Keynote Paper

Invariant correlation by using vectorial signatures and spectral index

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ABSTRACT

In this paper a non-linear correlation methodology to recognize objects is used. This new system is invariant to position, rotation and scale. This digital system has a low computational cost to achieve a significant reduction of processed information by using vectorial signatures. The invariant vectorial signatures are obtained from the information from both the target image as well as problem image. In this way, each image has its rotational and scale vectorial signature obtained through several mathematical transformations such as scale and Fourier transform. So, this method uses the great capacities from the non-linear filters to discriminate between similar objects. Vectorial signatures are compared using non-linear correlation. The result of this comparison is shown in a bi-dimensional plane where the x axis is the result of the rotation correlation and the y axis is the result of the scale correlation. In addition, spectral index and vectorial signature index are obtained through several mathematical transformations in order to recognize the objects in a more simple way. 21 different fossil diatoms images were used. The results obtained are analyzed and discussed.

Keywords: non-linear correlation, pattern recognition, vectorial signatures, spectral index, vectorial signature index

1. INTRODUCTION

Pattern recognition is an expanding field in optical and computer research since the first appearance of the classical matched filter[1]. Many advances have been made using different types of mathematical transformation taking advantage of their different properties such as invariance to position, rotation, and scale[2-10]. In the last years, the methods of correlation are the most used techniques in a wide variety of areas[10-17]. Recognition systems have achieved a high degree of reliability in objects recognition in addition to a low computational cost[18-19].

In this paper, vectorial signatures are compared using a non-linear correlation. However, two new methodologies based on spectral and vectorial signatures index are presented. Spectral and vectorial signatures index use the original image characteristic as well as the properties of mathematical transformations such as Fourier and scale transform resulting in the identification of the object in a more simple way. Also, the image information is radically reduced. These new methodological variations are used to recognize fossil diatoms, but can be used for recognition of any object. Fossil diatoms are photosynthetic organism that live in freshwater or marine, constitute a very important part of phytoplankton.

2. NON-LINEAR CORRELATION WITH VECTORIAL SIGNATURES

Figure 1 shows the algorithm used in this work. Step 1 and 2 follow the methodology described in Lerma-

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Aragón and Álvarez-Borrego[18]. This system is invariant to position, rotation and scale. The scale transform is given by[20]

$$D(c_\lambda, c_\theta) = \frac{1}{\sqrt{2\pi}} \int_0^\infty \int_0^{2\pi} e^{\lambda/2} f(\lambda, \theta) e^{\left[-j\left(\lambda_{c_\lambda} + \theta_{c_\theta}\right)\right]} d\lambda d\theta \quad , \tag{1}$$

where $\lambda = \ln r$ (r is the radial coordinate).

The non-linear filter is defined by[21]

$$NF = |F(u,v)|^k e^{-i\rho(u,v)} \quad , \quad 0 < k < 1 \, . \tag{2}$$

Equation (2) is applied in steps 3 and 4 (Figure 1) to the target and the problem image in order to obtain the correlation plane (step 5). In this system was used $k = 0.3$.

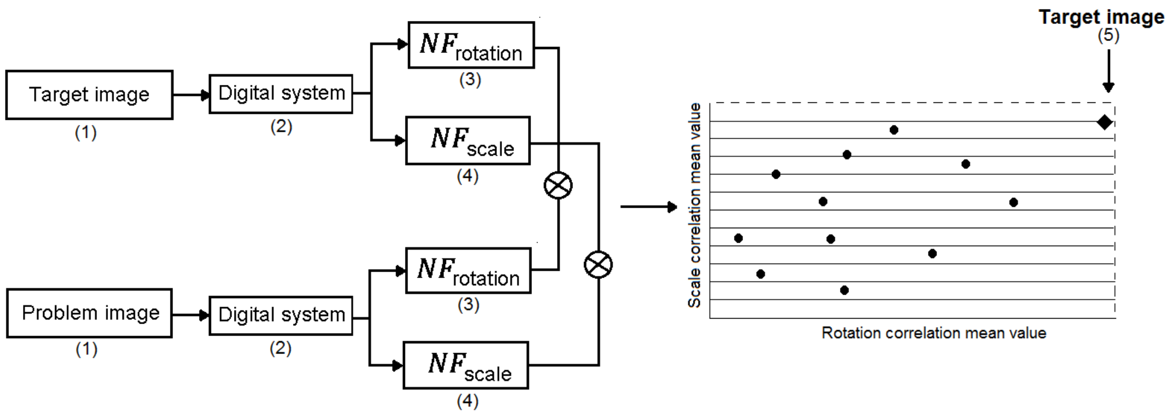

Figure 1. Output bidimensional correlation plane.

3. SPECTRAL AND VECTORIAL SIGNATURE INDEX

3.1 Spectral index

The procedure to obtain spectral index ($Index_1$ and $Index_2$) is shown in Figure 2. Figure 2 (a) shows the procedure to obtain $Index_1$. First, the target image is denoted by $f(x, y)$. Thus, if each value of this function (without taking into account the background) is summed, a representative value for this image is obtained which will be conserved even though the image is rotated, in this way invariance to rotation is obtained. In the step (1) this summation is denoted by $Volume$ and it is calculated with the next equation:

$$Volume = \sum_x \sum_y f(x, y) \quad . \tag{3}$$

The function $Area$ is calculated (step 2) and after these two steps $Index_1$ is defined by (step 3):

$$Index_1 = Volume / Area \quad . \tag{4}$$

Equation (4) is invariant to scale. The procedure to calculate $Index_2$ is shown in Figure 2 (b). Steps 1 to 5 are described in Lerma-Aragón and Álvarez-Borrego[18]. So, $Index_2$ is defined by the next equation (step 6):

$$Index_2 = \sum_{c_\lambda}\sum_{c_\theta}\left|D(c_\lambda, c_\theta)\right| \quad , \tag{5}$$

where $\left|D(c_\lambda, c_\theta)\right|$ represents the modulus of the scale transform. The object to be recognized will not overlap with different objects in the output correlation plane.

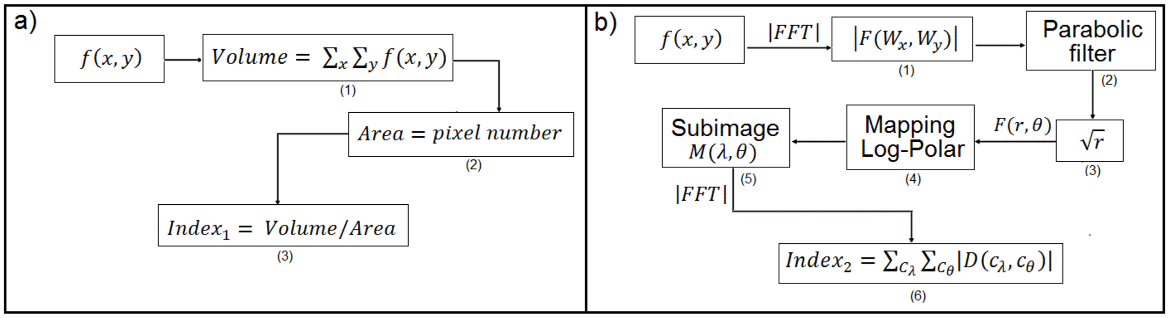

Figure 2. Procedure to obtain a) $Index_1$ and b) $Index_2$.

3.2 Vectorial signature index

The vectorial signature index is a value that represents the vectorial signature obtained with the procedure shown in figure 3. The steps to obtain the rotation and scale vectorial signatures (steps 1 to 9) were explained in Lerma-Aragón and Álvarez-Borrego[18]. Thus, when the vectorial signatures are obtained (step 8 and 9), a summation of each value that belongs to the rotation and scale vectorial signature is performed with the next equations (Steps 10 and 11):

$$Sum_t = \sum_{W_t} V_1(W_t) \quad , \tag{6}$$

$$Sum_s = \sum_{W_s} V_2(W_s) \quad . \tag{7}$$

So, vectorial signature index are defined as follows (step 12 and 13):

$$Index_R = Sum_t \cdot A \quad , \tag{8}$$

$$Index_S = Sum_s \cdot A \quad , \tag{9}$$

where $A = Index_1 \cdot Index_2$.

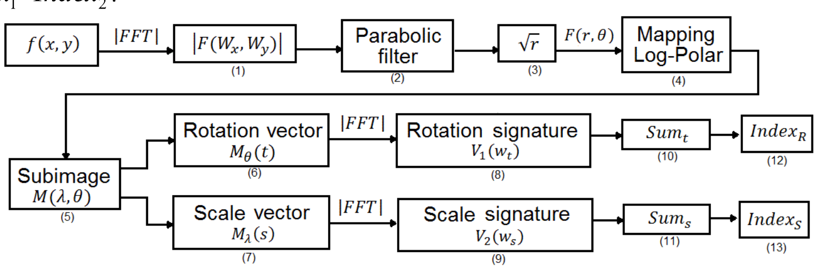

Figure 3. Vectorial signature index procedure.

4. COMPUTER SIMULATIONS

To evaluate the performance of the digital system, 21 different kind of fossil diatoms were used (figure 4)[22]. Each image was rotated 180 deg in increments of 1deg and scaled from 75% to 125% in increments of 1%. An image bank of 4851 images was obtained.

4.1 Non-linear correlation by using vectorial signatures of 21 fossils diatoms

Thus, each problem image (image that could be or not the target image) goes through the procedure shown in (figure 1) and each vectorial signature (rotation vectorial signature and scale vectorial signature) was compared using the non-linear correlation (*k*-law) between the target image and the problem image. Figure 5 shows the output correlation plane taking the diatom *Actinocyclus ellipticus morenensis* as target image. Statistic was performed and the mean value ±2SE (two standard error) was calculated. This algorithm has at least a 95.4% level of confidence for this case. In order to verify the results, each diatom was selected as target image. All the cases had at least 95.4% of confidence level (results are not shown).

4.2 Identification of fossil diatoms by using spectral index

In the spectral index methodology, each image goes through the procedure showed in Figure 2 to obtain $Index_1$ e $Index_2$. Figure 6 shows an example of the identification plane using *Actinocyclus ingens* as target image which is 100% identified without any kind of overlap regardless if it is rotated or scaled. Also, the results obtained selecting each diatom as a target image showed a clear identification with a confidence level greater than 95.4%.

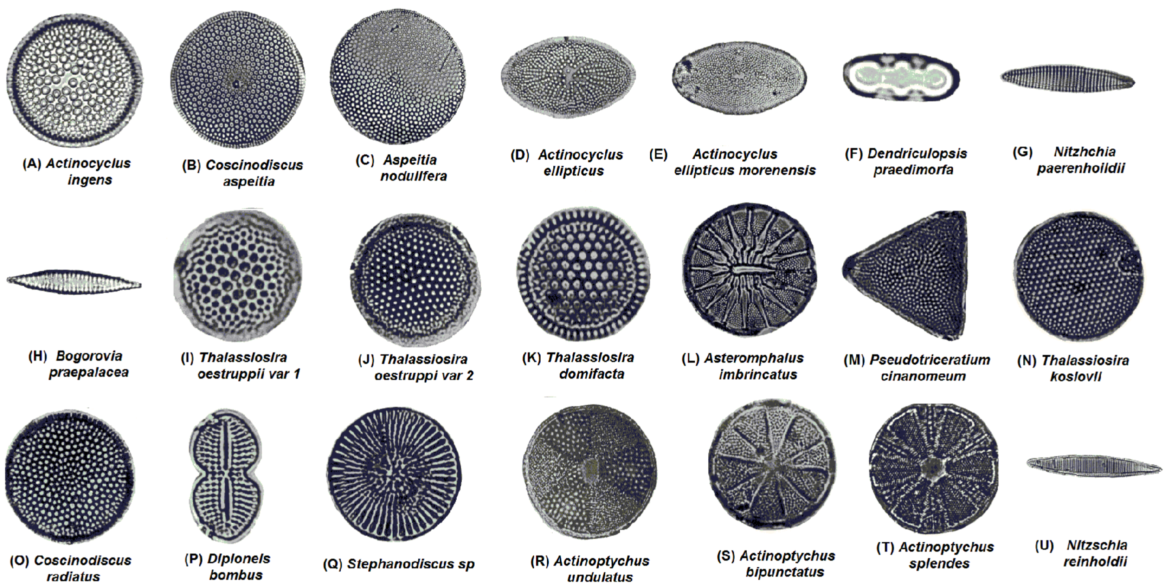

Figure 4. Species of diatoms used in this study.

4.3 Identification of fossil diatoms by using vectorial signatures index

In the case of the vectorial signatures index each image goes through the procedure shown in figure 3 to obtain $Index_R$ and $Index_S$. An example of the identification plane using *Pseudotriceratium cinanomeum* like target image is shown in Figure 7. 99% of the cases presented at least 95.4% of confidence level and just 1% has a lower confidence level (results are not shown).

5. CONCLUSIONS

The first two methodologies showed that it is possible to identify 21 fossil diatoms with a confidence level of 95.4%. Spectral index were introduced in order to recognize diatoms in a more simple way and with a lower computational cost. Finally, vectorial signatures index were used as identification tool and the results obtained were very similar than the spectral index methodology in terms of computational cost. The 99% of the cases presented a 95.4% of confidence level and just 1% had a lower confidence level.

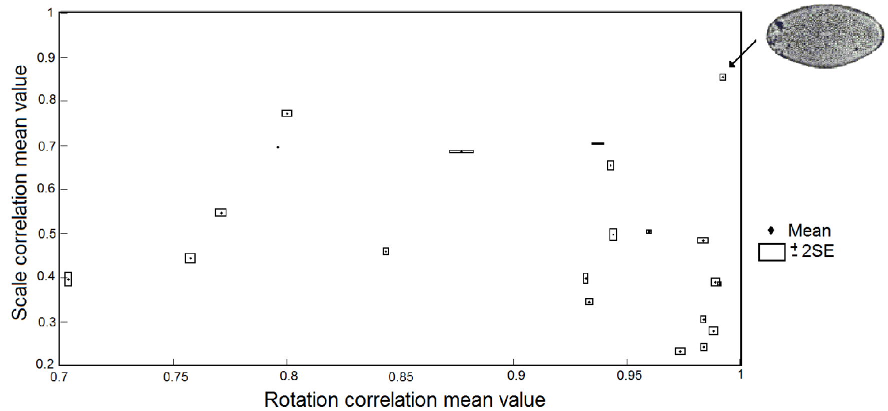

Figure 5.- Output correlation plane taking *Actinocyclus ellipticus morenensis* as target image

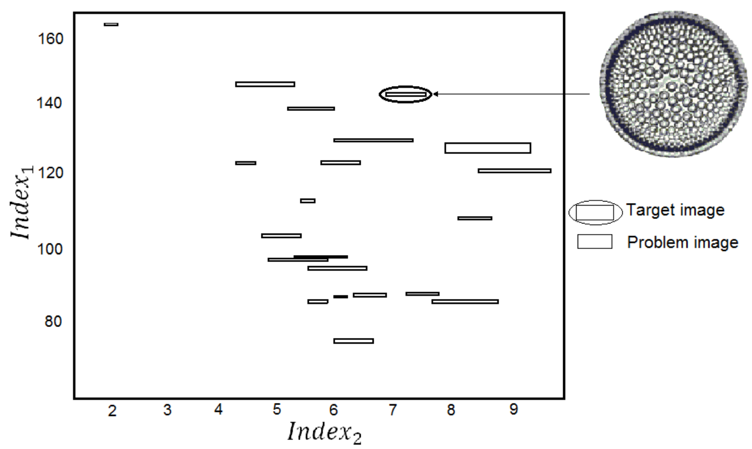

Figure 6.- Output plane obtained from the procedure shown in Figure 2.

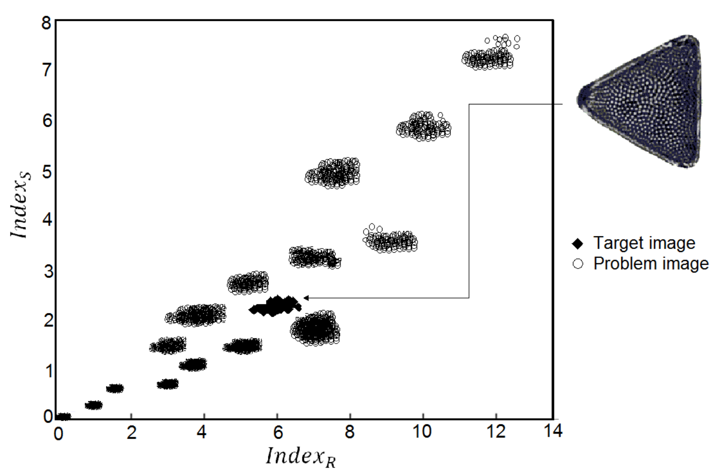

Figure 7. Output plane obtained from the procedure shown in Figure 3.

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