Iris print extraction from reduced and scrambled set of pixels

Nedjeljko Lekic[1], Andjela Draganic[1], Irena Orovic[1], Srdjan Stankovic[1], Vladan Papic[2]
[1]Faculty of Electrical Engineering, University of Montenegro, Podgorica, Montenegro
[2]Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), University of Split, Split, Croatia

***Abstract* – Iris recognition is a form of biometric identification based on unique patterns within the region that surrounds the pupil of the human eye. This technology uses pattern recognition algorithms in person identification procedure, and requires high-resolution images. The confidentiality of the stored data is an important issue, and the access to personal data should have only an authorized person. This paper focuses on iris recognition procedure using reduced and scrambled set of data. Namely, the number of available pixels from an iris image is reduced intentionally, according to the Compressive Sensing principles. Therefore, we deal with much less data than it is usually required. Scrambling is done according to the unique key, in order to provide secrecy of the data. When it comes to the identification, the set of received pixels is firstly reordered in original positions, and the rest of the pixels (the missing ones) are recovered by using the Compressive Sensign reconstruction algorithm. The theory is verified with the experimental results.**

Keywords – **Biometrics, Compressive Sensing, Iris recognition**

I. INTRODUCTION

Biometrics is used in the automatic identification of a person using physiological or behavioral characteristics. Identification based on the physiological characteristics of the individuals include recognition using fingerprints and palm prints, face recognition, iris recognition, DNA, etc. Behavioral characteristics are, for example, gait and voice. Nowadays biometrics is applied in more and more applications that require person identification. Since biometric identifiers are the property of the person, there is no need for additional identifiers like in traditional identification techniques, which use passwords, identification cards or some other types of identifiers [1]-[5].

The focus of this paper is on biometric identification method based on persons' iris recognition [1]-[5]. The iris is the colored part of the eye that controls diameter and size of the pupil. It lies in front of the lens and behind the cornea. The iris structure is developed until child's eight months and, in healthy conditions, stays unchanged during the rest of the life. In other words, iris pattern cannot be changed without damaging a person's vision. Having in mind that there are no two identical iris patterns (even if the persons are relatives or identical twins), and that the iris stays unchanged during the life, iris recognition became widely used in personal identification [3], [4]. One important advantage of iris recognition over the fingerprinting, which is also widely used in person identification, is scanning without a physical contact with the person. The possibility to use iris in the recognition was suggested by the F. Burch in 1939. The first algorithms for iris recognition are developed at the University of Cambridge by John Daugman [1]-[2].

Besides advantages of the use of iris recognition in biometrics, there are also some difficulties related to this process. Namely, the iris diameter is around 1 cm and therefore, in order to successfully scan the iris, the person should collaborate. Also, eyelids and occasional blinking make scanning more challenging. Nevertheless, iris recognition has small false identification ratio, and therefore, this technology is widely used in a large number of applications. It is implemented at the airports and the seaports, in the hospitals, it can be found in the mobile phones, etc.

The iris image is captured with the standard camera using both visible and infrared light. Wearing glasses or contact lenses does not affect the recognition. The procedure can be manual or automatic. In the manual procedure, the user needs to focus the iris in front of the camera. The camera should be distanced from six to twelve inches of the eye. The automatic procedure locates the face and iris automatically, which eases the whole procedure. After the image is captured, the next step of the recognition procedure is the extraction of the iris characteristics (iris print). Iris print is further used for comparing with iris prints stored in the database.

Biometric information is a secret information that requires a high level of security. The access to this information should be granted only to an authorized person. The idea behind this paper is to design a procedure that provides confidentiality of the data and at the same time, deals with much fewer data than usual. Namely, a small percent of iris image pixels is selected according to the Compressive Sensing (CS) principles [6]-[24]. The acquired pixels are scrambled using a key known to the user, in order to provide secrecy of the data. Before comparison procedure is performed, the pixels should be first reordered and then the CS reconstruction algorithms are applied to recover the missing coefficients. The CS allows reconstruction of the signal from a small set of available samples, using optimization algorithms. Storing just a small number of image pixels and at the same time scrambling them, increase the security level of the iris recognition procedure.

The paper is organized as follows. The theoretical background on the Daugman method for iris recognition is given in Section II. The procedure for iris recognition based on reduced and scrambled set of pixels is described in the Section

III. Section IV contains experimental results and conclusion is in Section V.

II. IRIS RECOGNITION TECHNOLOGY

The iris recognition technology combines different approaches in the identification process, such as pattern recognition, optics, computer vision, shape recognition. Identification should provide information about person’s identity in real time. Generally, there are several phases in the recognition process [3]:

-iris image capture;
-iris localization;
-iris normalization;
-extraction of the iris characteristics;
-comparison.

During the iris image capturing, the person is in the front of the camera, where the eye position is determined using the camera indicators. The photographing of the eye is a demanding task and requires person’s cooperation. The iris photograph should be of good quality, having in mind that the recognition depends on image quality. Localization of the iris is a determination of the inner and outer iris bounds on the digital image, as well as eyelashes and eyelids detection. The localization is done by applying a Daugman method [1], [2], [4] that uses integrodifferential operator according to the relation:

$$\max_{r,x_0,y_0}\left|\Gamma_\alpha(r)*\frac{\partial}{\partial r}\oint_{r,x_0,y_0}\frac{I(x,y)}{2\pi r}ds\right|, \tag{1}$$

where $I(x,y)$ is an iris image, $\Gamma_\alpha(r)$ is a smoothing Gaussian function of a scale α and * denotes the convolution. The operator searches for a maximum of the partial derivative of the contour integral of $I(x,y)$ [1], [4]. The circular arc ds has radius r and center coordinates (x_0, y_0). The operator searches for a circular path where the change of pixel value is maximal, changing the parameters (r, x_0, y_0), as well as lowering the value of α [1]. Fig. 1 shows the image with located inner and outer iris bounds.

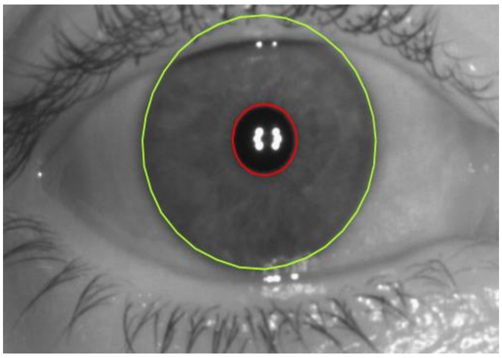


Figure 1: The eye image with localized inner and outer iris bounds

The next phase, iris normalization, provide unique iris dimensions for each photograph in order to be able to compare efficiently the iris codes. Namely, the iris size varies from person to person. Even iris of the same person may change the size due to the illumination or some other environmental factors, which can affect the iris matching. Therefore, those deformations should be compensated. In this stage of the recognition process, the Daugman-Rubber sheet model is used to transform the iris region from Cartesian to polar coordinates (r, θ). The parameters r and θ lie in the regions [0, 1] and [0, 2π], respectively. The transformation of the iris region from Cartesian to polar coordinates can be described as [1]:

$$\begin{aligned} &I(x(r,\theta),y(r,\theta))\rightarrow I(r,\theta)\\ &x(r,\theta)=(1-r)x_p(\theta)+rx_i(\theta)\ .\\ &y(r,\theta)=(1-r)y_p(\theta)+ry_i(\theta)\end{aligned} \tag{2}$$

The iris image in Cartesian coordinates is denoted as $I(x,y)$, while (x_p,y_p) are pupil coordinates and (x_i,y_i) are iris coordinates along the direction of θ (Fig. 2).

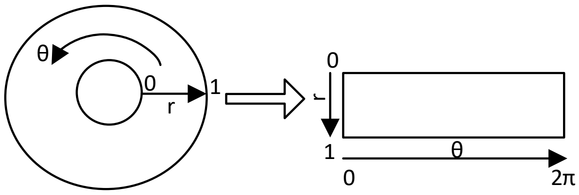


Figure 2: Unwarping of the iris

The extraction of the iris characteristics is final and the most important stage in the iris recognition process. In this stage, the 2D Gabor wavelet filter bank is used in order to extract the characteristics of the iris structure as an array of vectors in the complex plane. A certain area of the iris is projected onto a complex-valued 2-D Gabor wavelets [1], [4]:

$$\begin{aligned} &l_{\{R_e,I_m\}}=\\ &=\operatorname{sgn}_{\{R_e,I_m\}}\int_\mu\int_\varphi I(\mu,\varphi)e^{-i\omega(\theta_0-\varphi)}e^{-\frac{(r_0-\mu)^2}{\gamma^2}}e^{-\frac{(\theta_0-\varphi)^2}{\beta^2}}\mu d\mu d\varphi\end{aligned}, \tag{3}$$

where $l_{\{Re,Im\}}$ can be regarded as a complex-valued bit whose real and imaginary parts are 1 or 0 depending on the sign of the 2D integral [1]. The raw iris image in dimensionless polar coordinate system is denoted as $I(\mu,\varphi)$, β and γ are 2D wavelet parameters, ω is wavelet frequency, (r_0,θ_0) are polar coordinates of the iris region for which the phasor coordinates $l_{\{Re,Im\}}$ are computed [1], [4]. Only the phase information is used in recognition process [1], [4].

The comparison of the iris codes is done after the characteristics extraction. It is based on Hamming distance calculation, which provides information how many identical bits exist in two iris samples. The Hamming distance is calculated according to the relation:

$$H = \frac{\left\| (c_1 \oplus c_2) \cap m_1 \cap m_2 \right\|}{\left\| m_1 \cap m_2 \right\|}, \tag{4}$$

where c_1 and c_2 are iris codes, $\oplus$ is an XOR operator while m_1 and m_2 are their masks that assure comparison result would not be affected by different interferences such as reflections, eyelashes and eyelids presence, etc. The value of the Hamming distance H=0 represents a perfect match between two iris codes [1]-[4].

III. Procedure for Iris Print Extraction based on Scrambling and CS recovering

Let us assume that the image $\mathbf{I}_d$ is an under-sampled and the set of the available image pixels are scrambled in order to provide secrecy of the received data. This image is an input of the described procedure. In order to obtain the image $\mathbf{I}_{N\times M}$, on which the Daugman method is applied (see equation (1)), the received image should be re-scrambled and the missing pixels has to be recovered. The scrambling/re-scrambling procedure is described in the sequel.

Let us assume that the randomly under-sampled image is denoted as $\mathbf{I}_u$. First, the image $\mathbf{I}_u$ is transformed to vector $\mathbf{I}_v$ in a row-wise manner:

$$\mathbf{I}_v \leftarrow vect(\mathbf{I}_u)\,. \tag{5}$$

In the next step, the elements of the vector $\mathbf{I}_v$ are randomly permuted and the new vector with permuted elements $\mathbf{I}_v^p = \mathbf{I}_v(p)$ is formed. The parameter p denotes a unique key. Then the new image with permuted pixels is formed according to relation:

$$\mathbf{I}_{d_{N\times M}} \leftarrow mat(\mathbf{I}_v^p, N, M)\,, \tag{6}$$

where mat denotes operator that transforms vector $\mathbf{I}_v^p$ to $N\times M$ matrix.

In order to perform a comparison of the stored and captured iris prints, the re-scrambling procedure has to be done. For this purpose, the key p and image dimensions (N, M) have to be known. First, the matrix $\mathbf{I}_d$ is transformed into vector $\mathbf{I}_{v'}$ and the vector $\mathbf{Z}_{NM\times 1}$ is formed as:

$$\begin{aligned} &\mathbf{I}_{v'} \leftarrow vect(\mathbf{I}_d), \\ &\mathbf{Z}(p) \leftarrow \mathbf{I}_{v'}. \end{aligned} \tag{7}$$

The vector $\mathbf{Z}$, at the positions described with vector p, has elements from the vector $\mathbf{I}_{v'}$. Then the vector $\mathbf{Z}$ is reshaped and finally, the $N\times M$ matrix $\mathbf{I}_a$ is obtained. This matrix represents an image with available pixels at their original positions.

-In order to apply the iris recognition procedure, the missing pixels from the image $\mathbf{I}_a$ have to be recovered by using gradient-based reconstruction algorithm.

This algorithm belongs to the group of convex optimization approaches [6], [17], [24]. Here, the algorithm uses the 2D discrete cosine transform (2D DCT) as a sparsifying basis. The values of the available pixels are iteratively varied for adaptable step ±Δ. By changing the values of the available pixels the concentration of the signal is iteratively improved in the sparsity domain. The algorithm can be summarized within the following steps:

- First, let us denote image with missing pixels as $\mathbf{I}_{aN\times M}$ where pixels $(n,m) \in \mathbf{N}_a$ are the available pixels, and the values of the missing pixels are set to zero. Therefore, the image $\mathbf{I}_a$ can be represented as:

$$I_a^{(0)}(n,m) = \begin{cases} I(n,m), & \text{for } (n,m) \in \mathbf{N}_a \\ 0, & \text{for } (n,m) \notin \mathbf{N}_a \end{cases}, \tag{8}$$

- The initial value of the adaptable parameter Δ is set in the next step, according to the following relation:

$$\Delta = \max_{n,m} \left| I_a^{(0)}(n,m) \right|. \tag{9}$$

The parameter Δ is added and subtracted from the missing pixel, and two vectors $\mathbf{D}^+$ and $\mathbf{D}^-$ are calculated according to:

$$\begin{aligned} D^+(n,m) &\leftarrow 2D\,DCT\left\{ I_a^{(i)}(n,m) + \Delta \right\} \\ D^-(n,m) &\leftarrow 2D\,DCT\left\{ I_a^{(i)}(n,m) - \Delta \right\} \end{aligned}. \tag{10}$$

-Next step is the gradient vector calculation as a difference of the ℓ_1 norms of the vectors $\mathbf{D}^+$ and $\mathbf{D}^-$:

$$g^{(i)}(n,m) \leftarrow \frac{1}{NM}\left(\|\mathbf{D}^+\|_{\ell_1} - \|\mathbf{D}^-\|_{\ell_1} \right). \tag{11}$$

Then the value of the missing pixel is updated according to:

$$I^{(i+1)}(n,m) \leftarrow I^{(i)}(n,m) - g(n,m) \tag{12}$$

Variation of the values of missing samples is done until a stopping criterion is reached [6], and at the end of the gradient procedure, the recovered image $\mathbf{I}$ (on which Daugman procedure is applied) is obtained.

The system for iris recognition used in this paper consists of VistaFA2 Single Iris & Face Camera [25], MySQL database and PC application. The Biometric VeryEye 10.0 Software Development Kit (by NEUROtechnology) is used for system development [3].

IV. EXPERIMENTAL RESULTS

The performance of the proposed procedure is tested on the under-sampled iris image, whose original, the full version is shown in Fig. 4. It is assumed that only 30% of the image pixels are available. The pixels are scrambled according to the procedure described in Section III, and the obtained image is shown in Fig. 5a. As it can be seen from Fig. 5a, there are no indications that the eye is on the image. If the key *p* is known, the available pixels can be reordered. The resulting image is shown in Fig. 5b. Now, the eye can be visible but this image can not be used in the iris recognition procedure, due to its low quality. The result of the recognition applied to image from Fig. 5b is shown in Fig. 6.

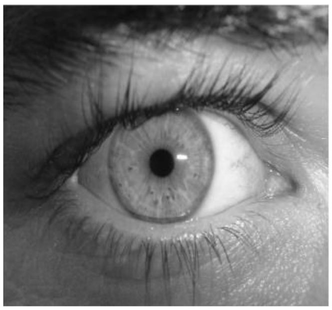
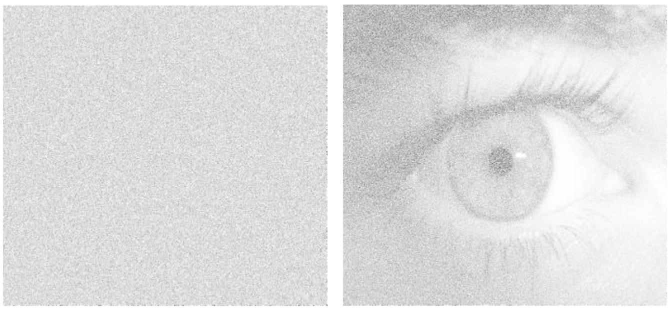


Figure 4. Original image



a) b)

Figure 5. a) The scrambled under-sampled image; b) The under-sampled image after the pixels reordering

☑ Zoom to fit

Iris image quality is too low.

Figure 6. The results of the recognition applied to the image with 70% of the pixels missing – failed to detect the iris

Quality: 68

☐ Zoom to fit 123 %

Figure 7. The results of the recognition applied to the image reconstructed by using the gradient-based algorithm – successful iris detection

Therefore, the missing pixels should be recovered prior the image is uploaded in the software for recognition. The gradient algorithm is used in the reconstruction process and the recovered image is shown in Fig. 7. In the same figure, the recognition results are shown. It can be seen that the recognition procedure is now successful and inner/outer iris bounds are detected.

V. CONCLUSION

A procedure for iris print extraction from reduced and scrambled set of iris image pixels is presented in the paper. The iris image is under-sampled and the available pixels are reordered according to a unique key. In such way, a secrecy of the personal data is provided. Prior to the iris comparison process, pixels have to be reordered in their original positions, after which the missing image samples are recovered by using the CS algorithm. The gradient-based algorithm is used in the reconstruction process. The experimental results show that it is possible to discard 70% of the image pixels and provide successful recognition. In other words, only 30% of the scrambled iris image coefficients are remained from the original image and based on them, the successful iris recognition is obtained.

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