Polyp Segmentation in NBI Colonoscopy

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Abstract. Endoscopic screening of the colon (colonoscopy) is performed to prevent cancer and to support therapy. During intervention colon polyps are located, inspected and, if need be, removed by the investigator. We propose a segmentation algorithm as a part of an automatic polyp classification system for colonoscopic Narrow-Band images. Our approach includes multi-scale filtering for noise reduction, suppression of small blood vessels, and enhancement of major edges. Results of the subsequent edge detection are compared to a set of elliptic templates and evaluated. We validated our algorithm on our polyp database with images acquired during routine colonoscopic examinations. The presented results show the reliable segmentation performance of our method and its robustness to image variations.

1 Introduction

Colorectal cancer is the second most common form of cancer in Germany for both women with 36,000 new incidents and men with 37,000 new incidents each year [1]. Endoscopic screening of the colon (colonoscopy) is aimed at locating and classifying polyps.

Colorectal polyps can be divided up into three classes: benign hyperplasias, malignant carcinomas, and adenomas which are benign polyps developing into cancer over a period of about 10 years. While hyperplasias should remain in the colon as polyp removal (polypectomy) may cause side-effects like severe bleeding or colon wall perforation, adenomas are removed by the medical practitioner during colonoscopy to prevent the development of cancer. Carcinomas have to be excised together with their neighbouring colon section during additional surgical interventions because of the high risk of spreading cancer. Tischendorf et al. applied Narrow-Band imaging (NBI) to highlight blood vessels structures which are an indicator for adenomatous tissue in a recent study [2].

A crucial step in an automatic colon polyp classification system is segmentation which will be discussed in this paper. To our best knowledge there are no publications on polyp segmentation in NBI colonoscopy available. However some approaches have been made to analyze white light endoscopic video images of the colon.

Bourbakis et al. detected abnormal regions including gastrointestinal bleeding [3]. Kang et al. used the Hough Transform on Canny Edge Detector results

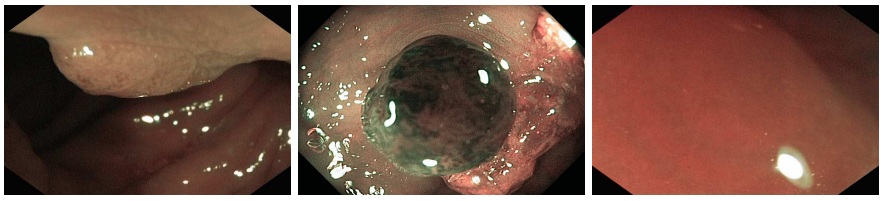
to locate colorectal polyps [4]. Hwang et al. used elliptical shape features on binary edge maps acquired by watershedding [5]. These two methods do not meet our requirements for the segmentation area in terms of ruling out colon wall segmentation.

The remainder of the paper is organized as follows. In Section 2 the proposed method for the segmentation of polyp surfaces in colonoscopic NBI image material is described. The validation setup is highlighted in Section 3 and results are summarized in Section 4. A closing discussion and future research are presented in Section 5.

2 Method

We developed a computer-aided system for the classification of polyps in images acquired by Narrow-Band Imaging [6]. During screening the investigator observes a polyp and activates NBI illumination. A screenshot picturing the polyp is taken and the proposed algorithm segments the polyp area. If the result is approved by the examiner the area is used as a region of interest for a classification algorithm based on NBI blood vessel features. The system provides an objective classification decision and reduces intra-investigator and inter-investigator variability. Segmenting polyps in colonoscopic NBI images is complicated because of variability and an individual angle of view. Figure 1 illustrates variations of polyp appearance. After examining various other options we decided to locate polyp surface via its outer boundary edges. We chose the Canny Edge Detector as it preserves long, connected edges. However NBI illumination causes an increased amount of edges in the edge maps because of the blood vessel enhancement. Thus to decrease noise and to eliminate minor edges in preparation for the segmentation all images were reduced in size to 147x126 pixels by subsampling. Resizing lowers processing time and memory requirements as well. We use Non-Linear Diffusion Filtering (NLDF) [7, 8] which is based on Fick's law of diffusion to reduce noise, to subdue smaller blood vessels, and to emphasize major edges. The NLDF is applied iteratively which increases its effect. In figure 2 the edge detection results with and without prior filtering are illustrated.

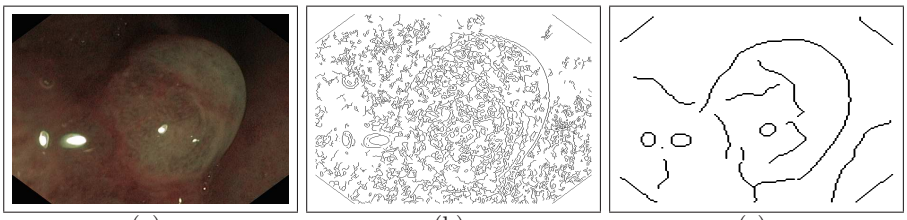
We store the results after 10, 15, and 20 NLDF iterations. Edges detected after 25 iterations are dilated and eroded N times to close gaps. In our experi-



(a) (b) (c)

Fig. 1. Lateral view of a polyp (a), top view of a polyp with characteristic texture for potentially malignant polyp (b), no distinct texture (c).

Fig. 2. Original image (a), Canny edge detector without prior filtering (b), results with prior filtering (c).

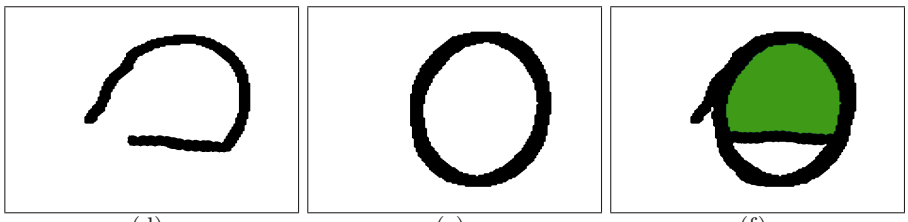


(a) (b) (c)

ments $N = 4$ was used. Subsequently the results are elongated by adjacent edge pixels from the 10 iterations edge map. If there are no edges found after 25 iterations, the results recorded after 20, 15, and 10 iterations are used successively instead.

We use a template matching approach to analyze the two longest resulting edges which we found to have a very high probability of being part of the polyp contour. The varying forms of the templates are generated by rotating a 3D ellipsoid while observing its projection onto a 2D plane. The projection result is subsequently scaled, rotated, shifted, and dilated to yield our template set.

The templates are evaluated by the rating function $r = \frac{n_{\text{over}}^3}{n_{\text{templ}}}$ where n_{over} is the number of overlapping pixels of template and edge image. n_{templ} is the number of pixels forming the template. r is the rating value by which the template is compared to other templates. The template with the highest score is combined with the potentially disjoint edge detection result. However the outcome is still a closed contour. The results are upsampled to match the original image size and the enclosed area as illustrated in figure 3 is used for classification. Our polyp classification algorithm requires a representative minimum area of 64×64 pixels to operate. However classification accuracy is obviously improved by using more input data. Thus it is desirable but not necessary to segment the entire polyp. On the other hand segmentation of colon wall (benign tissue) could cause misclassification of malignant polyps and needs to be ruled out.



(d) (e) (f)

Fig. 3. Artificial results of the filtering and edge detection process (a), template with highest rating (b), combined outcome and the segmented polyp area (c).

Table 1. Localization results for a preselected test set with 56 genuine polyp images

Detected area	$\geq 90\%$	$50\% - 90\%$	$\leq 50\%$	Wall inclusioon	False detection
Number of polyps	18	25	7	6	-
Category rate	32.14 %	44.64 %	12.5 %	10.72 %	-
Cumulative rate			89.28 %		10.72 %

3 Validation

We formed two test sets for the polyp classification software [6] with images taken from our polyp database which is maintained and extended in cooperation with our medical partners. The database consists of more than 1500 images of varying sizes from 320 polyps observed during routine colonoscopies. The first test set consists of 56 images which were selected because the polyps were completely pictured, the image quality was high and we had reliable histological results as goldstandard. The second test set includes images from all polyps that had reliable corresponding histological data available. Some show only small, distant polyps or parts thereof. Some images are unsharp and noisy. This test set represents a variety of 209 images taken during routine examinations.

4 Results

The polyp classification results are arranged into five categories. Category 1 includes segmentations with more than 90 % of the polyp area segmented. Category 2 consists of polyps with more than 50 % but less than 90 % segmented polyp area. Less than 50 % of the polyp area (but still enough for classification) was segmented for polyps in category 3. The fourth category 4 includes results where minor parts of the segmented area belonged to the colon wall. Results with large area of segmented colon wall are in category 5. The results of the first experiment with 56 preselected polyps presented in table 1 indicate a reliable polyp area detection. In less than 11 % of the cases we would expect the medical practitioner to reject the results. Possible reactions are to repeat the process or to manually select a region of interest for classification. More than 89 % of the segmentation results can be used as input for our polyp classification algorithm.

Table 2 illustrates complementary results for the extended test set with all 209 polyps which still yield more than 80 % positive detection rate proving the robustness of the approach.

5 Discussion

We presented a novel template matching approach for the segmentation of polyps in NBI colonoscopy. The performed tests suggest robust segmentation results for subsequent classification. In the future we will establish a quantitative analysis

Table 2. Localization results for an extended test set with 209 genuine polyp images

Detected area	$\geq 90\%$	$50\% - 90\%$	$\leq 50\%$	Wall inclusion	False detection
Number of polyps	25	70	75	22	17
Category rate	11.96 %	33.49 %	35.89 %	10.53 %	8.13 %
Cumulative rate			81.34 %		18.66 %

method for our algorithm to complement our qualitative evaluation. In addition we will continue to improve our algorithm. Possible ideas for enhancement include the creation of better edge maps by considering results from different colour channels and the replacement of the template matching steps by particle filter based methods or ellipse fitting. Furthermore we intend to implement our algorithm in C++ code as it is currently written for Matlab. This will enable us to run it on the real time demonstrator platform "RealTimeFrame" [9].

References

1. Gesundheitsberichterstattung des Bundes. Krebs in Deutschland 2003-2004: Häufigkeiten und Trends. 8th ed. Robert Koch Institut, Gesellschaft der epidemiologischen Krebsregister in Deutschland e.V.; 2008.
2. Tischendorf JJW, Wasmuth HE, Koch A, et al. Value of magnifying chromoendoscopy and narrow band imaging (NBI) in classifying colorectal polyps: A prospective controlled study. Endoscopy. 2007;39(12):1092–6.
3. Bourbakis N. Detecting abnormal patterns in WCE images. Procs IEEE BIBE. 2005; p. 232–238.
4. Kang J, Doraiswami R. Real-time image processing system for endoscopic applications. In: Canadian Conference on Electrical and Computer Engineering (IEEE CCECE). vol. 3; 2003. p. 1469–1472.
5. Hwang S, Oh J, Tavanapong W, et al. Polyp detection in colonoscopy video using elliptical shape feature. Procs ICIP. 2007;2:II–465–II–468.
6. Stehle T, Gross S, Behrens A, et al. Classification of colon polyps in NBI endoscopy using vascularization features. Procs SPIE. 2009;To appear.
7. Perona P, Malik J. Scale-space and edge detection using anisotropic diffusion. IEEE Trans Pattern Anal Mach Intell. 1990;12(7):629–639.
8. Weickert J. Anisotropic Diffusion in Image Processing. Universität Kaiserslautern; 1996. Available from: http://www.mia.uni-saarland.de/weickert/Papers/diss.ps.gz.
9. Gross S, Stehle T, Behrens A, et al. RealTimeFrame: A real time image processing solution for medical environments. In: 41. DGBMT-Jahrestagung Biomedizinische Technik (BMT). Aachen; 2007.