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Barrett esophagus: guided biopsies taken through digital image processing

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Abstract. The most important problem that Barrett esophagus presents is, undoubtedly, the possibility of its malignization. In order to be sure not only on the occurrence of a Barrett esophagus but also to diagnose its possible complications, it is absolutely necessary to obtain biopsies to make a histological diagnosis. This should be done under endoscopic control to avoid mucus areas that may co-exist within the columnar epithelial, which could lead to a false diagnosis.

In this paper we present a combination of two filters -a chromatic and a frequency filter- aiming at differentiating the various surfaces by highlighting the critical area to prevent false analysis and, consequently, false diagnosis.

1. Introduction

Reflux oesphagitis takes place when the mechanisms existing in the gastro esophageal union fail. When enough time has passed, it can produce complications or turn into a chronic condition. One of the injuries that may appear is called Barrett esophagus, which is considered precancerous. Due to these reasons, the interest in this particular pathology has increased in the last couple of years.

Barrett esophagus is caused by the reflux of gastric juices or intestinal content, which is rich in bilis, towards the esophagus [1]-[10]. This produces an epithelial damage, generally erosions or ulcers, whose ulterior curative process using basal pluripotentials cells, gives place to the different types of columnar epithelials that are seen in said alteration [11].

The first controversial point is to establish the criteria that define Barrett esophagus. Historically, it has been defined as a condition where a variable length of squamous epithelial of the distal esophagus is replaced by columnar epithelium [12]-[16].

There are various factors that complicate this simple definition. The first difficulty lies on knowing where the esophagus ends and the stomach begins. From the anatomical point of view, the gastro esophageal union is determined by the peritoneal reflection, the diaphragmatic hiatus and the muscular beam of the esophagus wall, but these characteristics are not applicable in medical practice [17].

The columnar epithelium of Barrett esophagus is of a heterogeneous nature. It is a kind of mosaic of cells, glands and architectural changes that show variable degrees of maturation towards the
intestinal or gastric epithelium [18][19]. Most studies have been done on biopsy material that gives only a partial view of the injury.

In various studies, the area distribution of the different tissue types has been recognized, with fundic epithelium and of the cardial type localized in the most distal part, and intestinal epithelium localized in the proximity of the metaplastic segment, which is important to know in order to choose the most adequate place for biopsy, even though there may arise exceptions to this localization [20]-[23].

Barrett esophagus is defined as the presence of columnar mucosa with intestinal metaplasia in the esophagus. In real life, the best identifying method is through endoscopic diagnosis. The importance of this point is that the metaplasia of Barrett is a histological criterion rather than an endoscopic one, because it is possible to identify the intestinal metaplasia only with a directed biopsy; that is, looking for areas of dysplasia presenting greater likelihood for neoplasia.

If the importance of Barrett esophagus lies on a high risk for malignant transformation, the treatments to induce its regression and the substitution of metaplastic mucosa by normal squamous epithelium may be the means to eliminate the risk of cancer. Because Barrett epithelium is a complication from chronic gastro-esophageal reflux, an efficient anti-reflux treatment could, theoretically at least, induce regression of the metaplasia. Such treatments include surgery and drugs to reduce gastric acidity.

Therefore, in order not only verify the occurrence of Barrett esophagus, but also to diagnose its possible complications, it is absolutely essential to obtain adequate biopsies that need to be performed under endoscopic control, so as to avoid areas of squamous mucosa that may coexist inside the columnar epithelium, which –in turn- could lead to a false diagnosis. It is of fundamental importance that the specialist performing the endoscopic study be given the means for distinguishing on the image the correct area to draw the biopsy samples, because the borders that envelop the illness are typically not well defined.

On the above accounts, the objective of this work is to use digital image processing to distinguish the different surfaces by highlighting the critical area so as to prevent any false analysis and, consequently, false diagnoses. We propose to use two filters, one chromatic and another a frequency-type filter, to improve the highlighting of endoscopic images and, thus, enable the specialist to differentiate, with a low error margin, the area affected by the transformation of the mucosa characteristics proper of Barrett disease.

2. Materials and Methods

2.1. Frequency filter: Fourier transform

When dealing with filtering an image to obtain an improved one, it is useful to work in the frequency domain. To represent data in the frequency domain, we use Fourier Transforms [24]-[28].

Let \( f(x) \) be a continuous function into the real values. The continuous Fourier Transform of \( f(x) \), denoted as \( F(u) \), is defined by the following equation:

\[
F(u) = \int_{-\infty}^{\infty} f(x) \exp(-j2\pi ux) \, dx \quad \text{where} \quad j = \sqrt{-1}
\]  

(1)

Given the transform \( F(u) \), \( f(x) \) can be obtained using the inverse Fourier transform as:

\[
f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(u) \exp(j2\pi ux) \, du
\]  

(2)

The Fourier transform can be easily extended to the bidimensional case. If \( f(x,y) \) is a continuous and integrable function, its Fourier transform is defined as:

\[
F(u,v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y) \exp(-j2\pi(ux + vy)) \, dx \, dy
\]  

(3)

While the inverse transform is stated as:

\[
F(u,v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x,y) \exp(-j2\pi(ux + vy)) \, dx \, dy
\]  

(4)
While processing digital images, we must work with a finite number of discrete samples. Those samples are the pixels that form an image. The discrete Fourier transform is a special case of the continuous Fourier transform.

The pair of discrete Fourier transforms, for images of size $M \times N$, become:

$$\begin{align}
F(u,v) &= \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \exp\left[-j2\pi \left(\frac{ux}{M} + \frac{vy}{N}\right)\right] \quad \text{for } u = 0,1,2,\ldots,M-1 \quad \text{and} \quad v = 0,1,2,\ldots,N-1 \\
f(x,y) &= \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v) \exp\left[j2\pi \left(\frac{ux}{M} + \frac{vy}{N}\right)\right] \quad \text{for } x = 0,1,2,\ldots,M-1 \quad \text{and} \quad y = 0,1,2,\ldots,N-1
\end{align}$$

Filtering in the frequency domain is very simple, powerful and flexible. The high spatial frequency is associated to abrupt changes, borders, lines, and a certain type of noise. On the contrary, low frequencies in the image are produced by gradual changes of image brightness. From the frequency domain, smoothing or sharpening filters can be designed.

In this work, we used a high-pass filter to sharpen borders, which emphasizes high frequencies. This filter heightens the borders in the tissue edge, which allows the expert to visualize easily the area where the esophageal mucosa has changed.

2.2. Method

This section describes the proposed algorithm.

Step 1: Chromatic filter: A color image is composed by three-color components: red, green and blue. Each component is stored in an MxN matrix, with values ranging between 0 and 255. When combined, the generated image is rendered in RGB colours [28].

The chromatic filter consists in modifying the intensity of each colour; i.e. modifying the values in each matrix by following a certain criteria. This depends on the goal pursued, which is to enhance the areas under study.

For this work the red component was attenuated because it is present heterogeneously in both tissues: the sick and the healthy ones. The blue component is taken to a slightly higher level that the original one. Finally, the green component is increased to its maximum level because it contains most of the high frequency information; it is the one corresponding to the borders.

Step 2: High-pass Filter: A high-pass filter is applied to the Fourier spectrum of each component of the RGB image obtained in the previous step. Such a filter is defined as follows:

$$H(u,v) = \begin{cases} k_0 & \text{si } D(u,v) \leq D_0 \\ k_1 & \text{si } D(u,v) \geq D_0 \end{cases}$$

where: $k_0,k_1,D_0 \in \mathbb{R}_{\geq 0}$ and $D(u,v) = \sqrt{u^2 + v^2}$.

Step 3: Fourier inverse transform: After obtaining the three filtered spectrum components, the Fourier inverse transform is applied, and the color image is re-composed.

Step 4: Visualization of the resulting image.

The algorithm was developed in Matlab® 7. We worked with standard functions of the signal processing library. We used RGB images of 495x294 pixels obtained with a Olympus series 145 endoscope.

3. Results

In this section, we show some application examples. 49 esophagus images suspected of presenting intestinal metaplasia were processed. The chromatic filter was applied by modifying the RGB intensities as follows: the red component was reduced in 20%, the blue component was increased in
20%, and the green component was increased in 100%. High-pass filter parameters were: \( k_o = 0.75 \), \( k_i = 2 \) and \( D_0 = 2 \).

Figure 1-(a) is a typical image of an esophagus endoscopy showing Barrett disease. Sick tissue is not clearly recognizable because the tissue change is masked by the high level of red component that both tissues (sick and healthy ones) present.

Figure 1-(b) shows the image resulting from applying the chromatic filter. On this image, we see that the limits of the tissue change more clearly than in the original image. However, the borders can be highlighted furthermore using the high-pass filter applied to each component of the image obtained after installing the chromatic filter, as can be seen in figure 1-(c). On this latter image, the borders are really clear. Figure 2 shows other examples of endoscopies enhanced with both filters. In every case, the definition of the areas presenting tissue changes has been enhanced successfully.

Currently, this work is at a testing stage. The algorithm is not implemented as yet in real time. However, the preliminary results evaluated by gastroenterologists are very promising.

In the following stage, this algorithm could be implemented in hardware through DSP. The specialist could apply the filter in real time and observe the enhanced image at the moment he is doing the test, and thus select the area for the biopsy at that very moment.

![Figure 1](image1.png)

Figure 1. (a) Original image. (b) Chromatic image. (c) Final image.

![Figure 2](image2.png)

Figure 2. (a)-(c) Original images. (b)-(d) Resulting images obtained after the application of the proposed filter.
4. Conclusions

The objective of Barret esophagus treatment is not to eliminate the symptoms, because it does not produce any signs on its own (excepting when some kind of complication has evolved, e.g. ulcers, stenosis, malignization, etc). Normally, the treatment is intended, instead, to prevent its progression into malady. However, it would be desirable to achieve a total regression using alternative methods. Until this is done, patients should have to be submitted to an adequate control and follow up, while trying to identify and early detect the changes preceding the malignant degeneration, so as to help define an efficient treatment.

This real-time enhancement technique is capable of facilitating the area selection for biopsy tissue extraction by minimizing errors and, thus, ensuring a more efficient malady development control and follow up, especially as regards an early detection of tissue change.

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