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Fully automated decision support systems for celiac disease diagnosis

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Abstract

In most recent computer aided celiac disease diagnosis approaches, image regions (patches) showing discriminative features necessarily need to be manually extracted by the medical doctor, prior to the automated classification pipeline. However, although the obtained classification outcomes based on such semi-automated systems are attractive, a human interaction finally is undesired. In this work, fully automated approaches are investigated which are based on the measurement of several image quality properties. Firstly, we investigate a method based on optimization of single quality measures as well as an approach based on weighted combinations of these metrics. Furthermore, a weighted decision-level and a weighted feature-level fusion method are investigated which are not based on the selection of one single best patch, but on a weighted combination. In a large experimental setting, we evaluate these methods with respect to the achieved overall classification rates. Finally, especially the proposed feature-level fusion method supplies the best performances and comes close to manual experts' patch selection as far as the accuracy is concerned.

Keywords: Endoscopy; Celiac disease diagnosis; Fully automated diagnosis; Medical imaging

1. Introduction

1.1. Celiac disease

Celiac disease, also known as gluten intolerance, is a complex autoimmune disorder which affects the small intestine in genetically predisposed individuals of all age groups after the introduction of gluten containing food. Characteristic for this disease is the inflammatory reaction in the mucosa of the small intestine. 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 any nutrients.

Endoscopy in combination with biopsy is currently considered as the gold standard for the diagnosis of celiac disease. During standard upper endoscopy at least four biopsies are taken. Microscopic changes within these specimen are then classified in a histological analysis according to the Marsh classification [1]. Subsequently, Oberhuber et al. proposed the modified Marsh classification scheme [2] which distinguishes between classes Marsh-0 to Marsh-3, with subclasses Marsh-3A, Marsh-3B, and Marsh-3C, resulting in a total number of six classes. According to the modified Marsh classification scheme, Marsh-0 denotes a healthy mucosa (without visible changes of the villous structure) and Marsh-3C designates a complete absence of villi (villous atrophy).

In accordance to previous work [3–5], we consider the four classes Marsh-0 and Marsh-3A to Marsh-3C only, since visible changes in the villi structure can be observed only for classes Marsh-3A to Marsh-3C. In this work we focus on the two-class case only (i.e. Marsh-0 and Marsh-3) since if considering this problem definition, the image data set available is well balanced with respect to the images in each class. Furthermore, this two classes case is most relevant for clinical practice.

The overall prevalence [6] of celiac disease in the USA is about one per cent. Fig. 1 shows example images, captured during standard upper endoscopy.

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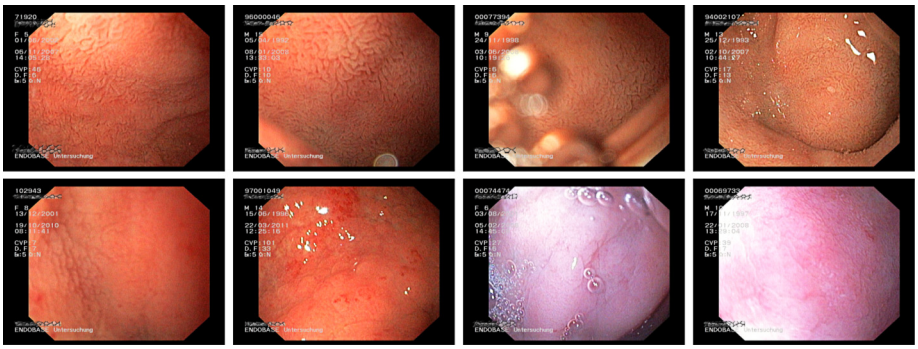

Fig. 1. Endoscopic images of healthy mucosa (top row) clearly showing the villi structure and of diseased mucosa (bottom row). In some regions the markers for celiac disease are visualized well whereas others suffer from strong degradations.

1.2. Computer aided diagnosis

For most computer aided celiac disease diagnosis approaches [3,7–10,4,11], reliable (ideal) image regions (e.g. patches with a size of 128 × 128 pixels) showing discriminative features have to be identified prior to the automated classification. This must be done to get ideal data which is free from strong image degradations as in case of strong degradations the classification accuracy of the decision support system decreases strongly [12,13]. The identification of reliable regions could be done manually [9,10] on the one hand or by means of a computer based method. Existing approach for detection of informative regions [14,15], do not directly focus on a succeeding computer aided diagnosis and are certainly not optimized for celiac disease diagnosis. Although the manual method works effectively if done by experienced medical doctors [13], there are two incentives to use a computer based selection method: First of all, a human interaction during endoscopy is time consuming and annoying which probably leads to a diminished acceptance of the decision support system by physical doctors. Apart from that, especially in case of physicians which are inexperienced, inattentive or just unfamiliar with the (new) decision support system, a weak selection automatically leads to decreased classification accuracies [13]. This can furthermore lead to an even more decreased acceptance of the semi-automated system.

The reason for the decreased classification accuracies in case of randomly or inappropriately selected patches (or if using the complete images) is the vulnerability of image classification methods to various types of degradations which are prevalent in endoscopic images. Recent work [12] showed that image degradations definitely affect the feature extraction stage and consequently lead to a reduced classification accuracy. Such degradations are blur, noise, a lack of contrast, underexposure and overexposure (reflections). They are potentially prevalent in any real world image data, however, endoscopic images are particularly affected because of the difficult capturing conditions. Blur occurs because the difficult handling does not allow to adjust the distance to the surface (mucosa) precisely. Furthermore motion often cannot be prevented. The small sensors used in the endoscopic devices are prone to noise. This liability is amplified in case of underexposure which is caused by the spotty lightning (as endoscopes are equipped with one or two spotty lights). Unfortunately, these spotty lightning not only leads to underexposed regions, but also to overexposed ones as well as small reflexion (bright spots). Example endoscopic images with various kinds of degradations are shown in Fig. 1.

1.3. Contribution

This article collects the two approaches for fully automated celiac disease diagnosis from our previous publications [13,16]. As previous methods for semi-automated celiac disease diagnosis [3,9,10,4,11] are optimized for manually extracted patches with a size of 128 × 128 pixels, focus of work on fully automated diagnosis [13,16] is on the selection of one or more such reliable patches. These reliable patches are sub-images which clearly show markers for a visual distinction (between class Marsh-0 and class Marsh-3) and which do not strongly suffer from image degradations. Thereby, after the selection of reliable patches, methods for semi-automated celiac disease diagnosis can be used to obtain a final decision.

In both papers on fully automated diagnosis, the availability of theoretically numerous small sub-images (in our case patches with a size of 128 × 128 pixels) in each original endoscopic image (768 × 576 pixels) is exploited in order to extract data for subsequent classification. Consequently, the initially required task is to automatically extract numerous potential sub-images (at fixed, predefined positions) distributed over the original endoscopic image. Then, the availability of large data firstly allows to select one best patch per original image as done in the first work on fully automated celiac disease diagnosis [13]. Additionally, it facilitates a redundant processing [16] (i.e. feature extraction and classification) of these multiple available patches aiming at improving the classification accuracy. In order to generate one final decision for each image, these redundant threads have to be fused. This can be done on different levels [17], such as feature-, score- or decision-level as successfully deployed in biometric systems [18,17,19]. As the simple (unweighted) fusion does not lead to improved accuracies, we utilize patch quality measures to introduce a weighting. Based on this weighting, a weighted decision-level as well as a weighted feature-level fusion method is investigated.

In this work, the techniques for fully automated celiac disease diagnosis are characterized as well as extensively analyzed and compared with each other. Therefore, several novel experimental scenarios are created. Additionally, the required com-