XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

A NOVEL ALGORITHM FOR THE AUTHENTICATION OF INDIVIDUALS THROUGH RETINAL VASCULAR PATTERN RECOGNITION

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Abstract: This paper describes an original numerical procedure for the recognition of images applied to the case of individuals' authentication by using biometric pattern, like the retinal vascular one. Because of the statistical nature of the recognition procedure, the 2x2 *confusion matrix*, typical of decision tests for binary classification models, is here considered in order to evaluate the performances of the proposed *matching algorithm.* An ad hoc procedure is then performed both to build the templates of reference database and to evaluate the threshold for the final decision test.

Keywords: biometric authentication, bio-pattern recognition, matching algorithm

1. INTRODUCTION

Reliability of human identification systems represents a crucial factor in matter of safety and privacy [1]. Anyone's identity is ascertained basing on a number of information required by the system of identification itself. For this reason, any individual must know (e.g. password), own (e.g. keys, chips and so on) and/or be (e.g. biometric features) [2], [3] in order to be recognized and confirmed by the system.

Biometry allows two forms of individual recognition; the first one consists in verifying someone's declared identity (authentication), the second form consists in establishing with high confidence the identity of an unknown individual (identification). Both the two forms of recognition require a specific methodology: the authentication requires the matching between the information acquired in a given moment (e.g. live-scan, password, chip, etc.) and the information associated with that individual uploaded from an opportune database; the identification instead requires a series of comparisons between the information acquired from the individual and a set of different information stored in a central database, searching for his presence. In both the cases, the individual is recognized if the matching succeeds, on the basis of some criteria to be specified.

Biometry is essentially a technology of bio-pattern comparison, which allows individual's recognition through the verification of specific biometric features [4], [5]. Biometric recognition systems allow individual's authentication and identification by the measurement of some biometric variables that are compared, using suitable algorithms, with the homolog ones already present in the system database.

- Usually, a simple biometric system consists of four steps:
- Biometric data acquisition through a sensor;
- Data extraction and processing;
- Bio-pattern matching, where testing images are compared against templates stored in an ad hoc database;
- Decision-making phase, where individual's identity is established, or a claimed identity is accepted or rejected.

It has been demonstrated [6], [7] that the retinal vascular pattern of each individual has characteristics of universality, uniqueness and invariability, right as the fingerprints. Among these features, retina may provide higher level of security due to its inherent robustness against impostures. Further, human retinal pattern experiences less modification during the life. In spite of these properties, retina has not been frequently used in biometric systems mainly because of technological constraints of the conventional equipment more easily available in the market [8], [9]. This is the reason why, in the field of research, most of the work is done testing algorithms on retinal images already stored in publicly-available database [10].

Retinal scanning is considered to be one of the most accurate techniques for individual identification. More specifically, retinal biometric identification allows individual's recognition using the image of the retinal blood vessels pattern obtained by an infrared camera (retinal scanning device) that collects data from the contrast of the back-scattered light from retinal blood vessels and eye fundus [11]. The image is so processed, in order to increase the discernibility of retinal vascular pattern and its ramifications (standardized segmentation procedure), and then compared with the reference ones (templates) enclosed in the database (matching procedure). This technique allows a rapid and efficient recognition.

Many researchers have made the greatest efforts in searching for always more efficient segmentation procedures of the vascular pattern from retinal images [12], [13], [14], [15] and [16]. Many algorithms have been proposed, but good quality results often come out in the face of high computational costs only.

In this paper, an effort has instead made to achieve an original algorithm for the recognition of binary images (thus, already segmented) applied to the case of individual's authentication through the use of his retinal vascular pattern, that has been established to be reliable and robust against impostures. At this aim, a procedure is also suggested to structure an opportune database of templates of reference, which can provides the optimal threshold for the matching algorithm itself.

2. SEGMENTATION ALGORITHM

In [17], M. A. Amin and H. Yan have developed a new segmentation method of blood pattern, which has the main advantage of obtaining segmentation of the scanned image almost in real time, unfortunately disfavouring the image quality.

This technique exploits the RGB image green channel of the retina, Fig.1, as the green channel is less easily masked by noise, while the red and the blue ones do not offer enough contrast between retinal blood pattern and the eye fundus. This method is based on the idea of the phase congruency of the images and takes on other methods based on local energy [18], [19].

Figure 1. RGB image from DRIVE database [20].

The principal criterion is identifying those values at which the spectral Fourier components are maximized in phase, so generating a filtered image. Then, a binary threshold has to be applied to it in order to obtain the segmentation of retinal blood pattern. In this paper, have been utilized the images stored in the DRIVE database and segmented by Amin and Yan's algorithm.

DRIVE database: The Digital Retinal Images for Vessel Extraction (DRIVE) database [20], consists of 40 retinal images, acquired using a Canon CR5 non-mydriatic 3CCd camera with a 45 degree FOV; the images have been cropped around the FOV, Fig. 1. Each image has been captured using 8 bits per colour plane at 768 by 584 pixels, and then stored at 565 by 585 pixels after cropping. The set of images has been divided into training and test set, each containing 20 images.

3. MATCHING ALGORITHM

The algorithm, developed on Matlab® environment, transforms the binary image into a matrix which dimensions equal the number of pixels of the image itself: in the present case, only ten 565 by 584 pixels images have been chosen from DRIVE database to result in 565 by 584 matrixes, so allowing to construct the working database (WDB), as explained further on. The matching algorithm is simply based on the use of the logical operator ex-or (EXOR) and has been tested on the binary images stored in the WDB and on other test images from DRIVE database but not included in the WDB. The EXOR operator works on the image to be verified and each one of the images stored in the WDB. Each comparison results in a Boolean matrix, where 0 indicates no discrepancy between the homolog pixels of the images under test, and 1 the contrary. In Fig.2, the third image is the ex-or matrix coming out from the comparison of the first two images: the white dots represent its "1" elements.

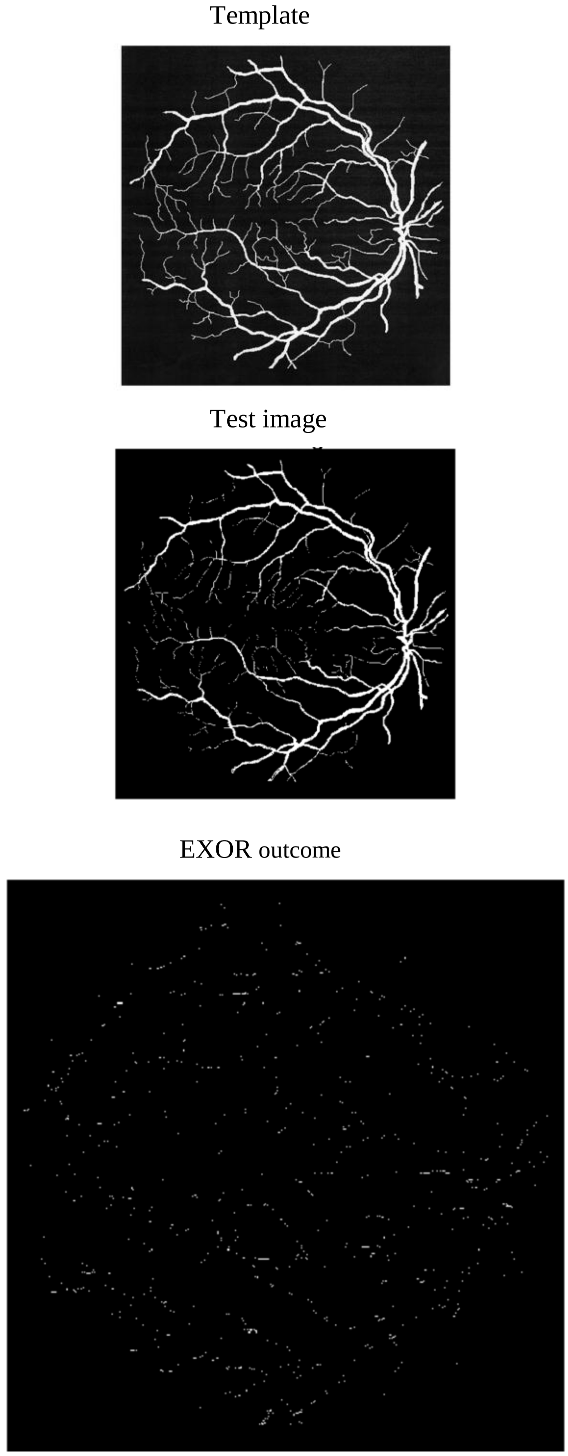

Figure 2. Example of the EXOR application

Adding up all the elements of the matrix, a number is obtained as total sum of the dissimilar pixels between the couple of compared images: it defines the matching score.

To each Boolean matrix coming out from the EXOR operation between the test image and those ones in the WDB a matching score is so associated.

The minimum score evaluated is then compared with the chosen threshold, so establishing the presence of the test image in the WDB when it results smaller than the threshold; on the contrary that image is classified absent and thus not authenticated.

The choice of a proper threshold has to be devised in order to get the lowest false negative and false positive rates.

WDB structure: The work database is here formed by only ten images (templates) for simplicity, built as follow. Each template results from the comparative analysis of n different B&W scanning of the same image:

from the n binary matrices so obtained, a new Boolean matrix is derived, where each element, x_(i,j), is given by the Boolean value 1 or 0, depending on its maximum frequency of occurrence in the homolog elements of the n matrices. This new matrix is called the maximum occurrence matrix, which is taken as template of the WDB. This procedure is a sort of calibration of the identification algorithm.

Now, the threshold can be established using again the EXOR operator between each template and each one of the n matrixes generating it, as previously described. Each EXOR comparison provides a score and thus a score vector is obtained for each template of the WDB, which maximum value is selected as the maximum error allowed for the recognition (the intent is avoiding a too strong filter for the acceptance of positive events and so to guarantee as the lowest false negative and false positive rates as possible). The threshold of the algorithm, then, is given by the maximum value among the maximum scores evaluated for all the WDB templates.

4. ALGORITHM PERFORMANCE

Reliability is the most important factor for establishing the level of efficiency of a biometric system. That is assessed on the basis of two consideration made during the authentication of a biometrical feature:

- if an individual is identified and successfully recognized, two different scenarios are possible: the recognition is a true positive or a false one respectively;
- if an individual is identified as unrecognized, still two cases arise: the system has been wrong, so generating a false alarm, or the person not recognized is in fact not present in the database, true negative recognition or false one, respectively.

So, two types of errors can be distinguished:

- FPR (False Positive Rate): false permissions percentage, corresponds to probability of acceptance for a not authorized individual
- FNR (False Negative Rate): false rejects percentage corresponds to the probability to reject a person that has instead to be authorized.

In decision test, given a classifier and a test set (set of instance), the table that reports the number of false positives, false negatives, true positives, and true negatives is called confusion matrix [21]. The confusion matrix, for a binary classification model (see Table I), is a 2 by 2 matrix that displays the number of correct and incorrect predictions made by the model compared with the actual classifications in the test data.

From that table the algorithm performances can be evaluated as:

$$sensitivity = TPR(\%) = \frac{TP}{TP+FN} \qquad (1)$$

that measures the proportion of actual positives which are correctly identified as such

$$specificity = 1 - FPR(\%) = 1 - \frac{FP}{FP+TN} \qquad (2)$$

that measures the proportion of negatives which are correctly identified as such.

TABLE I. CONFUSION MATRIX

		Condition		
		P	**N**	
Test outcome	***p***	***TRUE POSITIVE* (TP)**	***FALSE POSITIVE* (FP)**	***Positive predictive value (PPV)***
	n	***FALSE NEGATIVE* (FN)**	***TRUE NEGATIVE* (TN)**	***Negative predictive value (NPV)***
		Sensitivity	***Specificity***	

Additional terms can be further estimated as:

$$accuracy = \frac{TP+TN}{(TP+TN+FP+FN)} \qquad (3)$$

and

$$precision = PPV = \frac{TP}{TP+FP} \qquad (4)$$

where accuracy is the proportion of true results, either true positive or true negative, to the total outcomes in an experiment, so that it can be seen as the degree of trueness of a decision test; precision, instead, tells how much the algorithm is able to return more relevant results than irrelevant, and then it represents a measure of quality.

5. EXPERIMENTAL RESULTS

To test the proposed algorithm, a WDB has been built formed by 10 model images (templates) each of which has been obtained from n=10 different scanning of the same image (taken from DRIVE database), to provide the corresponding maximum occurrence matrices as shown on Fig. 3

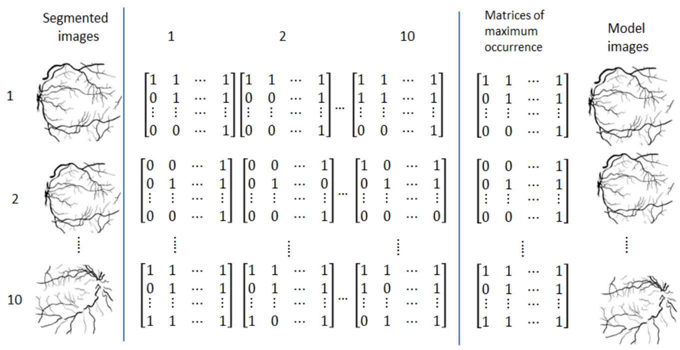

Figure 3. Database structure

Then, has been established a sample of 27 images scanned from the 10 WDB originals and 23 other retinal images scanned directly from DRIVE database images but not present in the WDB. The resultant confusion matrices of the test is shown in the following Table II, for 7 different threshold values chosen around the optimum value, given by the WDB construction procedure, as described in the 3rd paragraph.

TABLE II. CONFUSION MATRICES FOR 7 DIFFERENT THRESHOLDS OF THE TEST

I threshold	
TP = 1	*FP = 0*
FN = 26	*TN = 23*
II threshold	
TP = 10	*FP = 1*
FN = 17	*TN = 22*
III threshold	
TP = 13	*FP = 1*
FN = 14	*TN = 22*
IV threshold	
TP = 15	*FP = 1*
FN = 12	*TN = 22*

V threshold	
TP = 20	***FP = 2***
FN = 7	***TN = 21***
VI threshold	
TP = 26	*FP = 3*
FN = 1	*TN = 20*
VII threshold	
TP = 27	*FP = 23*
FN = 0	*TN = 0*

From the Table II, it is easy to verify that the optimum threshold estimated by the algorithm provides minimum FPR despite of a possible significant greater FNR, for the benefit of security, where that is relevant, despite of the sensitivity. The optimum threshold (the fifth threshold in Tab. II) is the point highlighted on the curves shown in Fig.4.

The performances obtained from the test are:

$$sensitivity = 0.74$$
$$accuracy = 0.82$$
$$precision = 0.91$$

Thus, the algorithm provides high precision, very good accuracy and good sensitivity, such performances depending from the established threshold, so proving it very efficient for the while simple experiment here considered (authentication procedure). An immediate and significant graphical representation can be given by the precision-recall versus ROC curves.

Precision-recall versus ROC curves: As well-know, the Receiver Operating Characteristic (ROC) curve [22] is insensitive to the changes of all confusion matrix class distributions. Thus, the ROC is a peculiarity of the experiment considered and its each point gives the sensitivity (also said Recall) and FPR for a well-defined threshold; equally, Precision-Recall curve provides the algorithm performances more explicitly. In Fig.4, are shown the mirrored ROC curve and the Precision-Recall curve for the different 7 decision thresholds of Table II .

A comment should be done about the impact of the parameter n on the performances of the matching algorithm, as it incurs into the building of the maximum occurrence matrix and affects the value of the threshold and then the performances of the algorithm itself. From the still few evaluations performed at this aim, it has been noticed that the decrease of n does not affect the precision, which has shown an insignificant variation, but rather the accuracy and sensitivity which decrease too.

Further, it has to be considered that, although the images of the WDB, deriving from a scanning process on a commercial equipment (considering also the type of segmentation experienced) are marked by poor quality, the authentication algorithm presents however high precision and accuracy, being n relatively low too.

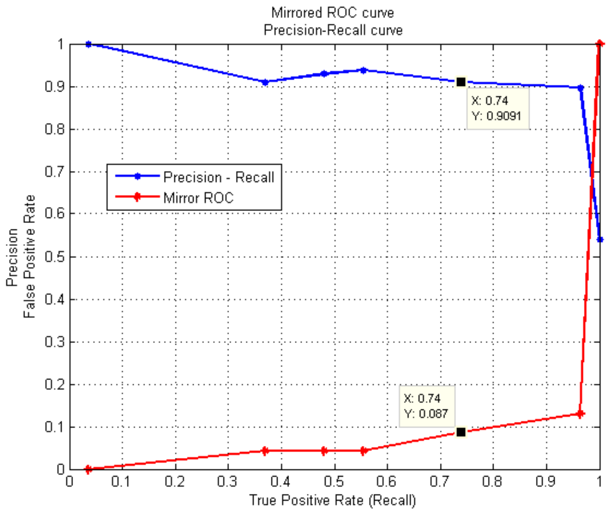

Figure 4. The ROC vs Precision-Recall curves.

6. CONCLUSION

In this paper, an original algorithm has been presented for the recognition of images (already subjected to segmentation) by comparison with the templates of a database. An application has been performed aimed to the authentication of individuals by using biometric pattern as the retinal vascular one, which has been established to be reliable and robust against impostures.

A procedure is also suggested to structure an opportune database of templates of reference, which provides the optimal threshold for the matching algorithm itself.

The tests performed have shown high performances of the assessed procedures, although the images of the WDB, deriving from a scanning process on a conventional equipment (considering also the type of segmentation experienced) were marked by poor quality; further, the authentication algorithm has exhibited high precision and accuracy, although the number, n, of the scanning used to build the maximum occurrence matrix was relatively low.

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