DETECTION OF LUMEN AND INTESTINAL JUICES IN WIRELESS CAPSULE ENDOSCOPY

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ABSTRACT: Wireless capsule endoscopy is the golden standard in the investigation of the small bowel, but is time consuming and burdening for the physicians, as the imaging conditions are challenging and the variability of the acquired frames is great. This paper carries out a study on the automatic detection of bubbles and debris, based on an algorithm combining colour slicing techniques, textures and position within the WCE frame and the intestinal tract. Their identification represents an important phase in the investigation of a video file furnished by the endoscopic capsule, as it allows the reduction of the important frames submitted to analysis for potential lesion detection. Experimental results prove that the algorithm is effective in reducing the number of WCE images with relevant content, reducing thus the time spent for the analysis of the images acquired by WCE.
KEYWORDS: Wireless Capsule Endoscopy, medical image analysis, image segmentation, artefact detection, artificial neural network

1. WIRELESS CAPSULE ENDOSCOPY

Wireless capsule endoscopy (WCE) is considered to be one of the most valuable tools available to the gastroenterologist for the examination of the small bowel [Swa03]. Its main use is to investigate areas that cannot be seen by other types of endoscopy. While gastroscopy and colonoscopy allow the visualization of the oesophagus, stomach, duodenum, terminal ileum and colon, the small intestine is inaccessible by these means and remains the most difficult segment to examine.
The WCE capsule is an ingestible device with a cylindrical shape (very similar to a larger pill); it measures around 26x11 mm and weights around 3 grams [Ron08]. It is equipped with imaging sensors to capture snapshots within the digestive tract, a LED array, an ASIC chip, an antenna system to transmit the images "outside" the patient and also a battery pack with approximately 8 hours functioning time (the average duration of a full digestive tract transit). Right before the ingestion, the capsule is activated and starts acquiring images. During its lifetime, it acquires more than 50000 frames (Fig. 1) which are subsequently recorded on external devices [V+11].

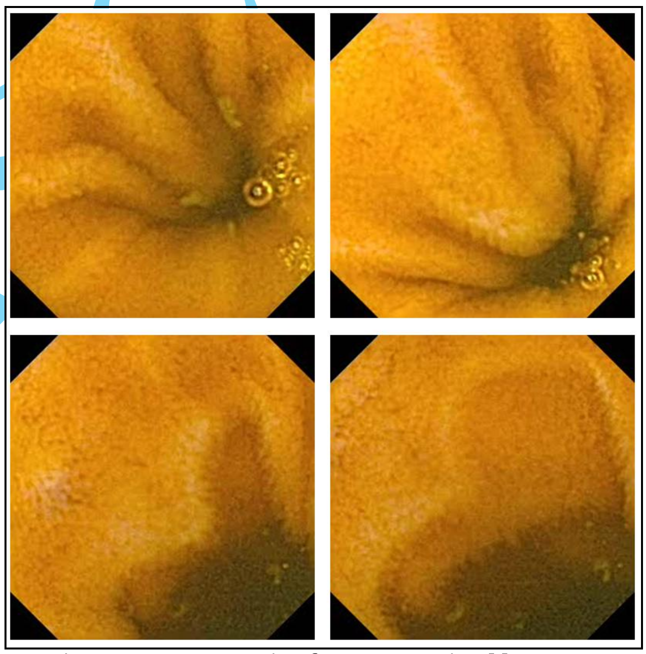

Fig. 1. Four successive frames acquired by WCE

The analysis of the video file, obtained by grouping the acquired frames, in order to establish a diagnosis is however long – from 2 to 4 hours for an experienced physician, so the overall examination time is a drawback for this optimal investigation method. Thus, the need for computer-aided support becomes obvious, in order to shorten the time spent for analysis by automatically segmenting the images, identifying and classifying the potential lesions, offering precision for the detection of injuries encountered in small number of frames or incompletely captured. The traditional processing techniques have been applied by many authors in order to accomplish this difficult task [Kar09, MFJ08, LM08, O+07], but the variability of the lesions and aspects is too great to be covered by one single technique. Thus, the whole process must be divided in phases that would lead the physician more and more close to the expected result. The general approach should cover the analysis of all acquired frames and, for each one, determine if it is a usable frame (determine whether it offers relevant information or not), eliminate potential misleading artefacts – lumen, bubbles, debris (Fig. 2), determine and extract the features of that specific frame, employ an artificial intelligence system to check if the extracted features correspond to a specific lesion and then classify it.

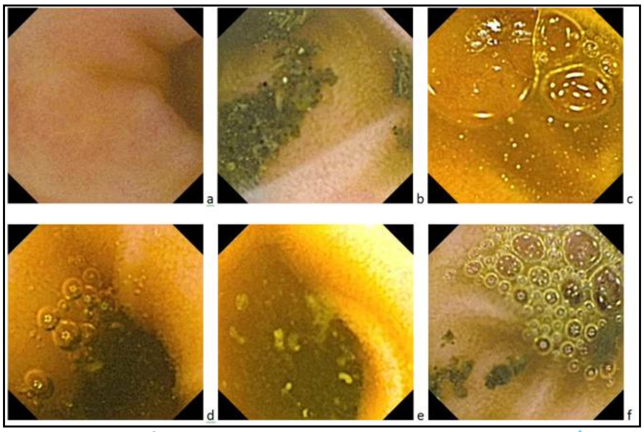

Fig. 2. Artefacts present in WCE images: lumen (a, d, e), bubbles (c, d, f), debris (b, e, f)

The most important time reduction is obtained by eliminating the non-informative frames – meaning those that present no relevant content for the physician (no lesion present). This paper comprises a study of the informative frames that contain misleading artefacts in the lesion analysis process: bubbles and intestinal juices (debris). A combination of texture and colour features, grouped with the position inside the frame is employed in order to detect artefacts and differentiate them from potential lesions. Thus, another filter is applied for informative frames, reducing the number of WCE images that potentially contain lesions and require a more thorough analysis. The results of this analysis represent new data for future research that would lead to the detection and classification of lesions. The use of automatic analysis would considerably reduce the overall investigation time of WCE, confirming its status of optimal examination method, being confortable for the patient (who can even perform basic tasks during the examination period), painless, non-invasive and with rare complications.

2. NON LESIONAL ARTEFACTS

Sometimes, the physical characteristics of the small intestine and different artefacts may be mistakenly considered as lesions (mostly polyps, due to bubbles' round shape) or abnormalities of the mucosa. Bubbles and debris are often present in WCE images, influencing the identification of potential lesions, since they do not behold relevant information, but they do impact the global features of an image. The intestinal mucosa is characterized by rather constant intensity, colour and texture, while areas presenting different artefacts exhibit sharp changes of contrast, due to strong edges, shadows, light reflection for bubbles, and specific colour and texture for debris. Due to their strong characteristics, a potential transformation of the frame to the grey scale domain may be performed prior to the processing activities, without risking losing valuable colour information. The identification of bubbles and debris in WCE images leads to a set of frames free of artefacts and is useful in order to eliminate potential items that may infer with automatic software detection and may sometimes generate confusion.

3. CHARACTERISTIC FEATURES

Two major factors in a correct automatic identification of bubbles and debris are their texture and their position within the digestive tract, as the normal aspect of the mucosa in several segments (oesophagus, stomach, small intestine or colon) may differ and may influence the final result. Within the same frame, it is possible to identify several textures, sometimes very similar, that may differentiate specific artefacts or lesions.

The term texture refers to properties belonging to the external surfaces of the objects and to the sensations induced by touch, being sometimes used to describe non-tactile sensations. Also, the textures may represent sub-dimensioned models, where the individual elements are placed one next to the other, in order to generate undistinguishable models. Textures are usually analysed and described based on linear and non-linear patterns. From a statistical point of view, texture is represented by the distribution of pixel values in space. Texture analysis may be performed using a series of methods like local binary patterns, co-occurrence matrices, histograms or autocorrelation. From a structural point of view, texture is defined by sets of elements or primitives (that may be regions with uniform features, line segments or even simple individual pixels), in association with their correspondent spatial arrangements.

The analysis must then be oriented in the extraction of the texture primitives, and the subsequent generalisation or modelling of the spatial arrangement constraints. The use of mathematic modelling of the relationships created between texture primitives is employed for the definition of these constrains (random field models, fractal models, epitome model, autoregressive model, etc.) [Ers11]. With filter based techniques, textures are obtained as results of the computation of filter responses' energy, by applying filter banks on images. Associated texture analysis methods use either the frequency domain or the spatial domain, or a combination of both. For this study, the textures of WCE images were determined using a bank of Gabor filters.

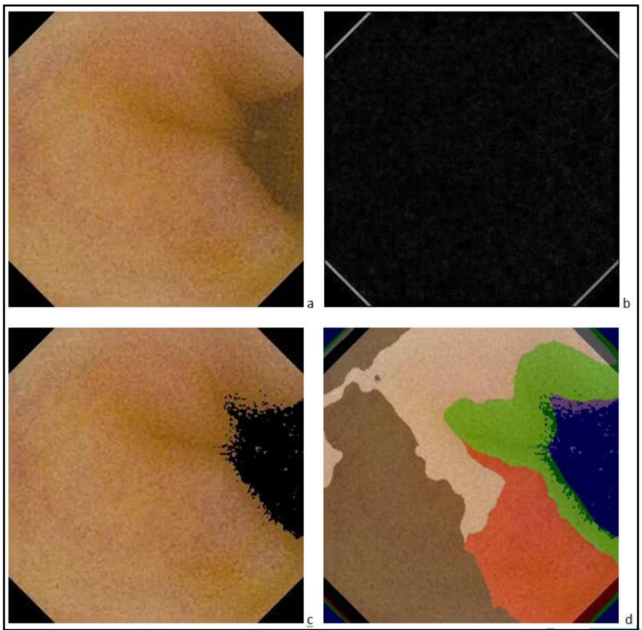

Fig. 3. a) WCE image where the lumen is present; b) Lumen contour detection; c) WCE image where the lumen has been removed; d) Texture enhancement superimposed over the WCE image without lumen

The colour characteristics of the key point elements from this paper – lumen, bubbles and debris – are also relevant for our analysis, compared with the previous features. The colour palette of the key elements is oriented towards the limits – dark shades for the lumen (Fig. 3a) and bright shades for the bubbles contour (Fig. 4a). Intestinal juices also have specific colours, touching a series of light green shades (Fig. 5a).

Based on the colour slicing technique, potential artefacts are separated from the surrounding tissue in a WCE image by emphasizing their specific range of colours.

Thus, the colour space of the image is divided into two non-overlapping areas, defining both corresponding ranges of colours [GW12]. The studied areas corresponding to each of the artefacts are considered as regions of interest shaped as spheres, for the ease of computation, within the colour space of each WCE frame. The most frequent shade of each artefact is considered the centre of the sphere, while the least frequent shade must be situated on the surface of the sphere, representing thus the radius that will be expressed as an Euclidian distance between two different points inside the colour space.

For each artefact, we identified during our study the associated colour range; subsequently, we have removed all colours included in this colour range from the WCE images in our study.

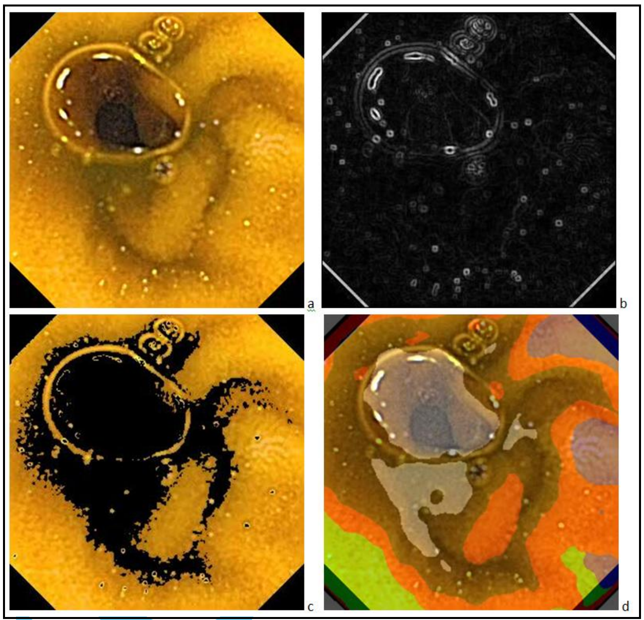

Fig. 4. a) WCE image where bubbles are present; b) Bubbles contour detection; c) WCE image where the bubbles contour is emphasized; d) Texture enhancement superimposed over the original WCE image

For an easy visual interpretation, the removed colours were replaced with black (indicating a lack of information in that specific area, thus no pixels to be further analysed).

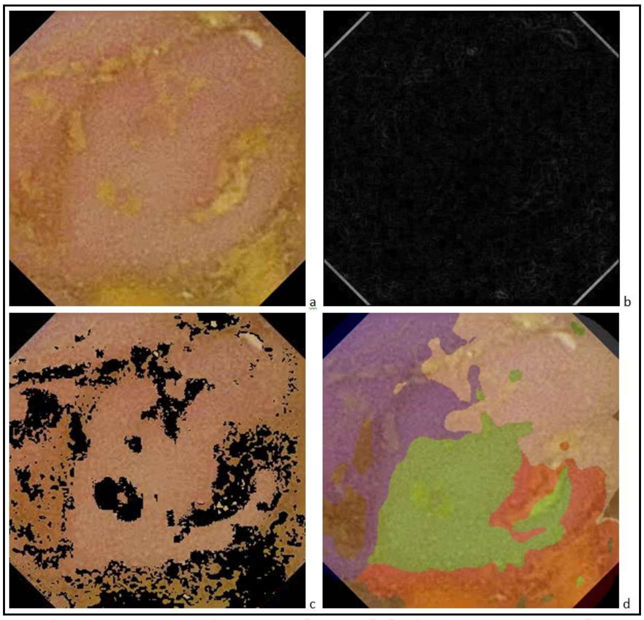

Fig. 5. a) WCE image where debris are present; b) Debris contour detection; c) WCE image where the debris have been removed; d) Texture enhancement superimposed over the original WCE image

Another feature with high importance for bubbles detection, but less use for others, is the shape. This characteristic is extensively used in image segmentation, but in WCE frames is irrelevant for most artefacts, except bubbles which are known for their round, bright and thick contour (Fig. 4b). Shape is determined in terms of edges of an image, being part of the segmentation process of a frame.

4. ANALYSIS AND CLASSIFICATION

The general approach groups the previously mentioned features, creating a combination of texture, contour and colour, based on weights. Next to edge detection, both texture and colour represent powerful cues for the segmentation process, being robust when the variation of brightness is significant [HG06, SL07]. For all frames in the analysed sequences, all features were extracted, yielding good or bad results, in accordance with the image characteristics. For a better visual analysis, the image defining the existing textures was superimposed over the original image before or after the removal of the potential artefact, to emphasize the results of the segmentation process based on textures.

The set of different features extracted for each frame represents in principle the input data for a feed forward back propagation multi-layer neural network (NN) which was trained to classify frames with and without artefacts, and then into three distinct classes, corresponding to each type of artefact. The NN consisted of an input layer, one hidden layer for data processing and a variable output layer which performed the classifications.

A key point in feature selection process is the fact that different lesions have different representative characteristics, thus several vector features must be composed and used for analysis. For example, intestinal juices are mostly represented by colour (and less by texture and / or shape – Fig. 5a, b, c, d), while bubbles are basically determined by their round shape (and less by texture – that may be very similar with the one of the surrounding intestinal mucosa). Thus, each feature must be fed into the neural network not with its effective value, but as a class of values, according to a set of thresholds that were experimentally determined.

5. RESULTS

Our study was performed on more than 10000 frames, grouped in 11 sequences. These sequences are part of 10 video files obtained after the investigation with the Olympus EndoCapsule EC ® of 10 pacients hospitalized in the 1st Medical Clinic from the Emergency Clinical County Hospital Craiova. This paper uses the most relevant frames to demonstrate the processing techniques applied.

Lumen detection had the best results based on its colour feature (Fig. 5c), as its range of colour is relatively constant, containing dark brown / black shades. The colour change relative to the normal colour of the intestinal mucosa is progressive, thus the edge detection process was irrelevant in most cases (Fig. 5b). The texture also led to the correct identification of the lumen in the WCE image (Fig. 5d).

Intestinal juices have a similar behaviour, being best identified according to their colour feature, since their range of shades is well separated from the palette of the normal intestinal mucosa, lumen or other artefacts. Edge detection and texture are not so representatives, having low weights in the artefact's detection.

Bubbles are mostly represented by their contour, best result being obtained in edge detection. Moreover, the thick contour led to a double edge detection, which is a unique feature and ensures that, in our sequences, bubbles are not mistaken with polyps. On the other hand, the interior of the bubbles is transparent, thus it displays a washout aspect of the normal mucosa. Since the bubbles are not constant in colour, this feature has a low weight in their automatic identification. Texture extraction has similar behaviour, being useful only for the interior of the bubble. Thus, a correct identification is based on a proper combination between the contour and the interior of the bubble.

Based on the artefacts' features analysis and their transformation of classes, the NN fed with these parameters showed good identification capabilities, similar to the human interpretation. Overall, the artificial neural network correctly identified 92.4% general artefacts (lumen – 87.3%; bubbles – 95.4%; debris – 93.6%). The NN had 93.85% training accuracy and 88.15% testing accuracy.

6. CONCLUSIONS

A correct identification of artefacts in WCE frames is of outmost importance for the reduction of the time spent on the analysis of the acquired images and, in the same time, for minimizing the risk of false positive findings in the diagnosis process (artefacts mistakenly considered as lesions).

The selection of features and the transformation of their effective values into classes turned out to be optimum, leading to a good accuracy of the automatic identification of artefacts.

The perceptron feed-forward multi-layered ANN with back-propagation algorithms is a useful representation of a computed-aided diagnosis system for medical diagnosis. Its use can bring significant improvement to the accuracy of image analysis methods. Future work must include other intelligent artificial classification systems, like genetic algorithms or support vector machines.

In conclusion, a proper feature extraction process combined with an optimum classification application represents a promising approach in artefacts identification in WCE images, producing rapid and accurate results. Thus, it improves the analysis of WCE videos, reducing the time spent by the examinator. The extension of this approach to lesion identification subsequent to artefact removal could provide fast and reliable diagnostic aid for the physician and represent future work goals.

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