ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

An Overview of Image Analysis Techniques in Endoscopic Bleeding Detection

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ABSTRACT: Authors review the existing bleeding detection methods focusing their attention on the image processing techniques utilised in the algorithms. In the article, 18 methods were analysed and their functional components were identified. The authors proposed six different groups, to which algorithms' components were assigned: colour techniques, reflecting features of pixels as individual values, texture techniques, considering spatial dependencies between pixels, contour techniques for edges and contours, segmentation techniques for dividing images into meaningful regions, decision mechanisms for final interpretation of the image and other techniques that do not match any of the introduced groups. Authors conclude that the algorithms could be still improved by applying more complete sets of techniques to address the importance of visual features of endoscopic bleeding. Also, improvement is possible in the area of decisive classifiers.

Keywords:endoscopy, medicine supporting systems, bleeding detection, image analysis

I. INTRODUCTION

The importance and size of potential benefits from the use of information systems in medicine give strong motivation for the research on new possibilities of supporting medical examinations. One of the crucial fields, where automated, computer analysis is highly desired is medical imaging. In recent years particularly much attention was paid to applications of automatic image analysis for endoscopic examinations of human gastro¬intestinal tract. In modern medicine, endoscopy is still the gold standard in diagnosis of many diseases of the digestive system, including lethal cancer diseases. It enables the physician to examine the interior of the organs and diagnose early stages of diseases, providing high chances of successful treatment. Further motivation, however, appeared along with introduction of Wireless Capsule Endoscopy (WCE) in 2001. The new examination procedure involves a small capsule capable of recording patient's organs after being swallowed. The procedure is less invasive than traditional endoscopy and potentially can record any part of the GI tract. However, since the length of the recording reaches up to eight hours,

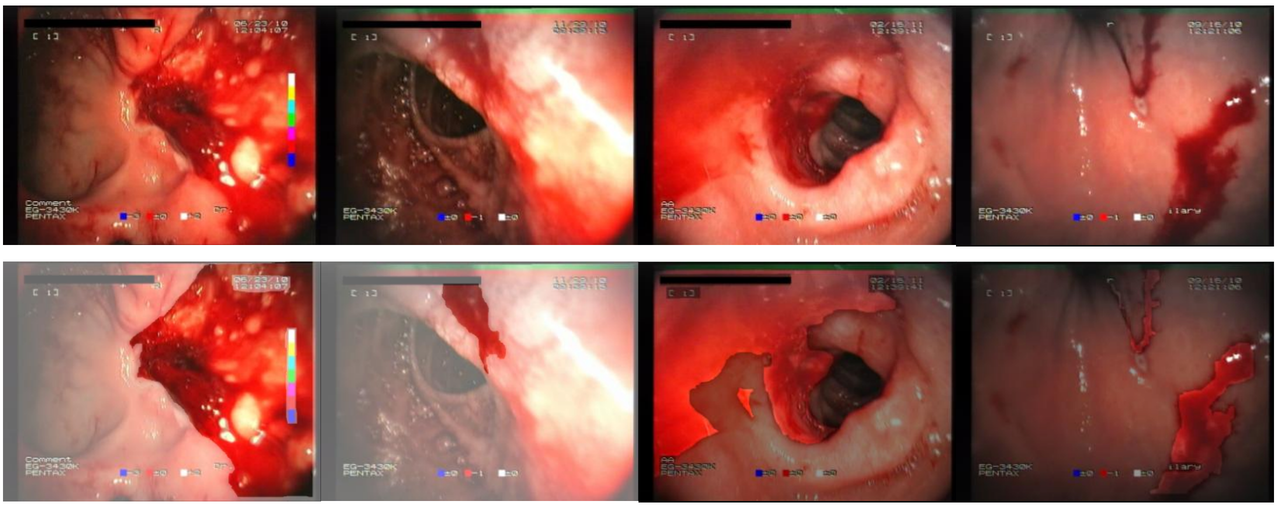

Fig. 1 Examples of gastrointestinal bleeding cases captured by an endoscope. The upper row presents original images. In the lower row bleeding areas where accented by fading the background.

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

which in addition will probably be increased in the future along with battery's lifetime, the examinations result in largeamounts of data requiring a lot of time and effort from the physician in order to make a diagnosis. The problem was addressed by the manufacturers of the capsules by providing simple tools for automated analysis, which are also capable ofindicating potential occurrences of bleeding by detecting red colour and therefore providing the physicians with certain support. Nevertheless, the tools were reported to be imperfect or insufficient [18], [34], which leaves the detection of bleeding in endoscopic videos as an open problem. From the medical point of view the issue is highly important, since the diagnostic process requires establishing cause for any bleeding discovered during the examination. In order to provide new supporting tools, bleeding detection algorithms are constantly being researched by the scientists. The task is, however, definitely challenging. Bleeding occurrences are not always clear, many of the cases cannot be recognized by an observer without medical training. Also multiple forms of noise tend to occur in endoscopic images, from natural findings like digestive juices, food debris, other fluids or bubbles, to technical difficulties resulting in blurry images or light-related distortions. Some examples of bleeding captured by an endoscope with relatively little noise were presented in figure 1, showing how bleeding can blend in with the surrounding tissues.
Despite significant difficulties, multiple methods of detecting endoscopic bleeding, mostly for WCE capsule, were developed. The authors of the algorithms often utilise various well-known image processing techniques. Application of the particular techniques enables measuring specific features of the phenomenon of bleeding. The techniques used by the authors can be considered as a set of valuable tools for efficient bleeding detection, which might be utilised in development of new detection methods. Therefore, in this paper, we review and compare selected bleeding detection methods, focusing the analysis on identifying the utilised image processing techniques and as well estimating which blood features are being considered by given methods.
The paper is organised as follows. Firstly, we introduce six categories to which the image processing techniques will be assigned. Then, the bleeding detection algorithms will be presented focusing on the considered types of techniques. The identified techniques will be also shortly described. Finally, discussion of the results of the analysis is presented and the conclusions are made.

II. BLEEDINGDETECTIONALGORITHMS

In order to clarify the results of the review process, the image processing techniques appearing in the algorithms were assigned to one of the following groups, reflecting the types of features considered by the techniques and their role in the recognition process:

- Colour based – techniques that process the image as sets of individual values without considering relations between pixels; only pixel values (colours) are considered,
- Texture based – considering spatial relations between pixels,
- Contour based – focusing on edge and contour detection,
- Segmentation – dividing images into meaningful regions basing on specific criteria,
- Decision – mechanisms responsible for making final decision (interpretation) on the bleeding presence,
- Other – unusual techniques which could not be assigned to any of the remaining categories.

The techniques appearing in the reviewed bleeding detection algorithms, assigned to proper categories, are presented in table I. The methods were grouped by the year of publication.

A. *Colour techniques*

The colour features, intuitively related with the phenomenon of bleeding, are utilised in all of the investigated methods. A common approach is to assume, that the colour of bleedings belongs to specific shades of red. The colour ranges are to be identified by analysing a set of bleeding pictures in the training step, or they are predetermined by the authors. The authors however propose different measures for evaluating the colour features of the considered images/regions. The simplest measures employ basic statistics computed from the RGB colour space, where mainly the R channel is involved. More commonly, though, HSI or closely related HSV colour spaces are used, which were proved to correspond better to human perception system [30]. Also, the HSI/HSV models overcome the problem of colour channels correlations occurring in the RGB model. The colour space can be as well expressed by the means of Karhunen-Loeve transformation computed from RGB colour space, which is closely related to the PCA model (Principal Component Analysis), also capable of removing correlations between the colour channels. Another approach, used by Bourbakis [3], is the utilisation of cone response transforms described by Susstrunk et al. [36].

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

TABLE I
IMAGE PROCESSING COMPONENTS OF THE ANALYSED BLEEDING DETECTION ALGORITHMS

Ref	Colour techniques	Texture techniques	Contour techniques	Segmentation techniques	Decision mechanisms	Other techniques
2005						
[3]	Cone response transform using a reference colour value	-	-	-	Artificial Neural Network	-
2006						
[7]	Scalable Colour MPEG-7 visual descriptor	Homogeneous Texture MPEG-7 visual descriptor	-	-	not applicable	-
2008						
[13]	K-L transformation and features	-	-	Fuzzy region segmentation utilizing Local-Global Graph	-	-
[12]	Colour spectrum transformation (combined R, G and B channels)	-	-	-	Thresholds on Colour Spectrum Transformation learned from blood samples	Ignoring over and under illuminated regions; Intensity adjustment (in HSI)
[21]	HSI histograms; 3D-DCT transforms of the histograms	3D Local Binary Pattern histograms	Colour and texture analysis of the neighbour-hood surround-ing candidate blood regions	Initial selection of bleeding regions basing on HSI	Principal Component Analysis; Support Vector Machine	Colour histogram adaptation over time; detection of specular highlights
[9]	HSV histogram; 8 Dominant Colours	Co-occurrence matrix of the Dominant Colours	-	-	A set of Support Vectors Machine classifiers; training data balancing based on over-sampling	Pre-processing with averaging filter form removing random noise
2009						
[31]	HSV colour space	RX algorithm for anomaly detection	Mumford-Shah functional	-	HSV thresholds for blood region candidates and actual bleeding	Ignoring small-sized detections; Ignoring too dark pixels
[29]	HSI and RGB colour values	-	-	-	Probabilistic Neural Network (PNN) classifier	Ignoring too dark pixels
[17]	HSI colour space; scaled Chebyshev polynomials of the H and S channels	LBPriu2 transformation on I channel, histogram, statistical measures	-	-	Artificial Neural Network	Image is divided into 36 blocks covering centre part of the image
[38]	HSV colour space, histogram of the combined H, S and V values, statistical featuresof the histogram	NTU transformation on R,G and B channels, statistical features	-	Segmentation based on homogeneity, HSI and CIELab	Bayesian, basing on Multivariate Gaussian approximation of learning data	-

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ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

[14]	Local HSV histograms	Grey Level Co-occurrenceMatrices, statistical features, Colour Wavelet Covariance	-	-	Artificial Neural Network; Support Vector Machine	-
			2010			
[32]	Adaptive colour histogram based on HSV colour space, reflecting colour ranges specific for endoscopic images	-	-	-	Neural network classifier for each cell and each block; merging the two sets of results with rule-based decision making	Division into 4x4 cells; merging 3x3 cells into blocks
			2011			
[28]	Author's pixel difference measures based RGB values and Grey intensity	-	-	Based on the colour measures, performs region growing from single blood pixels determined by fixed thresholds	Thresholds on the colour measures	Ignoring small-sized detections
[16]	RGB values ratios, normalized R value and HSV saturation	-	-	-	Thresholds on the colour features	Enhancing suspected blood regions; Focus on red regions
[8]	RGB values ratios	-	Canny Edge Detector for edge masking	-	Artificial Neural Network MLP	Ignoring too dark pixels; Ignoring small-sized detections
[20]	HSI Hue histogram, samples are weighted by Saturation; normalized RGB histogram	Spatial pyramid of the colour features	-	-	Support Vector Machine classifier	-
[11]	Local HSV histograms	-	-	-	Neural network classifier for each cell and each block; merging the two sets of results with rule-based decision making	Division into 4x4 cells; merging 3x3 cells into blocks
			2013			
[1]	HSV histogram; 8 Dominant Colours	Co-occurrence matrix over quantized colour image	-	-	A set of Support Vectors Machine classifiers;training data balancing based on clustering the majority samples and down-sampling	-

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

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Vol. 1, Issue 6, August 2013

The colour techniques usually employ histograms for measuring the colour features. Multi-dimensional 2D or 3D histograms are used to reflect features of combined channels of the colour spaces. An adaptive, balanced histogram was proposed by Poh et al. [32] in order to address the problems of the concentration of the values in small subspaces, which is typical for medical in-body images [35]. Also, Mackiewicz et al. [21] proposed compressing the histogram using 3D Discrete Cosine Transform.Several approaches are also used alternatively to histograms. Abouelenien et al. [1] and Giritharan et al. [9] use Dominant Colour feature described by Weijer and Schmid [37], composed of the values of 8 representative colours along with the variances and sizes as percentages of the image. Li and Meng [17] introduce Chrominance Moments computed as scaled Chebyshev polynomials of H and S channels of the HSI colour space. Coimbra and Cuhna [7] propose utilisation of MPEG-7 Scalable Colour descriptor [39]. Finally, for the KL transformation, Karargyris and Bourbakis [13] use colour features proposed by Ohta et al. [24].

B. *Texture techniques*

Some of the authors use common techniques for measuring texture features, which include Co-occurrence Matrices, originally proposed by Haralick et al. [10], Local Binary Patterns introduced by Ojala et al. [25], [26] and MPEG-7 Homogenous Texture descriptor [39]. Others use less known approaches. Penna et al. [31] employ Reed-Xiaoli (RX) detector [33], based on covariance matrix, in order to detect anomalies in the image. Wang and Yang [38] use Texture Unit Number (NTU) feature, which is closely related to the LBP feature. Lv et al. [20] measure texture features by constructing spatial pyramid of the colour features, following the approach proposed by Lazebnik et al. [15].

C. *Contour techniques*

Analysis of contours and edges is rarely used by the authors of the algorithms. Mackiewicz et al. [21] perform a dedicated colour and texture analysis of the thin area surrounding the considered image region, therefore measuring features of its boundaries. Penna et al. [31] use an adaptive version of the Mumford-Shah functional [23], capable of detecting edges in noisy images, while Fu et al. [8] utilise the well-known Canny edge detector [4].

D. *Segmentation techniques*

Initial segmentation appears in only four of the methods, each of them also uses a different technique. Notably, Karargyris and Bourbakis [13] proposed a fuzzy region segmentation, originally introduced in [2] and [22]. After edge-preserving smoothing operation, edges are detected in the image resulting in the initial segmentation of the image. Next, the segments are expanded with preserving a defined homegeneity feature, preferring the larger segments. The acquired structure is then represented as a Local Global graph consisting of local colour, texture, shape and size features, the internal shape of each segmented region and relationships between the segmented regions in the entire image, which is designed to follow human cognition. Finally, basing on the Local Global graph information, neighbouring regions of similar nature are merged, resulting in the final segmentation. In contrast, Mackiewicz et al. [21] performs initial selection of candidate bleeding regions by evaluating each pixel's probability of bleeding, basing on the HSI distribution of the training set. Wang and Yang [38] utilise a segmentation technique proposed by Cheng and Sun [6], where regions are firstly established by finding peak values of 2D homegeneity and the intensity histogram, the segments are further divided basing on the hue colour feature and finally merging of the regions of similar CIELab values is performed. Lastly, Pan et al. [28] used a region growing segmentation strategy based on the colour measures, starting from single blood pixels, which are identified by features comparison against the cluster centre of the bleeding samples from the training set.

E. *Decision mechanisms*

The most popular decision components are simple thresholding and techniques and well known classifiers: Neural Networks and Support Vector Machines. Various configurations are used however, including multilayer perceptron neural networks, probabilistic neural networks and different kernels for SVMs. Principal Component Analysis (PCA) is also used in order to assist the classification by initial reduction of redundant data from the feature vector. Giritharan et

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

al. [9] and Abouelenien et al. [1] used in their works interesting approaches for dealing with natural imbalance in the training set between the negative, non-bleeding samples and the positive, bleeding cases, which are harder to collect. The former approach is using over-sampling strategy originally presented by Chawla et al. [5]. Over-sampling is achieved by generating synthetic samples similar to the minority class, which are found in feature space using k-nearest neighbours algorithm. Also, an interesting Bayesian classifier was proposed by Wang and Yang [38]. The feature vectors are classified by estimating it's probability of belonging to each of the classes using the Bayesian formula and choosing the maximum. The formula uses also posterior probabilities of each class, which are obtained by estimating the training set with the multivariate Gaussian probability density function.

F. *Other techniques*

The remaining techniques were mainly related tothe pre-processing of the images and post-processing of the results. In many methods dark regions are initially detected and excluded from the further analysis. Similarly, over-illuminated regions are eliminated. An advanced method for that purpose , based on Intensity-Saturation histogram, originally proposed by Ortiz and Torres [27], was used by Mackiewicz et al [21], who also employed an interesting technique of colour histogram adaption over the time in endoscopic videos. In the post-processing step, some of the methods are eliminating small detections, considered as noise. Also, a common practise is to divide the image into smaller blocks, which are then independently analysed and classified.

III. DISCUSSION

The authors of the algorithms apply multiple advanced image processing techniques in their methods. Clearly, most of them focus on colour features of the images, which is strongly justified by the nature of the typical bleedings' appearance. However the remaining features, that is texture, contours and use of segmentation, are not considered by all of the methods, although they are crucial for human vision and object recognition. Some problems can be also found at the classification level. The decision mechanisms tend to be too simple (thresholds) or hardly controllable or explainable (support vector machine, neural networks).

Also, a short note on the efficiency of the reviewed methods must be made. As was already noticed by Liedlgruber and Uhl [19], a direct comparison of the methods is hard to make due to the test data used. The problem is caused by the significant difficulties in gathering endoscopic data, which is hard to acquire, furthermore the process requires a lot of time and effort. In addition, no publicly available endoscopic images database suitable for testing the algorithms exists, so the research groups are forced to build their own image databases. However, in some cases the testing sets are too small, which affects the credibility of the methods. Nevertheless, the tests carried out by the authors of the methods show high sensitivity, specificity and accuracy rates, often exceeding the level of 95%, which confirms the bleeding detection potential of the methods.

IV. CONCLUSIONS

Recent advancement in the area of endoscopic bleeding detection algorithms resulted in establishing a great number of image processing techniques achieving high efficiency rates. The selected and evaluated techniques can be successfully utilised in construction of new bleeding detection methods providing even higher efficiency. A new possible direction of research is application of the established techniques for the recognition of lower-level, simpler, basic features of the phenomenon of bleeding, instead of directly detecting the presence of bleeding. The features should preferably be related to the aspects of the endoscopic images, which are considered by the examining physicians. This way the detection algorithm can reach higher level of abstraction by making a clear, controllable decision basing on a set of understandable features, which could be driven by a set of rules or a probabilistic approach. In other words, a shift to the cognitive approach and expert systems seems reasonable and as well possible here.

However, it seems that there is still a strong need for a detailed study of the particular visual features, which are silently considered by the physicians during the examination of the images, and which were not sufficiently analysed and described yet. Since the physicians consider certain, precise and describable aspects of the appearance of endoscopic bleeding, it can be the key to efficient bleeding detection, hopefully closer to the outstanding efficiency of the trained professionals. We expect that the combination of the techniques established by the researcher with deeper knowledge and application of the endoscopy specialists' reasoning will enable reaching higher level of quality for the bleeding detection methods, which could finally lead to including them in the clinical procedures.

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 6, August 2013

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ISSN(Online): 2320-9801
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Vol. 1, Issue 6, August 2013

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