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The classification of endoscopy images with persistent homology☆,☆

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ABSTRACT

Aiming at the automatic diagnosis of tumors using narrow band imaging (NBI) magnifying endoscopic (ME) images of the stomach, we combine methods from image processing, topology, geometry, and machine learning to classify patterns into three classes: *oval*, *tubular* and *irregular*. Training the algorithm on a small number of images of each type, we achieve a high rate of correct classifications. The analysis of the learning algorithm reveals that a handful of geometric and topological features are responsible for the overwhelming majority of decisions.

1. Introduction

We study magnifying endoscopic (ME) images applied to the diagnosis of diseases in the gastrointestinal tract. The ME technology permits the detailed visualization of the mucosal micro-surface pattern and the vascular architecture to be obtained. For enhanced contrast between vessels and background mucosal surface, we use the narrow band imaging (NBI) system that became available during the last ten years. In combination, ME and NBI make it possible to find and to differentiate suspicious cancerous lesions in the stomach at an early stage during the procedure.

From patterns to diagnoses. For the diagnosis of tumors with NBI-ME, the VS-classification of Yao et al. [18] is widely accepted. It is based on the observed microvascular architecture ('V' for vascular) and microsurface structure ('S' for surface). Both patterns are evaluated independently. According to this classification, there are two types of microvascular patterns

- *regular*, with clearly defined and uniform geometric shape and position of vessels;
- *irregular*, with non-uniform geometric shape and position of vessels.

The first type is typical for the non-neoplastic surface structure of the stomach without malignant changes. For the early stomach cancer, Nakayoshi et al. [19] define two basic types of irregular microvascular pattern

- *fine network pattern*, with a large number of microvessels connected in a fine network;
- *corkscrew pattern*, with vessels of twisted shape that do not join to form a network.

As shown in Table 1, we refine the classification of regular and irregular microvascular patterns by distinguishing between open and closed loops. In the irregular case, the open loops are characteristic of corkscrew patterns, while the closed loops correspond to fine network patterns.

The microstructure of the stomach surface consists of gastric pits and sulci. There are several key components in the microanatomy of the epithelial surface: *crypt opening*, *marginal epithelium*, *intravenous part*. The surface structure of the normal stomach mucosa consists of rounded and oval pits, which histologically correspond to gastric glands. In the NBI vessels become dark and, as a result, we can see the specific pattern of the gastric mucosa as bright areas surrounded by a dark rims; see Fig. 1. The types of microsurface structure we observe are

- *regular*, with marginal epithelium that has uniform geometric shape and size;

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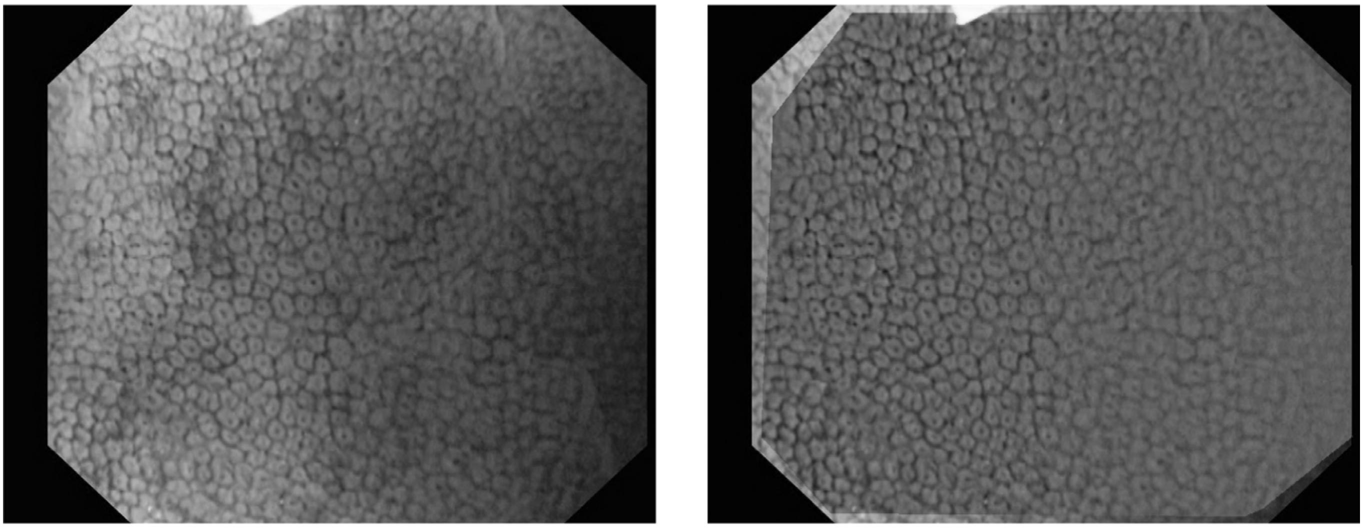

Fig. 1. The microsurface pattern is regular and oval, the microvascular pattern is regular with closed loops. The grayscale image before brightness equalization on the *left* and after the brightness equalization on the *right*.

Table 1
Classification of the medical cases, each represented by a small set of endoscopic images. We write LGD for low-grade dysplasia, HGD for high-grade dysplasia, and AC for adenocarcinoma, with associated probabilities estimated from a small sample of patients at the Yaroslavl Regional Cancer Hospital.

		Vessels			
		Regular		Irregular	
Surface		Closed (%)	Open (%)	Closed (%)	Open (%)
Regular	Oval	LGD – 0 HGD – 0 AC – 0			
	Tubular		LGD – 8.9 HGD – 9.8 AC – 0		
	Villous		LGD – 0 HGD – 0 AC – 0		
Irregular			LGD – 30 HGD – 0 AC – 30	LGD – 28.8 HGD – 42.9 AC – 28.8	LGD – 0 HGD – 57.2 AC – 42.9
Absent				LGD – 0 HGD – 10.3 AC – 89.7	LGD – 0 HGD – 8.3 AC – 91.7

- *irregular*, with marginal epithelium that has non-uniform geometric shape and size.

But it is also possible that the microsurface pattern is *absent*. The combination of microsurface and microvascular patterns defines the probability of one of three types of cancer risk: *low-grade dysplasia*, *high-grade dysplasia*, and *adenocarcinoma*. In our work, we focus on three combinations of patterns

OVAL: oval surface structure combined with regular closed microvessels;
TUBULAR: tube-like surface structure combined with regular open microvessels;
IRREGULAR: without any microsurface structure combined with irregular microvessels.

The first type is indicative of a no risk, second type of a low risk and the third of a high risk for cancer. While the three categories cover only five of the shaded fields in Table 1, this limitation is forced on us by a shortage of image data. With time the database will grow to cover the remaining fields. The methods given in this paper can then be used to solve the correspondingly larger classification problem.

Prior work and results. The medical aspects of our work are discussed in [12], where the structure of images from different parts of the stomach obtained by the NBI technique and relevant types of tumors are described, and in [14], where the irregular pattern of colon mucosa for various cancer stages are explained.

On the computational side, the use of image processing and machine learning techniques to analyze images is wide-spread, but the use of computational topology methods in the analysis is novel. The use of Bayes' Rule to predict the histological structure of mucosa based on endoscopic image analysis predates our paper; see [8], and so does the use of geometric properties, such as the area and perimeter of vessels to diagnose colorectal oncological tumors; see [16]. Closest to our work is that of Häfner's group in Austria; see [5,6,8,9] and additional publications exploring variations of the same theme. The main differences to our work are (i) that they look at endoscopic images of the colon, which in medical practice are easier to classify than images of the stomach, (ii) that they distinguish between two to five classes – compared to three classes in this paper – but in contrast to our data, each of their images represents one uniformly classified surface piece, and (iii) that they do not use topological features, which are essential to the success of our classification efforts.

In summary, the main innovative aspect of our work is the use of topological features derived from the persistent homology of the images. These are essential to achieve our best result of about 89% of correct classification, which is obtained using a selection of three geometric and two topological features.

Outline. Section 2 explains the *methods* used in our approach, discussing the necessary background from image processing in Section 2.1, from computational topology in Section 2.2, from geometry in Section 2.3, and from machine learning in Section 2.4. Section 3 presents the *results* obtained using our approach, discussing the data and test setting in Section 3.1, the selection of features in Section 3.2, and the success rate of our classification algorithm in Section 3.3. Section 4 concludes this paper.

2. Methods

The input data consists of endoscopic color images (BMP and PNG formats, either of size 664 × 528 pixels or 786 × 576 pixels)

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