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Local fractal dimension based approaches for colonic polyp classification

Michael Häfner[a], Toru Tamaki[b], Shinji Tanaka[c], Andreas Uhl[d], Georg Wimmer[d,*], Shigeto Yoshida[c]

[a] St. Elisabeth Hospital, Landstraßer Hauptstraße 4a, Vienna A-1030, Austria
[b] Department of Information Engineering, Graduate School of Engineering, Hiroshima University, 1-4-1 Kagamiyama, Higashi-hiroshima, Hiroshima 739-8527, Japan
[c] Department of Endoscopy, Hiroshima University Hospital, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8551, Japan
[d] Department of Computer Sciences, Jakob Haringerstrasse 2, University of Salzburg, Salzburg 5020, Austria

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ABSTRACT

This work introduces texture analysis methods that are based on computing the local fractal dimension (LFD; or also called the local density function) and applies them for colonic polyp classification. The methods are tested on 8 HD-endoscopic image databases, where each database is acquired using different imaging modalities (Pentax's i-Scan technology combined with or without staining the mucosa) and on a zoom-endoscopic image database using narrow band imaging. In this paper, we present three novel extensions to a LFD based approach. These extensions additionally extract shape and/or gradient information of the image to enhance the discriminativity of the original approach. To compare the results of the LFD based approaches with the results of other approaches, five state of the art approaches for colonic polyp classification are applied to the employed databases. Experiments show that LFD based approaches are well suited for colonic polyp classification, especially the three proposed extensions. The three proposed extensions are the best performing methods or at least among the best performing methods for each of the employed databases.

The methods are additionally tested by means of a public texture image database, the UIUCtex database. With this database, the viewpoint invariance of the methods is assessed, an important features for the employed endoscopic image databases. Results imply that most of the LFD based methods are more viewpoint invariant than the other methods. However, the shape, size and orientation adapted LFD approaches (which are especially designed to enhance the viewpoint invariance) are in general not more viewpoint invariant than the other LFD based approaches.

1. Introduction

In this paper, texture analysis methods are applied for the automated classification of colonic polyps in endoscopic images under unknown viewpoint and illumination conditions. Endoscopic images occur with different scales, orientations or perspectives, depending on the distance and perspective of the camera to the object. Fig. 1 shows some examples for the field of view depending on the endoscopic viewpoint to the mucosal wall.

The varying viewpoint condition combined with the large intra-class and small inter-class variations of polyps make it very difficult to distinguish between different types of polyps. The viewpoint invariance of the employed methods is an important feature to at least reduce the problem with the varying viewpoint conditions.

Uhl et al. (2011) and Häfner et al. (2014c) showed that methods based on fractal analysis are able to combine viewpoint invariance with high discriminativity and are quite suitable for endoscopic image classification.

The term "fractal" was first used by the mathematician Benoit Mandelbrot as an indication of objects whose complex geometry cannot be characterized by an integral dimension. Fractal geometry is able to describe the irregular or fragmented shape of natural features as well as other complex objects that traditional Euclidean geometry fails to analyze. The fractal dimension is the key quantity to describe the fractal geometry and the heterogeneity of irregular shapes. Roughly spoken, the fractal dimension is a ratio that compares how the detail of a shape changes with the scale at which it is measured.

However, the fractal dimension is only one number, which is not enough to describe an object.

As an extension to the classical fractal analysis, multifractal analysis provides more powerful descriptions. Applied to image processing, first define a point characterization on an image according to

* Corresponding author.
E-mail addresses: uhl@cosy.sbg.ac.at (A. Uhl), gwimmer@cosy.sbg.ac.at (G. Wimmer).

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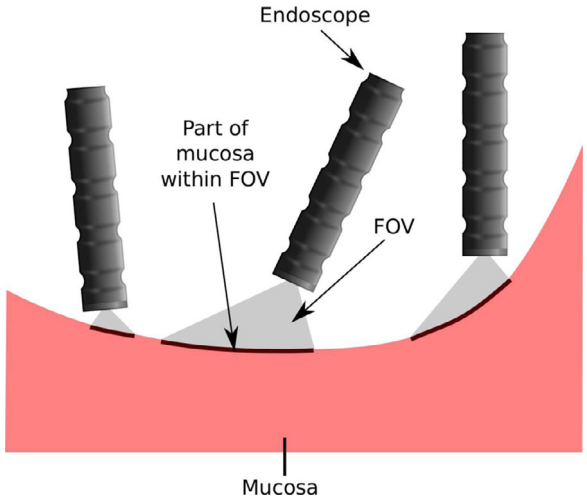

Fig. 1. The field of view (FOV) depending on the endoscopic viewpoint to the mucosal wall.

some criteria (e.g., the intensity values of the pixels), then the fractal dimensions are computed for every point set from this categorization (e.g., categorize the image pixels by their intensity and obtain binary images by setting a pixel to 0 if its intensity value is in the considered set and to 1 otherwise). The collection of the fractal dimensions of the binary images is called a multi fractal spectrum (MFS) vector.

Another extension to the classical analysis to provide a more powerful description is to compute local fractal features. These features are already the norm in fractal based image segmentation (Chaudhuri and Sarkar, 1995; Xia et al., 2006).

In Xu et al. (2009), local fractal based features (we denote them as local fractal dimensions, LFD's) are computed densely followed by applying multifractal analysis to these features (categorize the LFD's by their values, thereby obtain binary images followed by computing the fractal dimension of the binary images). Another approach (Varma and Garg, 2007) using the LFD is pre-filtering the image with the MR8 filter bank obtaining eight filtered images on which the LFD's are computed. Subsequently, the bag of visual words (BoW) approach is used to build histograms of the LFD's. It has been shown that the LFD is invariant to bi-Lipschitz transformations, such as local affine or perspective transformations and certain smooth, non-linear transformations (Xu et al., 2009). The LFD is also invariant to local affine illumination changes as showed in Xu et al. (2009).

Roughly speaking, the LFD at an arbitrary location of an image is computed by summing up intensity values in disk shaped areas with fixed radii surrounding the considered (pixel) location followed by analyzing the increase of the sums for increasing radii. Actually, the scale and perspective of the object or texture in the image at the considered location is not taken into account, the radii are always the same and the areas are always disk shaped. In Häfner et al. (2014c), a more viewpoint adaptive approach is presented. This LFD based approach uses ellipsoidal areas instead of disk shaped areas. The sizes, shapes and orientations of the ellipsoidal areas are adapted to the local texture structure by analyzing the shape, size and orientation of connected components (blobs). Instead of a dense computation of the LFD's like in Xu et al. (2009) and Varma and Garg (2007), the size, shape and orientation adapted LFD's in Häfner et al. (2014c) are computed only for interest points, more precisely only for those points that are the centers of the area of a blob.

A review about methods using fractal and multifractal analysis is presented in Lopes and Betrouni (2009).

In this work we compare methods based on the LFD, compare their classification results on different image databases, analyze the reasons for those results and examine the affine invariance of the methods. We will test the LFD approaches on nine different endoscopic image databases, which consist of highly detailed endoscopic images with nine different imaging modalities. Additionally we apply the LFD based approaches on a public texture database with huge viewpoint variations, the UIUCtex database (Lazebnik et al. , 2005).

The contributions of this manuscript are as follows:

- We apply seven LFD based methods for the automated classification of colonic polyps using nine different endoscopic image databases. Eight databases are gathered using an HD-endoscope with eight different imaging modalities (Pentax's i-Scan in combination with staining the mucosa) and one database is gathered using a zoom-endoscope with narrow band imaging (NBI) as imaging modality. To the best of our knowledge, this is the highest number of endoscopic polyp databases that has been used in publications so far. The results of the LFD based methods are compared and the differences between the methods and their impacts to the results are analyzed.
- Five (non LFD based) state-of-the-art approaches for colonic polyp classification are applied to the classification of our databases to compare their results with the results of the LFD based methods.
- We present three novel extensions of an LFD approach. For each database, the results of these extensions are among the best results of all the employed methods.
- We assess the viewpoint invariance of the methods by means of a public texture database, the UIUCtex database (Lazebnik et al., 2005). Results imply, that most of the LFD based methods are more viewpoint invariant than the other methods. The size, shape and orientation adapted LFD methods are generally not more viewpoint invariant than the other LFD based methods.

Already in Häfner et al. (2014c), an LFD-based method was proposed for the classification of colonic polyps. However, this publication used only one endoscopic image database (one of our 8 HD-endoscopic image databases) and compared the result of the proposed method with only one other LFD based approach and three non LFD based approaches. Furthermore, neither the differences between the two LFD based approaches were analyzed nor the viewpoint invariance of the approaches was tested.

This paper is organized as follows. In Section 2 we briefly introduce the concept of the computer-assisted diagnosis of polyps by the automated classification of mucosa texture patches and review the corresponding state-of-the-art. In Section 3, we describe the feature extraction approaches and compare the approaches that are based on computing the LFD. The experimental setup, the used databases and the results are presented in Section 4. Section 5 presents the discussion and Section 6 concludes our work. The acronyms used in this work are listed in the Appendix.

2. Colonic polyp classification

Colonic polyps have a rather high prevalence and are known to either develop into cancer or to be precursors of colon cancer. Hence, an early assessment of the malignant potential of such polyps is important as this can lower the mortality rate drastically. As a consequence, a regular colon examination is recommended, especially for people at an age of 50 years and older. The current gold standard for the examination of the colon is colonoscopy, performed by using a colonoscope. Modern endoscopy devices are able to take pictures or videos from inside the colon, allowing to obtain images (or videos) for a computer-assisted analysis with the goal of detecting and diagnosing abnormalities.

Colonic polyps are a frequent finding and are usually divided into hyperplastic, adenomatous and malignant. In order to determine a diagnosis based on the visual appearance of colonic polyps, the pit pattern classification scheme was proposed by Kudo et al. (1994). A pit pattern refers to the shape of a pit, the opening of a colorectal crypt.