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A computer-aided diagnostic system for intestinal polyps identified by wireless capsule endoscopy

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Abstract

Small bowel polyps present in images acquired by wireless capsule endoscopy are more difficult to detect using computer-aided diagnostic (CAD) systems. We aimed to identify the optimum morphological characteristics that best describe a polyp and convert them into feature vectors used for automatic detection of polyps present in images acquired by wireless capsule endoscopy (WCE). We prospectively included 54 patients with clinical indications for WCE. Initially, physicians analyzed all images acquired, identifying the frames that contained small bowel polyps. Subsequently, all images were analyzed using an automated computer-aided diagnostic system designed and implemented to convert physical characteristics into vectors of numeric values. The data set was completed with texture and color information, and then analyzed by a feed forward back propagation artificial neural network (ANN) trained to identify the presence of polyps in WCE frames. Overall, the neural network had 93.75% sensitivity, 91.38% specificity, 85.71% positive predictive value (PPV) and 96.36% negative predictive value (NPV). In comparison, physicians' diagnosis indicated 94.79% sensitivity, 93.68% specificity, 89.22% PPV and 97.02% NPV, thus showing that ANN diagnosis was similar to that of human interpretation. Computer-aided diagnostic of small bowel polyps, based on morphological features detection methods, emulation and neural networks classification, seems efficient, fast and reliable for physicians.

***Keywords*:** small bowel polyps, morphological features, artificial neural network, computer-aided diagnosis system.

Introduction

Wireless capsule endoscopy (WCE) is a modern investigation, which allows a complete and non-invasive examination of the small bowel. This investigation technique has been particularly successful in identifying the cause of gastrointestinal bleeding of suspected small bowel pathology [1–4]. Capsule endoscopy is painless, with fewer complications, it does not require sedation and thus, patients do not need hospitalization during this examination [5, 6]. During the eight hours procedure, every patient may proceed with his usual activity [7]. The large diagnostic yield of WCE for small bowel diseases represents another advantage of this investigation [8–13].

WCE offers a significant set of images covering most of the digestive tract, but it is also time-consuming for physicians performing the analysis of all acquired frames (approximately 55 000 per patient). During the past years, many scientists attempted to implement software applications that could automatically identify lesions located in the digestive tract, especially at small bowel and colon level [14–16]. The most successful ones seem to focus active bleeding and angiectasia, due to their color feature that is easier to detect. Other indications like Crohn's disease, celiac disease, ulcers or tumors have also been the subject of research. Polyps are a common finding in WCE images, especially when using capsules dedicated to colon investigations; therefore, a series of authors have developed algorithms for their automatic detection [17–20]. They usually appear as round, elliptical or semicircle shaped, with textures and colors close to those of the intestinal mucosa. Thus, shape seems to be the most important feature that defines them.

Aim

Our aim was to determine the optimum morphological features to be used as input data for a computer-aided diagnostic (CAD) system able to detect the contours and other characteristics of small bowel polyps. This system was developed by a research team from the Research Center of Gastroenterology and Hepatology, University of Medicine and Pharmacy of Craiova, Romania, based on an artificial neural network (ANN) designed to identify the presence of intestinal polyps. The identified features helped us develop additional modules that improved the performances of the system.

Patients, Materials and Methods

Patient inclusion and diagnosis

We have prospectively included in our study 54 consecutive patients who were investigated using Olympus EndoCapsules EC®. Our inclusion criteria were occult gastrointestinal bleeding, iron deficiency anemia, chronic unexplained abdominal pain, chronic diarrhea, suspected polyposis syndromes or small bowel tumors, with inconclusive endoscopic and serologic investigations prior to capsule ingestion. We have established the exclusion criteria according to current guidelines for small bowel capsule endoscopy: known or suspected small bowel obstruction, swallowing disorders, pacemakers or other implanted cardiac devices, pregnant.

All investigations took place in the Research Center of Gastroenterology and Hepatology, University of Medicine and Pharmacy of Craiova. A team of experienced physicians established the initial diagnostic, based on clinical and imagistic data. The developed CAD system used this as reference for results comparison. We have conducted our study in conformity with the Declaration of Helsinki, after the approval of the Ethics Committee of the University of Medicine and Pharmacy of Craiova. All patients included in the study gave their informed consents on the use of WCE and agreed so that we could use their anonymized results in order to develop our CAD system modules.

The subjects included in our study group had at least one of the following symptoms: chronic abdominal pain, transit disorders, weight loss, occult gastrointestinal bleeding and clinical signs such as anemia, occult gastrointestinal bleeding. All patients included in the study group underwent small bowel capsule endoscopy. The capsule contains a complementary metal oxide silicone (CMOS) camera module, a lens system, light emitting diodes, an optic dome and an application specific integrated circuit (ASIC). The electrodes attached to the patient's abdomen receive the recorded images through the RFID (radio-frequency identification) antenna. The recorded images are stored on the recording device and downloaded after that for visualization and analysis on a dedicated station. The preparation for capsule endoscopy involved an overnight fast for 12 hours prior to capsule ingestion. Polyethylene glycol solution was administered for improving the quality of the acquired images. All patients received permission to drink liquids after three hours from the beginning of the procedure, and to eat light meals after five hours. The capsule is usually propelled by peristalsis and it is eliminated through the anus into the toilet, one or two days after ingestion.

Data collection and pre-processing

For all patients included in the study group, we have analyzed the full-length WCE films. We have also split the movies in individual frames, for a more detailed image analysis. The initial phase of the study consisted in the manual analysis of the entire set of frames, in order to detect any potential lesions.

The second phase consisted in pre-processing the original frames included in the analysis set, prior to submitting them to the classification algorithm. Those phases are emphasized in Figure 1.

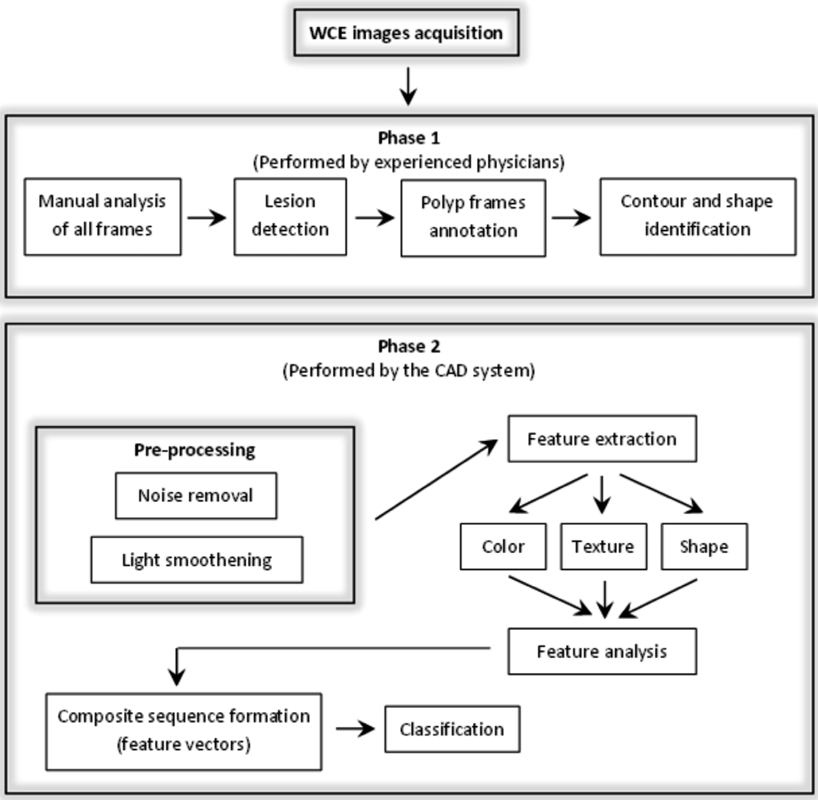

Figure 1 – ***Main phases of the system: working algorithm. WCE: Wireless capsule endoscopy; CAD: Computer-aided diagnostic.***

Algorithm design and methodology

From a structural point of view, the CAD system comprises the generic phases of any classification algorithm: feature extraction, feature analysis, composite sequence formation, and classification. Color, texture and shape represent the most common imagistic descriptors used in the majority of content-based software applications for image analysis. A thorough analysis of the visual aspect of small bowel polyps indicates the shape as the main characteristic, followed by texture and color.

Statistical analysis

We used GraphPad Prism 6.0 (GraphPad Software Inc., LaJolla, CA, USA) to perform statistical analysis. We computed the positive (PPV) and negative (NPV) predictive values, specificities, sensitivities, for both human analysis and computer-aided results.

The McNemar's test was used for the comparison of the differences between the specificity and sensitivity of the ANN model and physicians' lesions evaluation-based diagnosis.

The significance threshold for p-value was 0.05.

Results

Characteristics of the study group

The study group consisted of 54 patients (21 men and 33 women), investigated with the wireless capsule. From the study group, eight patients presented small bowel polyps.

We identified duodenal polyps in two patients, while jejunal and ileal polyps we found in two, respectively six patients. Two patients had several polyps, one of them had duodenal and ileal polyps, while another one had in jejunum and ileum. All polyps had a normal surface mucosa. Abdominal pain, hereditary polyposis syndromes, occult gastrointestinal bleeding, and anemia represented the main inclusion criteria of patients with polyps (Table 1).

During the investigation, we have not encountered any incidents.

Macroscopic description of intestinal polyps

The macroscopic aspect of the polyps recorded by wireless capsule endoscopy was of an excrescence on the inner lining of the bowel. The main characteristic of the sessile polyps was the partially round or oval shape, and their texture was similar to the one of the surrounding mucosa. In case of the jejunal pedunculated polyp, the shape was close to a sphere. We have approximately estimated the location of the identified polyps as duodenal, jejunal or ileal considering the endoscopic aspect of the intestinal mucosa, the timing of polyp presence after entrance of the wireless capsule to the duodenum and the total small bowel passage time. We considered that the visualized small bowel during the first 15 minutes after the wireless capsule has exited the pylorus passage is the duodenum, while the intestine visualized after <50% and >50% of the small bowel transit time was estimated to be the jejunum and the ileum, respectively.

The location of the small bowel was estimated by analyzing the transit time of the wireless capsule between pylorus and ileocecal valve. Moreover, the jejunum was characterized by the prominent folds and high narrow villi, while fewer folds and shorter villi were observed in the ileum. The size of polyps was estimated using as a reference the diameter of an open pyloric orifice (10 mm). Therefore, we classified polyps with a diameter <10 mm as being small and large >10 mm. Only one sessile polyp found in the ileum was large, while all other polyps detected were small. These aspects are shown in Table 2.

Table 1 – ***Main inclusion criteria and identified intestinal lesions for patients included in our study group***

Identified intestinal lesions	Main inclusion criteria				
	Abdominal pain	*Refractory diarrhea*	*Hereditary polyposis syndromes*	*Occult gastrointestinal bleeding*	*Anemia*
Angiectasis	2	1	0	5	5
Polyp	3	0	1	3	1
Signs of bleeding	1	1	0	2	2
Nodular lymphoid hyperplasia of the small bowel	1	0	0	0	0
Small bowel tumor	1	0	0	0	1
Crohn's disease	0	1	0	0	0
Celiac disease	1	0	0	0	1
Without pathology	8	4	1	3	5
Total	17	7	2	13	15

Table 2 – ***Distribution and size of polyps of the eight patients investigated with WCE***

Patient No.	Gender	Age [years]	Location of small bowel polyps	Type of polyps	Size
1.	M	80	jejunal	sessile	small
2.	M	31	duodenal and ileal	sessile	small
3.	F	57	duodenal	sessile	small
4.	F	61	ileal	pedunculated	small
5.	F	77	jejunal and ileal	sessile	small
6.	M	31	ileal	sessile	small
7.	F	42	ileal	sessile	small
8.	F	68	ileal	sessile	large

WCE: Wireless capsule endoscopy; M: Male; F: Female.

Description and testing of the algorithm

Experienced physicians annotated all frames containing polyps, for further comparison with the ones provided by the software application. They also identified the correct contour and shape of each polyp, in order to determine the accuracy of the corresponding phase in the automatic detection algorithm. The modules were refined and tested using this set.

We then implemented separate modules within our CAD system as follows: noise removal, followed by a light smoothening of the images, in order to uniform the intestinal mucosa. Then, each image was submitted to the set of software modules implementing a complex algorithm for polyp identification and classification.

We have developed dedicated modules able to convert the morphological characteristics into feature vectors, composing thus a complex set of vectors for every potential polyp encountered in the analyzed images. Feature vectors were completed with information related to polyps' position within the WCE frame, a potential comparison with the lumen diameter (if possible), degree of change for their texture and color relative to the ones corresponding to surrounding mucosa present in the image (Figure 2). This final set of data was fed into the ANN.

Based on the available images, we have composed a set of 90 images, 32 of them containing small bowel polyps, the rest representing images without any pathology, in order to test the modules of our CAD system. Figure 3 presents several WCE images containing polyps.

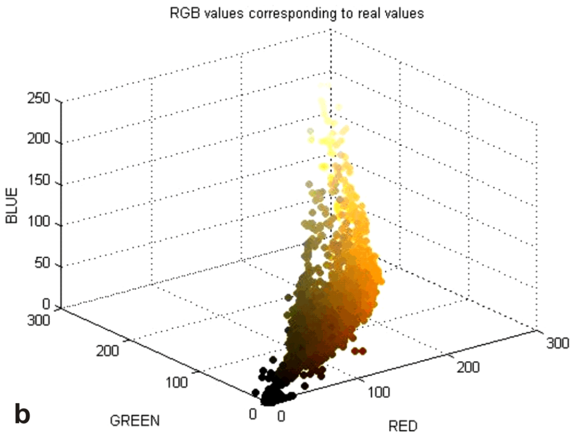

Figure 2 – ***Processed images: (a) Original image containing a polyp; (b) Color chart; (c) Texture detection; (d) Partial contour detection.***

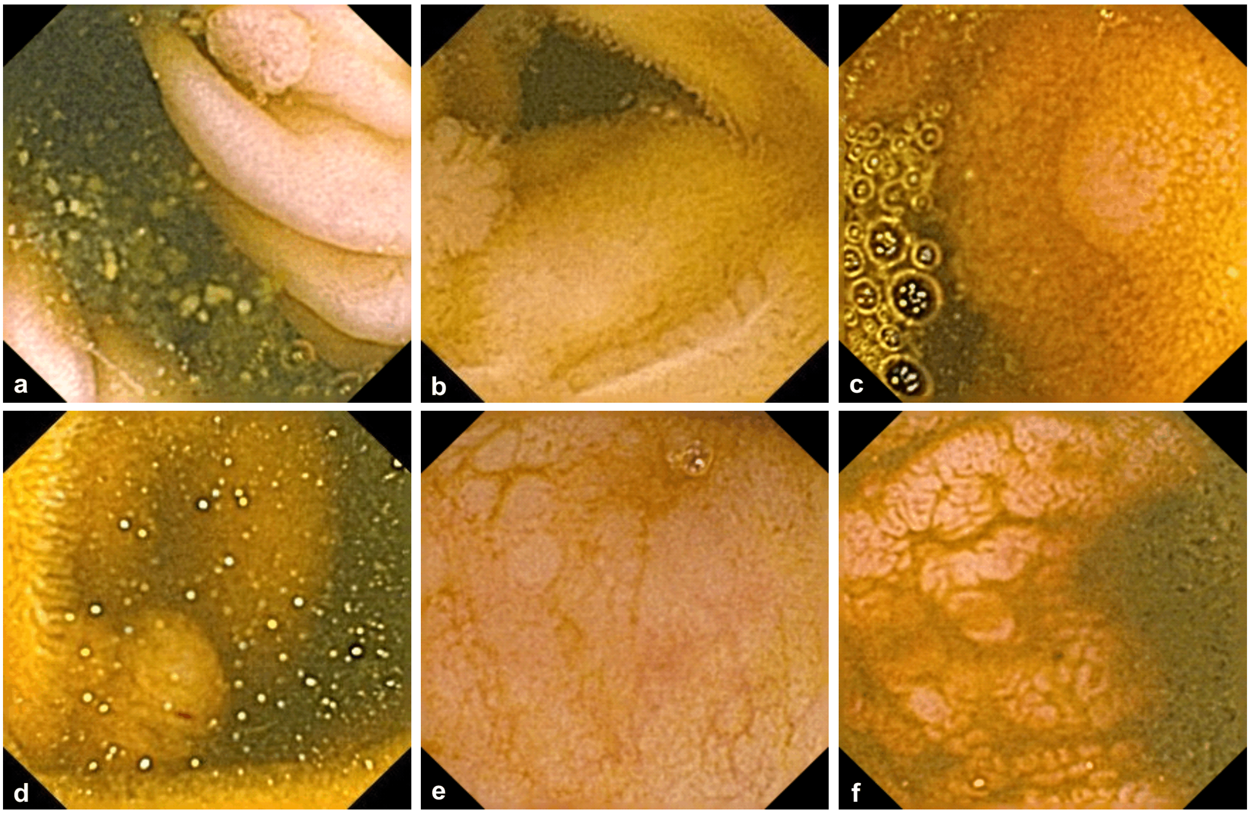

Figure 3 – ***Morphological aspects of intestinal polyps identified for several patients included in our study group: (a) Sessile polyp of 2–3 mm with normal surface mucosa; (b) Sessile polyp of 3 mm with normal surface mucosa; (c) Sessile polyp of 4 mm with normal surface mucosa; (d) Pedunculated polyp of 4 mm with normal surface mucosa; (e and f) Ileal mucosa with polypoid and granular aspect.***

These images were extracted from WCE movies belonging to patients included in our study group. Initially, several physicians manually analyzed all images acquired by WCE, obtaining the following results: 94.79% sensitivity, 93.68% specificity, 89.22% PPV and 97.02% NPV. Physicians have also independently marked the visible contour pixels for each polyp. After automatic analysis of all images from the test set, the contour detection phase showed 97.68% accuracy in pixel detection and approximation. Regarding the final classification, the CAD system indicated almost similar results compared to human interpretation: 93.75% sensitivity, 91.38% specificity, 85.71% PPV and 96.36% NPV. The system correctly classified 30 lesions as polyps, missing two polyps. At the same time, five intestinal folds partially present in some images were defined as polyps, based on their elliptical contour resembling polyps. The differences between CAD and human classification of small bowel polyps present no statistical differences regarding specificity (p=0.231) and sensitivity (p=0.446).

Discussion

Even though wireless capsule endoscopy has many advantages, the long time necessary for the interpretation of recorded images represents an important disadvantage [21–23]. This investigation implies many steps: first, the preparation for the examination, which involves an overnight fast for 12 hours prior to capsule ingestion. Before the activation of the capsule, the physician attaches electrodes on the patient's abdomen, and finally he/she swallows the capsule. After the capsule is swallowed, the investigation lasts around eight hours, the average time of a normal gastrointestinal transit. The mean time for the visualization and analysis the WCE videos is around two to four hours, depending on the experience of the examining physician [24]. Among these steps, we can reduce only the time needed for the interpretation of all recorded images. Our study showed that a CAD system for intestinal polyps might reduce the necessary time for the visualization and analysis of acquired videos, implicitly the diagnosis time. The processing time obviously depends on the computational characteristics of the station used; however, it may lead to a minimum 50% reduction.

Scientific literature contains mostly reports regarding automatic detection of colonic polyps following colonoscopy, virtual colonoscopy or computed tomography (CT) colonography, as the visual appearance of the colon is more accessible for shape and contour detection, using algorithms for image processing. In addition, incidence of colonic polyps is higher than the incidence of small bowel polyps [25]. However, early identification of precancerous polyps present at this level is of utmost importance, significantly decreasing cancer incidence, which unfortunately is rising [26]. Most polyps present in WCE images are difficult to detect as they do not have precise margins, or they might be affected by noise induced by charge-coupled device (CCD) camera. Their texture and color may be similar to those of normal intestinal mucosa, thus making it hard to differentiate them, unless the shape is properly emphasized. By using certain contour detection methods, it is possible to miss polyps' margins, or to detect them only partially, with the risk of not corresponding to the real contours. Despite these drawbacks, there are methods useful in detecting the contours of intestinal polyps, with a low false negative rate. One of the factors influencing a correct identification is not necessarily the used classifier, but rather the ability to identify features that best represent a lesion, and to quantify them in order to be input data for a specific classifier. Most software applications process color, texture and shape. These also represent the foundation of WCE images global analysis, reflecting the main elements analyzed by human physicians. Other supplementary features like rotation, relative location between two consecutive frames, partial contours detection or movement speed complete the physical features of each analyzed frame [27–29]. We focused our study on shape, which is the most important visual feature of polyps. Concretely, the computer-aided diagnosis system has contributed in shortening the necessary time for establishing the diagnosis.

The modest number of the patients from the study group, the patients presenting intestinal polyps, and the diversified pathology represent a limitation of the study, but the number of the analyzed images (more than 2 700 000) with our CAD system is representative. In addition, using a unique type of capsules limits the capability of the system. We may overcome this drawback by testing our system with richer data sets acquired by capsules provided by various manufacturers, thus limiting the corresponding bias. Our set of images did not allow an exhaustive testing of our algorithm, but it showed promising results. Our new objective is related to the construction of Bézier surfaces that would reproduce in 3D the visible part of intestinal polyps, based on the entire sequence of frames that contain it.

Conclusions

We presented a report on using an ANN computer-aided diagnostic system joint with an emulation of intestinal lesions based on shape and texture, for the correct classification of intestinal polyps. Our algorithm was based on identifying the optimum morphological characteristics to be converted into feature vectors, followed by the use of neural networks for classification. Global results upon the study set are similar to those obtained by human interpretation: 93.75% sensitivity and 91.38% specificity. Based on these values, the system proved efficient in polyp detection.

Conflict of interests

The authors declare that they have no conflict of interests.

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