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Scale invariant texture descriptors for classifying celiac disease

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ABSTRACT

Scale invariant texture recognition methods are applied for the computer assisted diagnosis of celiac disease. In particular, emphasis is given to techniques enhancing the scale invariance of multi-scale and multi-orientation wavelet transforms and methods based on fractal analysis. After fine-tuning to specific properties of our celiac disease imagery database, which consists of endoscopic images of the duodenum, some scale invariant (and often even viewpoint invariant) methods provide classification results improving the current state of the art. However, not each of the investigated scale invariant methods is applicable successfully to our dataset. Therefore, the scale invariance of the employed approaches is explicitly assessed and it is found that many of the analyzed methods are not as scale invariant as they theoretically should be. Results imply that scale invariance is not a key-feature required for successful classification of our celiac disease dataset.

1. Introduction

Texture analysis is one of the fundamental issues in image processing. The majority of existing texture analysis methods work with the assumption that texture images are acquired from the same viewpoint (Zhang and Tan, 2002). This limitation makes these methods useless for applications, where textures occur with different scales, orientations, or translations. Therefore, scale and orientation invariant texture analysis approaches have been proposed (see Tan (1995) or Zhang and Tan (2002) for surveys on this topic). Invariance is important for many applications in medical image processing, since medical images are often acquired at different scales and viewpoints. This is especially true for endoscopic imagery since mucosal texture is seen from different perspectives and distances to the cavity wall depending on the relative position of the endoscopes tip and the mucosa surface. Fig. 1 illustrates that, depending on the angle between endoscope and the surface (middle case) and the curvature of the surface (rightmost example), different distances between camera and surface may even occur within a single image.

In gastroscopic (and other types of endoscopic) imagery, mucosal texture is usually found with different perspective and scale (see Fig. 3). That means that the mucosal texture shows different spatial scales, depending on the camera perspective and distance to the mucosal wall (see Fig. 1).

As a consequence, endoscopic imagery typically exhibits mucosal texture with different and/or mixed spatial scales, depending on the corresponding acquisition conditions (see Fig. 3 for examples from our celiac disease database).

In this work, we focus on scale invariant texture classification approaches being applied in computer-assisted diagnosis of celiac disease. While most of the used techniques in this work exhibit additional invariance to other transformations like rotation, translation, and illumination, we specifically concentrate on scale invariance for the reasons explained above. The contributions of this manuscript are as follows:

- We apply general purpose scale invariant texture descriptors for the classification of duodenal mucosa texture imagery aiming at the staging of celiac disease.
- Several approaches have been developed to achieve scale (and often orientation) invariance for multi-scale and multi-orientation wavelet transforms. These techniques are mostly applicable to any multi-scale and multi-orientation transform. We employ the Dual-Tree Complex Wavelet Transform (DT-CWT) (Selesnick et al., 2005) instead of the originally proposed transforms and are able to show that our approach works better for the target celiac disease database than other wavelet-type transforms (like e.g. Gabor filters (Fung and Lam, 2009) or steerable pyramids (Montoya-Zegarra et al., 2007) (see Table 3). An additional benefit is the improved ability to compare the different strategies to achieve scale invariance if the underlying transform is the same in all cases.
- We propose a new affine invariant method based on Local Ternary Patterns (LTPs).

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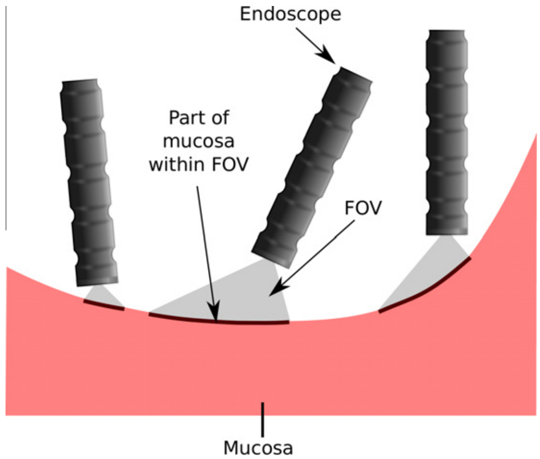


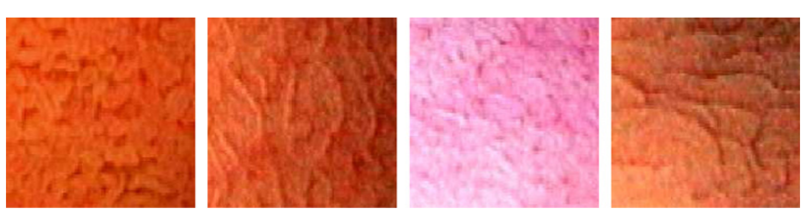
Fig. 1. The field of view (FOV) depending on the endoscopic viewpoint and distance to the mucosal wall.

- We conduct explicit experimental tests for scale invariance for all feature descriptors considered based on the Columbia–Utrecht (CUReT) (Dana et al., 1999) dataset and the Celiac Disease Scale (CDS) database (see Section 6.2.2) following ideas in Varma and Zisserman (2009), revealing that claimed scale invariance cannot be verified for many of the schemes investigated.
- Most approaches are tested for their ability of invariant texture analysis on public databases like Brodatz (Brodatz, 1966), CUReT (Dana et al., 1999), KTH-TIPS (Hayman et al., 2004), or the UIUCTex (Lazebnik et al., 2005) database. Correspondingly, most of the considered methods have been optimized for the corresponding datasets. Hence we have adjusted some of these methods (e.g. using different parameters or replacing parts of the original algorithm) to make them applicable in a sensible manner for the classification of celiac disease (e.g., use of different measures in techniques based on fractal analysis in Section 4 or application of a different clustering strategy for the dense Scale Invariant Feature Transform (SIFT) features in Section 5).
- We show, that methods extracting highly contrast sensitive information work well for the classification of celiac disease, specifically methods based on fractal analysis.

This paper is organized as follows. In Section 2 we briefly introduce the concept of computer-assisted diagnosis of celiac disease by automated classification of duodenal mucosa texture patches and review the corresponding state-of-the-art. In Section 3, we describe strategies to achieve scale invariance for wavelet transforms including the application of the discrete cosine transform (DCT) or the discrete Fourier transform (DFT) to the feature vectors of the wavelet transforms (Häfner et al., 2010; Lo et al., 2004), re-arrangement of feature vectors (cyclic shifting, dominant scale, and slide matching) (Montoya-Zegarra et al., 2007; Lo et al., 2009; Fung and Lam, 2009), or methods that preprocess the image before the wavelet transform is being applied (Pun and Lee, 2003). Section 4 describes techniques based on fractal analysis while Section 5 covers a heterogeneous set of additional approaches to generate scale invariant texture descriptors (e.g. neural nets (Ma et al., 2010; Zhan et al., 2009), SIFT features and region detectors (Fei-Fei and Perona, 2005; Zhang et al., 2006), and multiscale blob features (Xu and Chen, 2006)) as well as a new affine invariant method we propose which is based on scale-normalized Laplacian maxima combined with Local Ternary Patterns (Hegenbart and Uhl, 2013). Experimental results with respect to classification of the celiac disease dataset and with respect to effective scale invariance (by means of the CDS database and parts of the CUReT database) are presented in Section 6. Section 7 concludes our work.

2. Computer-assisted diagnosis of celiac disease

Celiac disease is a complex autoimmune disorder in genetically predisposed individuals of all age groups after introduction of gluten containing food. The gastrointestinal manifestations invariably comprise an inflammatory reaction within 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, hyperplasia of the enteric crypts occurs and the mucosa eventually



(a) Marsh-0 (b) Marsh-3a (c) Marsh-3b (d) Marsh-3c

Fig. 2. Example images for the respective classes.

(a) Marsh-0 (b) Marsh-3a (c) Marsh-3b (d) Marsh-3c

Fig. 3. Images with different perspective and scale.