the patients with negative or incomplete conventional endoscopy, or with contraindications. The main advantage of WCE is represented by the fact that this examination technique does not imply sedation, being a non-invasive and painless procedure.

Due to the fact that WCE requires an average time of 2-3 hours for the analysis of the recorded videos, the use of software applications represents an optimal solution for reducing the time necessary to view the recorded images [C+15]. Besides reducing the analysis time of the obtained frames, computer-assisted WCE video examination has the advantage of providing also a second opinion, increasing in this way the performance of the exploration. Reading software is provided by each company along with the WCE system in the purpose of speeding up the interpretation process and of improving the diagnosis. Even though all the provided reading software applications by the manufacturing companies of WCE are based on different algorithms, each of them lacks unity or is incomplete. A series of researchers have tried to overcome this disadvantage, by developing various algorithms meant to perform video segmentation, non-informative frame filtering, intestinal contraction detection, but also to achieve bleeding and abnormalities identification, such as polyps or some other pathology [IK14a, LU11, CL12]. Software applications oriented on automatic polyp detection try to emulate the examining physician, thus they are initially based on the same detection process as applied by human observers.

The small bowel, despite being the longest segment of the gastrointestinal tract, is a region where benign tumors or primary neoplasms rarely develop. Benign tumors may develop in this segment as a single lesion or as multiple lesions like: adenomas, hyperplastic polyps, stromal tumors, lipomas or hemangiomas. [Pow02]. Polyps that develop in the colon are slow-growing overgrowths of the colonic mucosa. Colonic polyps present a small risk of malignancy; however, because their prevalence increases with age in the general population, they confer an important risk to colon cancer [N+13].

Software applications used for automatic detection of polyps within images obtained following WCE generally follow an algorithm with multiple steps: original image pre-processing, segmentation, edge detection associated with region(s) of interest

identification, texture analysis combined or not with colour information, followed in the end by the classification of specific areas. Classification may be done using neural networks, support vector machines or any other method based on pre-defined weights applied on the previously detected features that composed the WCE image.

2. POLYPS CHARACTERISTICS

Polyps are protrusions risen from the intestinal and colonic mucosa membranes. They may be pedunculated or sessile, depending on the presence of a stalk connecting them to the mucosa. Pedunculated polyps' shape is similar to an almost closed sphere, being therefore easier to identify, mostly when they are projected to the lumen area (defined by darker shades compared to the rest of the WCE image).
In case of sessile polyps, the differentiation from the mucosa is often very weak, and they are more difficult to detect. Their main characteristic is also their shape, defined as a partial vague oval contour visible upon the mucosa (Fig 1 a, b). The illumination produced by the 6 LEDs of the capsule creates this contour, as the light is reflected from the polyp's visible surface, determining a thin shadow area on the mucosa. Unlike bubbles that are transparent and allow the visualisation of the mucosa directly through them, the light cannot pass through a polyp, whose structure is dense, similar to that of the surrounding mucosa.

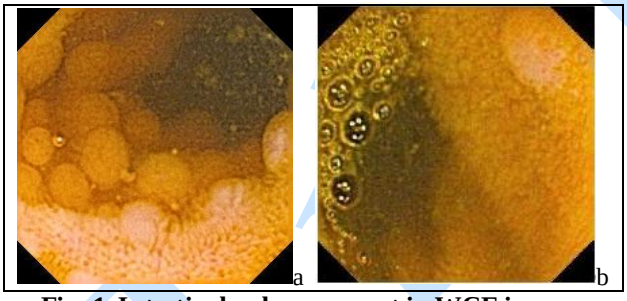

Fig. 1. Intestinal polyps present in WCE images

Depending on the degree of development and its type, the contour of a polyp may be emphasized on less than half of its circumference (transposed in 2D), as showed in Fig. 1. For a polyp to have a completely closed contour, visible in the image, the wireless capsule must be oriented in a proper position. Considering the anatomic structure of the digestive tract, such a position is not commonly met, so most of the polyps present in WCE images will be visible from a certain angle, determining thus a more or less closed contour.
Usually, polyps' texture does not differ significantly from the rest of the surrounding mucosa, making them difficult to identify within WCE images, even for experienced physicians. But, since polyps are abnormal tissue growths, from an imagistic point of view, they display similar characteristics with those of the surrounding mucosa. There are cases when polyps are accompanied by small ulcerations, thus conferring them a specific aspect, characterized by modified textures compared to normal areas. Depending on their size, their apical region may be placed closer to the capsule's dome compared to the digestive tract wall, thus polyps may sometimes reflect better the light coming from the capsule and they may display a brighter area in their central region. This particularity may be used in the detection process and also to perform differential diagnosis.

2.1 General detection algorithm

The majority of automatic detection algorithms present in the scientific literature employ an algorithm with several steps: original image pre-processing, segmentation, edge detection associated with region(s) of interest identification, texture analysis combined or not with colour information, followed in the end by the classification of specific areas (Fig. 2). The performance of each proposed algorithm is assessed in terms of either accuracy, specificity, sensitivity or area under ROC curves.

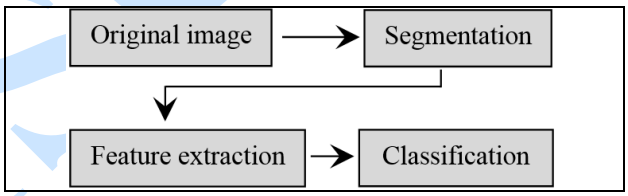

Fig. 2. General algorithm for automatic polyp's detection

The pre-processing phase usually implies either a reduction of the noise present in the WCE images due to the physical characteristics of the camera, or potentially an intensity equalisation. Given the shape of the capsule and the optical specifications of the camera, the intensity is diminishing as we move from the centre of the image to its margins – this fact is known as vignetting. Besides the traditional noise reduction methods, we mention Zheng et al. that have proposed a correction algorithm based on radial gradient symmetry, in order to perform intensity normalization [Z+08, M+14].

2.2 Shape

The analysis of imagistic characteristics belonging to intestinal and colonic polyps has revealed as particular feature a specific shape, partially rounded. This is one of the most useful discriminating features in detecting candidate polyps, together with their size and texture. Therefore, the main automatic detection methods of polyps are based on the contours detection, more or less closed, from the original WCE images. Most of the

studies from the scientific literature regarding the detection methods of the intestinal polyps consider mainly contours identification, using thus geometric shape features. Initial approaches in applying software applications for shape detection included contour oriented algorithms and edge detection filters like Sobel, Canny or SUSAN. The use of oriented Gabor phase congruency patterns, more specific the phase responses of Gabor filter banks, lead to better results than the previous methods, as proven by several authors. The computation of the associated curvature is a measure of the polyps' protrusion and it is an important phase in automated polyps' detection process.

Karargyris and Bourbakis have initially leaned upon a local curvature estimation together with Log-Gabor filters for the shape detection [KB09]. Then, they improved they method, applying the SUSAN edge detector after filtering the original images using the previously mentioned filters. The resulting segmented images were subsequently analysed based on an algorithm that considered the boundaries of identified sections for computing the associated curvature in each point. Based on these values, only a set of points were used in the following phase of the detection algorithm. For each selected point, they determined the centres of curvature, forming a cloud of centres within the segmented areas. This set of points was clustered based on a two-threshold sequential clustering algorithm, the results being later expanded on the original image converted to grey levels, using active contours. Thus, potential polyp candidates were detected, however with a lower specificity, due to crisp textures associated to normal tissue, instead of polyps [K+12, ST14].

Gabor filters were also used by S. Hwang and M. Celebi, as marker selection for a watershed segmentation, also in association with K-means clustering [H+12]. Following this segmentation phase, the potential candidates were detected upon the assumption that they are partially or fully elliptical or circular. Based on these detected contours, the authors have also computed the associated curvature centres, most of them being located within the polyp's area [ST14].

P. N. Figueiredo et al. have also used the local curvature notion in automatic polyp detection, since their shape represents the most emphasized feature. Their algorithm combines mean and geometric curvatures, but does not take into account other features like texture and / or colour. Thus, since the protrusion measure is the main guidance, too small polyps are likely to be considered normal mucosa [F+11, CB12, F+10].

Similar notions like convexity are also used and implemented in various software applications meant to detect gastrointestinal polyps based on WCE images, based on the computation of the Gaussian surface curvature in 3D images [K+13].

A series of authors have used only the phase response of Gabor filters in order to obtain the polyps contours, or speeded up robust features (SURF), while others like Silva et al. have used the circular Hough transform for contour identification [Hwa11, S+14]. Discrete wavelet transform (DWT) expressed in RGB and HSI colour spaces was used by B. Li and M. Q-H Meng as a foundation to extract imagistic features and perform polyp detection using Uniform Local Binary Patterns (ULBP) [LM12]. Geometric features – shape, contour – may also be obtained by successively applying low-pass filters in convolution with Gaussian kernels [M+14].

Contour used as unique detection feature does not seem to offer satisfactory results, thus many algorithms take into account other specific features.

2.3 Texture

Many authors have increased the performance of their algorithms by adding texture as another polyp's specific feature, next to contour and shape. Granularity, homogeneity or coarseness may be clues that indicate the presence of this type of lesions in WCE images and discriminate between polyp and non-polyp areas. Texture analysis is usually performed on specific regions of interest (ROIs), previously obtain after image segmentations using various methods.

When it comes to texture detection, Local Binary Patterns (LBP), together with its associated forms (Uniform LBP or LTP – Local Ternary Patterns), seems to be a frequently employed method [A+09, BB15]. Qian and Meng have proposed another detection technique of the polyps using novel colour texture features integrated with LLE (Locally Linear Embedding) -based LBP texture feature [QM11]. Textural analysis may also be obtained using co-occurrence matrixes, as their main advantage is a set of fixed dimensions that only depend upon the resolution of grey-scale images. These matrixes may be subsequently used as basis for other features extraction, like entropy, contrast and others [S+14].

Kodogioannis and Boulougoura also propose a texture-based method that relies upon a new combined feature obtained using chromatic and achromatic spectra of a previously segmented ROI, proving that texture is also an important feature characterizing polyps [KB07].

Texture may also be described as a fractal. The Lacunary fractal property is useful in defining how space is filled, therefore it is used in the analysis of textures that associate the same fractal dimension. Thus S. Jadhav and S. Dabhole have combined Bi-dimensional Ensemble Empirical Mode Decomposition (BEEMD) and Differential

Lacunarity (DLac) in order to refine the analysed image and to extract textural information [JD14].

2.4 Colour

Colour is a feature less determinant for gastrointestinal polyps, thus authors only use it to enhance the polyp's features and increase the performance of the algorithms mainly based on shape and texture features. There are authors that have analysed this feature individually and have used it initially for global image analysis. More recent software applications decomposed original images according to colour components expressed in various colour spaces; then, each sub-image was analysed using Gabor filters or wavelet transforms, leading to a more relevant image descriptor.
Colour wavelet features were used by Vasquez et al. in a new method developed for WCE image analysis, which yielded good results in polyps' detection. These features are based on covariance between a series of second order textural features upon wavelet features [VBW11, ST14].
Yuan and Meng proposed a new feature that, besides the shape and edge information under multi-resolution, preserves also colour information for polyp detection. This method integrates the Gabor filter and Monogenic-Local Binary Pattern (M-LBP) in colour components [YM14].
D. Iakovidis and A. Koulaouzidis have extracted the hue component in the HSV colour space and filtered it using Gabor filters. The results were combined with co-occurrence matrixes for texture analysis and geometric curvature features for shape, obtaining a robust method [IK14a].
Other authors have used multiple colour components in various colour spaces, filtered through Gabor filters, in combination with LBP descriptors specific for the Gabor responses, thus combining colour and texture features in one global descriptor [YM14].
Colour information is also useful in detecting salient points and generating colour vectors based on each point neighbourhood, which prove to be efficient in detecting small polyps [IK14a, IK14b, S+09, PD14].

2.5 Classification

Classification may be done using artificial neural networks (ANN), support vector machines (SVM) or any other method based on pre-defined weights applied on the previously detected features that composed the WCE image.
In terms of classification methods, authors have used various methods based on ANN, adaptive neuro fuzzy inference systems (ANIFS), SVM or boosting-based classifiers, either single used or in cascades [S+14, BB15, KB07, JD14, VJ01, S+13].

3. DISCUSSIONS

The general consensus is that the round shape is the most specific imagistic feature that characterizes intestinal polyps. Thus, most of the authors that have embraced the challenge of automatically detecting gastrointestinal polyps have mainly used methods that emphasize the polyps' curvature and contour. But, similar to the examining physician, any software applications designed with this goal must not employ only one feature, but a combination of their physical characteristics: shape, contour, curvature, texture and colour.
Obviously, there is no general method that would cover all specific features of polyps. Also, not all imagistic features are useful in the same measure in detecting this type of lesions. Often, an ingenious algorithm is needed, in order to extract the best clues indicating the presence of a polyp within a WCE image. What software applications must do is to simulate the real physician, but also to leverage the computational power of modern processors.
Most polyps present in WCE images are difficult to identify, as they do not have clear margins, they may be affected by the noise induced by the CCD camera, their texture and colour may be very similar to those of the normal mucosa, only slightly discriminating itself from it. Thus, using certain contour detection methods, it is possible that the polyp's margins would not be detected, or be partially detected. Depending on the light provided by the WCE's LEDs, there may not be a clear differentiation between mucosa and polyp colour. Another factor that impacts the process of correct detection of contour is represented by potential intersection with other elements superimposing on their surface.
Despite these drawbacks, there are also methods that may seem, at first glimpse, to detect the majority of polyps present in WCE images, while offering as less false positive results as possible. Combined methods for contour, texture and colour detection amplify the chances of a correct automatic detection.

CONCLUSIONS

WCE is a modern investigation for the gastrointestinal tract, used especially for the small bowel pathology. Software applications could improve the performance of WCE by shortening the reading time of the recorded images, but also by offering support in the analysis, as second opinion.
Various authors have attempted to identify methods and techniques to perform automatic detection of polyps, given their prevalence and potential risk of complications. Most of them proved efficient and useful in detecting polyps located in the digestive tract.

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REFERENCES

[A+09] **S. Ameling, S. Wirth, D. Paulus et al.** – *Texture-based Polyp Detection in Colonoscopy*, Bildverarbeitung für die Medizin, Algorithmen — Systeme — Anwendungen Proceedings des Workshops vom 22. bis 25, p. 346-350, 2009.

[BB15] **S. Bhuvana, A. J. Bhuvaneswari** – *Computer aided automatic detection of polyp for colon tumor*, International Journal of Advance Research In Science And Engineering, Vol. No.4, Special Issue (02), 2015.

[CB12] **F. Condessa, J. Bioucas-Dias** – *Segmentation and detection of colorectal polyps using local polynomial approximation*, ICIAR'12 Proceedings of the 9th international conference on Image Analysis and Recognition - Volume Part II, p. 188-197, 2012.

[CL12] **Y. Chen, J. Lee** – *A Review of Machine-Vision-Based Analysis of Wireless Capsule Endoscopy Video*, Diagnostic and Therapeutic Endoscopy, vol. 2012.

[C+15] **A. F. Constantinescu, M. Ionescu, I. Rogoveanu, M. E. Ciurea et al.** – *Analysis of Wireless Capsule Endoscopy images using Local Binary Patterns*, Applied Medical Informatics, vol. 36, no 2: 31-42, 2015.

[F+10] **I. N. Figueiredo, S. Prasath, Y. H. R. Tsai et al.** – *Automatic detection and segmentation of colonic polyps in wireless capsule images*, UCLA-CAM Report 1065, 2010.

[F+11] **P. N. Figueiredo, I. N. Figueiredo, S. Prasath et al.** – *Automatic polyp detection in pillcam colon 2 capsule images and videos: Preliminary feasibility report*, Diagnostic and Therapeutic Endoscopy, no. 182435, 2011.

[Hwa11] **S. Hwang** – *Bag-of-visual-words approach to abnormal image detection in wireless capsule endoscopy videos*, in Advances in Visual Computing. Springer, p. 320-327, 2011.

[H+12] **S. Hwang, M. Celebi, B. Andre et al.** – *Content-based retrieval in endomicroscopy: Toward an efficient smart atlas for clinical diagnosis*, Lecture Notes Comput. Sci., vol. 7075, 2012.

[IK14a] **D. Iakovidis, A. Koulaouzidis** – *Automatic lesion detection in Wireless Capsule Endoscopy – A simple solution for a complex problem*, in IEEE International Conference on Image Processing (ICIP), 2014.

[IK14b] **D. K. Iakovidis, A. Koulaouzidis** – *Automatic lesion detection in capsule endoscopy based on color saliency: closer to an essential adjunct for reviewing software*, Gastrointest Endosc. 80 (5), p. 877-883, 2014.

[JD14] **S. T. Jadhav, S. H. Dabhole** – *An Optimal Detection of Polyp and Ulcer in WCE Images using Fast BEMD with DLac Analysis*, International Journal of Innovative Technology and Exploring Engineering, vol. 4 (7), 2014.

[KB07] **V. Kodogiannis, M. Boulougoura** – *An adaptive neurofuzzy approach for the diagnosis in wireless capsule endoscopy imaging*, Int. J. of Information Technology, vol. 13, p. 46 - 56, 2007.

[KB09] **A. Karargyris, N. Bourbakis** – *Identification of polyps in wireless capsule endoscopy videos using log Gabor filters*, in IEEE Workshop LiSSA, p. 143 -147, 2009.

[K+12] **A. Karargyris, N. Bourbakis, H. C. Huang et al.** – *Affinity aggregation for spectral clustering*, in Proc. IEEE Conf. Comput. Vis. Pattern Recognit., p. 773–780, Jun. 2012.

[K+13] **A. Kukushkin, D. Mikhaylov, I. Zhukov et al.** – *Recognition of Polyps in the Images of Wireless Capsule Endoscopy*, International Journal of Emerging Trends & Technology in Computer Science, vol. 2 (2), 2013.

[LM12] **B. Li, M. Q.-H. Meng** – *Automatic polyp detection for wireless capsule endoscopy images*, Expert Systems with Applications, vol. 39 (12), p. 10952–10958, 2012.

[LU11] **M. Liedlgruber, A. Uhl** – *Computer-Aided Decision Support Systems for Endoscopy in the Gastrointestinal Tract: A Review*, IEEE Reviews in Biomedical Engineering, vol. 4, 2011.

[M+14] **A. V. Mamonov, I. N. Figueiredo, P. N. Figueiredo et al.** – *Automated polyp detection in colon capsule endoscopy*, in IEEE Transactions on Medical Imaging, vol. 33 (7), 2014.

[N+13] **R. Nishihara, K. Wu, P. Lochhead et al.** – *Long-term colorectal-cancer incidence and mortality after lower endoscopy*. N Engl J Med. 369(12) p. 1095-105, 2013.

[Pow02] **S. M. Powell** – *Direct analysis for familial adenomatous polyposis mutations*, Mol Biotechnol, 20(2), p. 197-207, 2002.

[PD14] **V. B. S. Prasath, R. Delhibabu** – *Automatic contrast enhancement for wireless capsule endoscopy videos with spectral optimal contrast-tone mapping*, International Conference on Computational Intelligence in Data Mining (ICCIDM), Proc. Springer SIST, p. 243-250, 2014.

[P+10] **C. Petruzziello, S. Onali, E. Calabrese, F. Zorzi et al.** – *Wireless capsule endoscopy and proximal small bowel lesions in Crohn's disease*, World J Gastroenterol; 16(26): 3299-3304, July 2010.

[QM11] **Z. Qian, M. Q. H. Meng** – *Polyp detection in wireless capsule endoscopy images using novel color texture features*, 9th World Congress on Intelligent Control and Automation (WCICA), p. 948-952, 2011.

[Ron08] **E. Rondonotti** – *Capsule endoscopy - The revolution of small bowel endoscopy*, Vrije Universiteit, 2008.

[ST14] **T. Sudhalavanya, S. S. Thamilselvi** – *Segmentation of Gastroenterology Images Using Normalized Cuts*, The International Journal Of Science & Technoledge, vol. 2 (12), 2014.

[S+09] **T. Stehle, R. Auer, S. Gross et al.** – *Classification of Colon Polyps in NBI Endoscopy Using Vascularization Features*, Medical Imaging: Computer-Aided Diagnosis, 2009.

[S+13] **J. Silva, A. Histace, O. Romain et al.** – *Towards real-time in situ polyp detection in WCE images using a boosting-based approach*, Conf Proc IEEE Eng Med Biol Soc., 2013.

[S+14] **J. S. Silva, A. Histace, O. Romain et al.** – *Towards embedded detection of polyps in WCE images for early diagnosis of colorectal cancer*, International Journal of Computer Assisted Radiology and Surgery, Springer Verlag (Germany), vol. 9 (2), p. 283-293, 2014.

[VJ01] **S. Viola, M. Jones** – *Rapid object detection using a boosted cascade of simple features*, in Proceedings of the 2001 IEEE CVPR Conference, p. 511-518, 2001.

[VBW11] **E. Vazquez, R. Baldrich, J. Weijer** – *Describing reflectances for color segmentation robust to shadows, highlights, and textures*, IEEE Trans. Pattern Anal. Mach. Intell., vol. 33 (5), p. 917–930, 2011.

[V+08] **C. C. Vere, F. Sima, F. Ţapu, T. Ciurea** – *Videocapsula endoscopică si enteroscopia cu balon, metode moderne de explorare a intestinului subţire*, Craiova Medicală, vol 10, nr 1, 2008.

[YM14] **Y. Yuan, M.Q.-H. Meng** – *A novel feature for polyp detection in wireless capsule endoscopy images*, IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), p. 5010 – 5015, 2014.

[Z+08] **Y. Zheng, J. Yu, S. B. Kang, S. Lin et al.** – *Single-image vignetting correction using radial gradient symmetry*, in IEEE Conference on Computer Vision and Pattern Recognition, 2008.