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Automated classification of duodenal imagery in celiac disease using evolved Fourier feature vectors

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ABSTRACT

Feature extraction techniques based on selection of highly discriminant Fourier filters have been developed for an automated classification of magnifying endoscope images with respect to pit patterns of colon lesions. These are applied to duodenal imagery for diagnosis of celiac disease. Features are extracted from the Fourier domain by selecting the most discriminant features using an evolutionary algorithm. Subsequent classification is performed with various standard algorithms (KNN, SVM, Bayes classifier) and combination of several Fourier filters and classifiers which is called multiclassifier. The obtained results are promising, due to a high specificity for the detection of mucosal damage typical of untreated celiac disease.

1. Introduction

Celiac disease is a complex autoimmune disorder that affects the small bowel in genetically predisposed individuals of all age groups after introduction of gluten containing food. Commonly known as gluten intolerance, this disease has several other names in literature, including cœliac disease, c(o)eliac sprue, non-tropical sprue, endemic sprue, gluten enteropathy or gluten-sensitive enteropathy. Characteristic for the disease is an inflammatory reaction in the mucosa of the small intestine caused by a dysregulated immune response triggered by ingested gluten proteins of certain cereals (wheat, rye, and barley), especially against gliadine. During the course of the disease the mucosa looses its absorptive villi and hyperplasia of the enteric crypts occurs leading to a diminished ability to absorb nutrients.

Endoscopy with biopsy is currently considered the gold standard for the diagnosis of celiac disease. Besides standard upper endoscopy, several new endoscopic approaches for diagnosing celiac disease have been applied [7].

The modified immersion technique described in [1] is based on the instillation of water into the duodenal lumen for better visualization of the villi. Furthermore magnifying endoscopy (standard endoscopy with additional magnification) has been investigated [2]. For the performance of capsule endoscopy [3] the patient swallows a small capsule equipped with a camera that takes images of the duodenal mucosa during its passage through the intestine. All these techniques aim for detection of total or partial villous atrophy and other specific markers. These specific markers show a high specificity for celiac disease in adult patients if all of them are found during endoscopy: scalloping of the small bowel folds, reduction in the number or loss of Kerkring's folds, mosaic patterns, and visualization of the underlying blood vessels [4].

Figs. 1 and 2 show examples for duodenal images with positive and negative indications for celiac disease.

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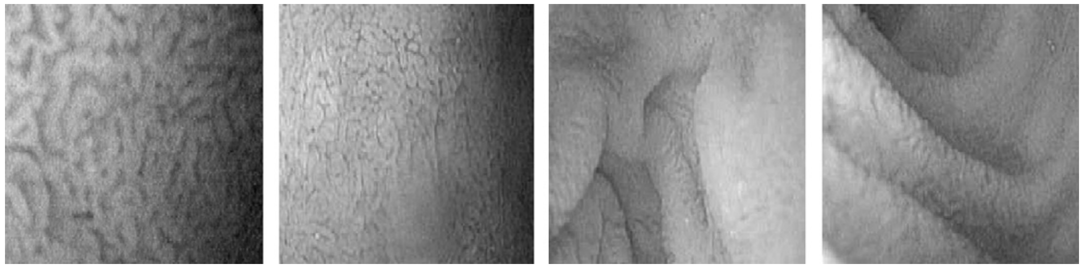

Fig. 1 – Negative celiac disease indication: normal mucosal state.

During endoscopy at least three duodenal biopsies are taken. Microscopic changes within these specimen are classified according to Marsh classification [5].

The routine diagnostic work-up of celiac disease, including duodenoscopy with biopsy, is a time-consuming and cost-intensive process. To save costs, time, and manpower and simultaneously increase the safety of the procedure it would be desirable to develop an approach avoiding biopsy. Recent studies [1,6] investigating such endoscopic techniques report reliable results. These could be further improved by analysis of the acquired visual data (digital images and video sequences) with the assistance of computers.

In this work we apply several techniques that were developed for Pit pattern classification of magnifying endoscopic images to imagery obtained from small bowel endoscopy. The aim is the detection of the villous atrophy and classification with respect to its extent (no villous atrophy, partial, or total villous atrophy).

2. Automated classification

Computer-based image classification is usually performed in three steps. The first step is to detect image regions that show high informational content for the particular classification problem. Since almost no classification algorithms can cope with high-dimensional input data, we have to reduce the dimension of these image regions. Next, the discriminative information of an image is encoded by a numerical feature vector describing the relevant information. Various techniques can be used for this process. Finally, the features are used for training of the classification algorithm (i.e. determining the optimal parameters for the specific classification problem). Any unknown image that is presented to the classification algorithm is then classified according to the previously learned settings.

2.1. *Image preprocessing*

Many of the images used throughout our experiments are very blurry. Apart from that they often suffer from a low contrast. This is why we decided to carry out experiments with preprocessing, too.

To enhance the contrast we use an advanced contrast enhancement technique called CLAHE (Contrast Limited Adaptive Histogram Equalization) [8]. Compared to other contrast enhancement algorithms (e.g. histogram equalization), this algorithm operates on local image regions. For this purpose the image is subdivided into image tiles (so-called contextual regions) and the contrast is enhanced within each of these regions. To avoid artifacts between two adjacent tiles an interpolation algorithm is employed. Apart from that, to avoid amplification of present noise, the contrast enhancement is limited within homogenous regions (which can be identified easily by high peaks in the histogram of the according region).

To sharpen the images we use Laplace sharpening [9]. Basically this technique computes a gradient image using convolution with a suitable kernel. This gradient image is then added to the original image. Usually this algorithm is used with a rather small kernel (e.g. 3×3). Regarding the images available this would very often result in highlighting present noise, which is the main reason for using a 9×9 kernel throughout our experiments. The effect of the preprocessing steps is shown in Fig. 3.

2.2. *Fourier-based feature extraction*

For classification we employ features from the Fourier domain [10]. Multiple ring shaped filters with variable widths are applied to the centered Fourier spectrum of each color channel (RGB) for selecting relevant subsets of the most discriminative coefficients that keep the scatter within each class small and

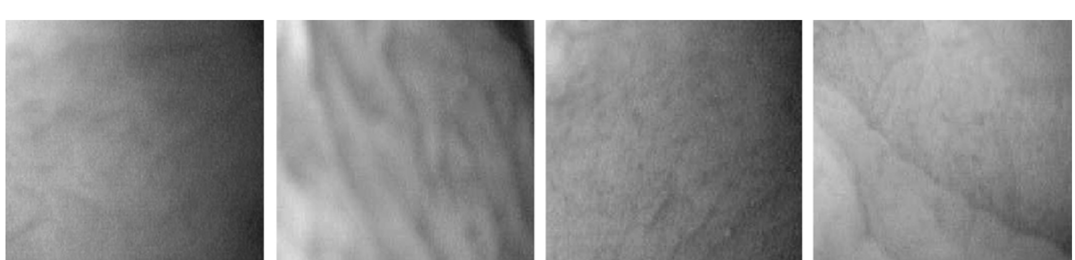

Fig. 2 – Positive celiac disease indication: villous atrophy.