ABSTRACT
This paper presents the design of an algorithm that joins different digital image processing techniques; which is applied to endoscopic images of vocal folds. The aim of this research is to provide a method to analyse vascularization level to the doctor, in order to support his diagnosis and change the current subjective view. The processing is based on the FFT Band Pass Filter, the mathematical operations and Hough Transform between treated images, in order to highlight the level of vascularization. The final result will be presented in a results report with the following information: the processed image with veins detected and highlighted by Hough Transform.

KEY WORDS
Hough Transform, Biomedical image processing, Diseases, FFT band pass filter

1. Introduction
Nowadays, the diagnosis of vocal pathologies is expressed by the specialist in a subjective way. Until now, the pathologies which affect vocal fold morphology (for example, nodules, polyps, cysts…) have been successfully detected, and it is possible to obtain relative measurements regarding their size [1]. However, there are others, such as Reinke’s edema [2] (a chronic non-inflammatory uni- or bilateral edema in the two thirds before the vocal cords), which are more difficult to detect because their symptoms are less evident in the image captured.

The vascularization of the vocal cords is an indicator of pathological cords, but the disorder suffered by the patient cannot be diagnosed solely with this information.

The main reason for this research is to provide otolaryngologists with a tool which gives them more information by improving the images, highlighting the vascularization, that is, it enables them to make a diagnosis more easily, a diagnosis that is more reliable.

Because of this, Hough Transform has been used whose effectiveness is very recognized in other applications.

2. Objectives
This paper has been drawn up considering the context of development in clinical medicine and telemedicine [3] applications in the otolaryngology field, which allows the doctor to prepare a pre-diagnosis for those patients whose geographical location (rural areas) or physical situation (disabled) denies them access to hospital for certain medical specialities.

The main aim is to provide the specialist, or even the family doctor, with a work tool that makes objective indicators available to them in support of their diagnosis. The following specific objectives arise from this aim:

- To create a database with records of endoscopic images [4] of both healthy and pathological vocal cords.
- To establish a standardisation and pre-processing of the images in the database.
- To design the algorithm using digital image processing techniques so as to highlight and isolate the veins in the original image.
- To analyze the level of vascularization in the database images using Hough Transform.

3. Methods
A combination of a great many digital image processing techniques was used during this research work, some of which are described below:

3.1 FFT Band Pass Filter
3.1.1 Fast Fourier Transform (FFT)
The Fast Fourier Transform (FFT) is an efficient algorithm for calculating the Discrete Fourier Transform, which is used above all for digital signal processing. The DFT formula (1) is as follows:

\[
F[k] = \sum_{n=0}^{N-1} f[n] e^{-j2\pi nk/N} \quad k = 0, 1, ..., N-1
\]
The great advantage of the FFT is that the number of complex operations changes from $N^2$ to $N\log(N)$, providing the same result as the DFT. The algorithm depends on the factorisation of $N$. However, when working with images, the bi-dimensional DFT must be used, its formula being:

$$X_{k,u} = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) e^{-j2\pi(u/M)x} e^{-j2\pi(u/N)y} \quad k,u = 0,1,\ldots,N-1$$

The matrix calculation will be necessary to make the FFT calculation.

### 3.2 FFT Band Pass Filter

A band pass filter will be used in the frequency domain. In fact, both small and large structures from a determined number of individually different pixels are filtered using a Gaussian filter. The large structures are related to the high frequencies whereas the small structures correspond to low frequencies. According to the number of pixels selected, a version of the image is extracted with the filtering of the large structures. On the other hand, with the small structure filtering, the greater the number of pixels, the smoother the resulting image. Furthermore, horizontal and vertical stripes can be extracted from the image by deleting the Fourier components belonging to the horizontal or vertical axis respectively.

Taking into account the intrinsic characteristics of vocal chord images, the following parameters were used for the research work involved in this paper: filtering large structures down to 19 pixels, filtering small structures up to 1 pixel and the deletion of horizontal stripes.

### 3.3 Hough Transform

The Hough transform [5] (developed by Paul Hough and patented by IBM) is a technique which can be used to isolate features [6] of a particular shape within an image. Because it requires that the desired features be specified in some parametric form, the Hough transform is most commonly used for the detection of regular curves such as lines, circles, ellipses, etc. It retains many applications, as most manufactured parts (and many anatomical parts investigated in medical imagery) contain feature boundaries which can be described by regular curves. The main advantage of the Hough transform technique is that it is tolerant of gaps in feature boundary descriptions and is relatively unaffected by image noise.

The Hough technique is particularly useful for computing a global description of a feature, where the number of solution classes need not be known a priori, given local measurements. The motivating idea behind the Hough technique for line detection [7] is that each input measurement indicates its contribution to a globally consistent solution.

We can analytically describe a line segment in a number of forms. However, a convenient equation for describing a set of lines uses parametric or normal notion:

$$x \cos \theta + y \sin \theta = r$$

where $r$ is the length of a normal from the origin to this line and $\theta$ is the orientation of $r$ with respect to the X-axis.

In an image analysis context, the coordinates of the point(s) of edge segments in the image are known and therefore serve as constants in the parametric line equation, while $r$ and $\theta$ are the unknown variables we seek.

If we plot the possible $(r, \theta)$ (see in Figure 1) values defined by each $(x_i,y_i)$ points in cartesian image space map to curves (i.e. sinusoids) in the polar Hough parameter space.

This point-to-curve transformation is the Hough transformation for straight lines.

![Figure 1. Hough Transform point definition](image)

### 4. Design

The algorithms described below (in Figure 2), have been tested with a database of 10 patients. 5 of them has healthy vocal folds and the others have different vocal pathologies.

#### 4.1 Vascularization Measure Algorithm

In this section the block that computes the vascularization algorithm is explained. The first thing to be pointed out is that the original image must be in the RGB colour model, as can be seen in Figure 3a. Figure 2 shows that two differentiated parts can be distinguished within the design produced: the pre-processing and the processing itself. The former requires the original image to be adjusted according to the characteristics of the processing to be carried out, and the latter is based on performing the suitable mathematical transforms that allow the final purpose to be achieved.
4.1.1 Pre-processing stage
The first transform to be performed is to change the image to 8 bits. Then a division is made into three images of 8 bits containing the components of each channel (Red, Green and Blue). The blue component is going to be used due to past experience and because the veins are more efficiently highlighted this way. The size of the image must then be changed so that all images are of the same resolution: 350 x 300 pixels. In fact, the process is independent from the resolution, but as it is necessary to compare the results of several images, the same resolution needs to be established for all of them. Moreover, the brightness and contrast of the image also need to be adjusted.

By means of this process, what is sought is the highlighting of veins in the image, so that they can be more easily detected in the following stage. The result can be seen in Figure 3b.

4.1.2 Processing stage
One of the most commonly used tools in signal processing is the FFT (Fast Fourier Transform), as it is necessary to work in the domain of frequency on certain occasions. In digital image processing one of the most frequently used applications of the FFT is that of highlighting the variations within an image, for example, in order to see how the position of an object varies between two consecutive frames.

As the final aim of this section is to manage to isolate the veins, use of the FFT is essential. This process is carried out by using a Band Pass Filter in the frequency domain.

The veins in vocal cords are small in size, whether the images are from patients with or without some kind of pathology. It is therefore necessary to apply this filtering to the pre-processing image twice, that is, the pre-processing image must first be filtered, and then the result of this first filtering must, in turn, also be filtered, so that the final result is enhanced, as can be appreciated in Figure 4a.

The filtered image must be added to the pre-processed image, thanks to which it can be observed that the areas where there was a variation in pixel value -going from a muscular area to a vein- maintain their pre-processed image value. However, other areas of the image verge on white values. It is also necessary to carry out an equalisation of this image, so as to ensure that the distribution of pixel values is uniform. This task was performed by taking the square root of the original histogram values as a reference. The result of the equalisation can be seen in Figure 4b.

Finally, the equalised image must be subtracted from the pre-processed image in order to be able to better appreciate the degree of vascularization as regards the original image. The process is similar to the previous one: the pixel values not belonging to veins tend to have white values (255), and therefore, the result of the subtraction verges on zero, that is, on black values. On the other hand, the pixels of the veins end up with intermediate values.

Figure 2. Vascularization Process Flow chart.
Figure 3. a) The original image. b) The pre-processed image

Figure 4. a) Image after FFT band pass filter applied. b) Equalization of the added image.

Now an edge detection is applied to the image in order to eliminate the useless data using a Canny filter. The next step is to make the Hough Transform. Then, it is necessary to found the peaks of the Hough Transform. These peaks mean what points are supposed to be a line. The lines are computed, using the \( \theta \) and \( r \) calculated in the Hough Transform.

At last, the lines are put over the processed image enhancing the veins.

Figure 5. a) Final result. b) Hough Transform.

5. Results

In this chapter the results obtained from the digital processing of the signal applied to images are described with the aim of determining which a way to help the doctor to obtain a diagnosis.

The obtained results with regard to vascularization, are presented in the table below:

<table>
<thead>
<tr>
<th>Pre-processed Images</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image 1</td>
<td><img src="image1.png" alt="Image 1" /></td>
</tr>
<tr>
<td>Image 2</td>
<td><img src="image2.png" alt="Image 2" /></td>
</tr>
<tr>
<td>Image 3</td>
<td><img src="image3.png" alt="Image 3" /></td>
</tr>
</tbody>
</table>

Table 1

Final results of the vascularization algorithm.

In the cases where vascularization lines (Image 2 and image 3, in the previous table) do not exist, Hough Transform just highlights the edges of vocal folds themselves because there are no veins inside them.

In image 1, it can be seen vocal folds with high degree of vascularization and the results offered to the specialist show the most important veins highlighted.

6. Conclusion

This study is part of a complete design of an automated diagnosis application with which it will be possible to detect present-day morphologic problems of the vocal folds.

The measurement of vascularization with digital image processing techniques is very innovative, and it is very useful to the specialist.

Actually, the conclusion is very satisfactory because the specialist could add the original and the result images, highlighting the veins and generating a final report which may include the objective measurements provided by the application.
Nowadays, new techniques of digital image processing are been used in the study of the vascularization level measurement, like the Wavelet Transform. It is used for obtaining the most meaningful data of the image [8].

Acknowledgement

The authors wish to acknowledge the University of Deusto, which kindly lent infrastructures and material for this research work. In particular, we are thankful to Doctor Agustín Pérez Izquierdo, otholaryngologist at Basurto Hospital in Bilbao, who helps our research group with recording his patients’ images and videos.

References