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Automated diagnosis of celiac disease using DWT and nonlinear features with video capsule endoscopy images

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HIGHLIGHTS

- Automated detection of celiac disease using video capsule images.
- Employed DWT and nonlinear features techniques.
- Accuracy of 86.47% was achieved with the 10-fold cross-validation strategy.
- Accuracy of 85.91% was attained with LOOCV technique.

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ABSTRACT

Celiac disease is a common immune response when gluten is ingested. Over time, this response will impair the lining of the small intestine and result in malabsorption. This could bring about critical health complications. However, the symptoms of celiac disease vary and hence, it is relatively challenging to make an accurate diagnosis. This results in a high percentage of misdiagnoses. Therefore, a computer-aided detection (CAD) system is proposed to overcome the challenges. Hence, this study employed the discrete wavelet transform (DWT) to decompose the video images, after which textural and nonlinear features were extracted. Thereafter, the particle swarm optimization (PSO) was performed to choose 30 optimal features for classification. An accuracy level of 86.47%, and sensitivity and specificity of 88.43% and 84.60%, respectively, was achieved with the 10-fold cross-validation strategy. Moreover, an accuracy of 85.91% was attained with the leave-one-out cross-validation (LOOCV) technique. This methodology demonstrates potential for accurately identifying celiac disease. It can therefore be noted that the developed CAD system may improve the diagnostic performance in the detection of celiac disease, and thus reduce the number of misdiagnoses.

1. Introduction

Celiac disease is a critical lifelong autoimmune condition, whereby the consumption of gluten (protein that is present in barley, rye, and wheat) will damage the small intestine of genetically vulnerable individuals [1]. The disease is due to the inflammatory reaction in the mucosa of the small intestine that is resulted from a dysregulated immune response, stimulated by ingested gluten [2]. Fig. 1 shows some examples of healthy and damaged villi. Intestinal villi consist of millions of finger-like projections extending from the lining of the small intestine, that enable the efficient absorption of nutrients from digested food. When the villi are damaged or inflamed, they become flattened and are unable to absorb nutrients, leading to malabsorption.

This disease affects roughly 1% of the human population globally, although the majority with celiac disease are undiagnosed [3]. Furthermore, the prevalence of this disease is multiplying at a fast rate. Thus, there is a need to develop a proper diagnostic technique to accurately diagnose celiac disease [4]. This is also because it is difficult to diagnose celiac disease, and it is often misdiagnosed. However, if the disease is left untreated, there will be long-term health effects; celiac disease is correlated with having

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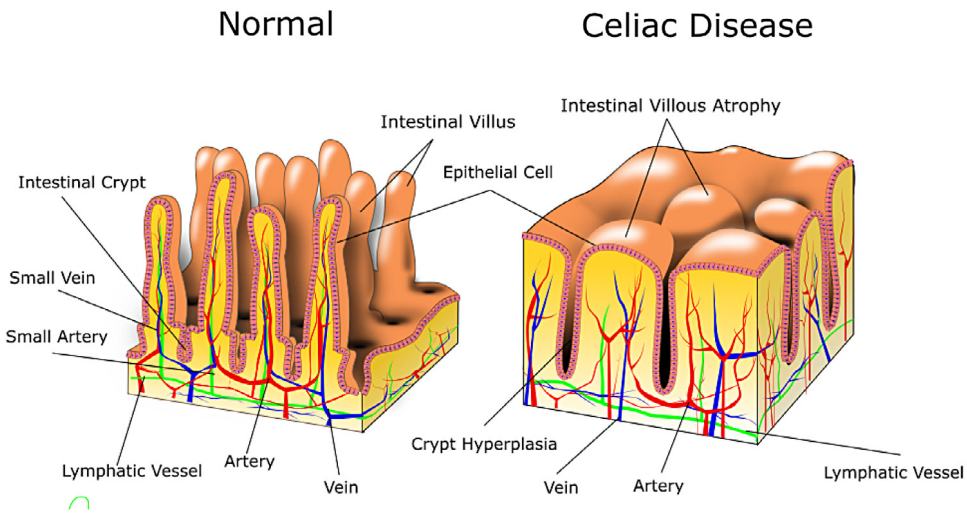

Fig. 1. A representation of (a) healthy and (b) damaged villi.
Source: Adapted from: https://www.dreamstime.com/stock-illustration-celiac-disease-medical-illustration-modification-intestinal-mucosa-subject-image41508355.

a higher probability of developing cancer and it might possibly also contribute to the onset of other autoimmune diseases.

Celiac disease may be divided into classical, non-classical, or silent, as stated by the World Gastroenterology Organization [5].

Classical: This group presents clear signs and symptoms of malabsorption which includes weight loss and diarrhea.

Non-classical: This group experiences slight gastrointestinal symptoms without explicit indications of malabsorption or are present with unassociated symptoms.

Silent: This group is also termed as having asymptomatic celiac disease. No clear symptoms are exhibited but the patients experience villous atrophy within their small intestine.

Presently, endoscopy with biopsy is the gold standard to confirm the diagnosis of celiac disease [6]. Typically, the healthcare professional inspects the duodenum, as it is the entrance to the small intestine, and is considered the area that is often the most affected. However, the procedure is invasive, time-consuming, and costly. By comparison, video capsule endoscopy is a pain-free, noninvasive, and more economical alternative to standard endoscopy [7]. Furthermore, it has portrayed its sensitivity toward the detection of celiac disease, and it can capture images of the entire small intestine. The pill-shaped device, which contains a video camera, is swallowed and subsequently travels through the gastrointestinal tract. A data recorder will be attached to the patient's body and then is removed after eight hours. The pill will be expelled from the body in the stool after one or two days.

Following data acquisition, images obtained from the data recorder are characterized according to Marsh's criterion [8]. Nevertheless, the grading of the endoscopic images is somewhat subjective and is susceptible to inter-operator variabilities. Therefore, it can be relatively challenging to manually diagnose the patients. Moreover, the lack of physician awareness of celiac disease plays a part in the underdiagnosis of the disease. Thus, a computer-aided detection (CAD) system for celiac disease using video capsule endoscopy images is proposed to aid doctors in the diagnosis of the disease. Also, in this study, previous work conducted using video capsule endoscopy are summarized and discussed.

2. Data used

The video capsule images utilized in this work were acquired from 13 control subjects and 13 celiac patients. They were obtained from the Columbia University Medical Center, New York. These subjects swallowed a PillCam that could acquire images of the duodenal mucosa through the passage of the small intestine. Two samples of normal and damaged villi can be observed in Fig. 2.

In this work, two different PillCam devices—the PillCam SB2 (older data) and SB3 (new data) were used. The image acquisition rate is approximately 2 frames per second (constant for SB2 but variable for SB3) and these video clips vary in length (either 100, 200, or 1000 images). These videos have a resolution of 576 x 576 pixels.

Old data: five video clips were obtained from five levels in the small intestine. The levels were approximately the duodenal bulb, duodenum, distal duodenum/proximal jejunum, distal jejunum, and proximal ileum.

New data: three video clips were obtained from three levels—duodenum, jejunum, and ileum.

3. Methodology

Different types of feature extractors were employed in this study to obtain characteristic features to characterize the *two* classes. The proposed CAD algorithm is illustrated in Fig. 3. The input data were first masked and subjected to the discrete wavelet transform (DWT) [9]. After which, various features were employed to extract significant features from the decomposed coefficients. Then, an optimizer technique, the particle swarm optimization (PSO) [10] was implemented to select a set of features for classification. Lastly, two different cross-validation strategies (10-fold and leave-one-out) were employed to validate the detection capability of the proposed technique.

3.1. Pre-processing

Firstly, the border of the video images obtained was masked to remove the wording bordering the image, prior to converting to a grayscale, and then the discrete wavelet transform (DWT) is applied to the images. The masking is done to ensure that the words on the video capsule images will not introduce any bias in the automated decision-making.

Subsequently, DWT was applied to the grayscale images [11–13]. In this study, the mother wavelet bio-orthogonal 3.1 is used to decompose the images up to 3 levels of decompositions with