CORRECTION METHOD FOR NONIDEAL IRIS RECOGNITION

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ABSTRACT

The use of iris as biometric trait has emerged as one of the most preferred method because of its uniqueness, lifetime stability and regular shape. Moreover it shows public acceptance and new user-friendly capture devices are developed and used in a broadened range of applications. Currently, iris recognition systems work well with frontal iris images from cooperative users. Nonideal iris images are still a challenge for iris recognition and can significantly affect the accuracy of iris recognition systems. In this paper, we propose a method to correct off-angle iris image. Taking into account the eye morphology and the reflectance properties of the external transparent layers, we can evaluate the distorting effect that is present in the acquired image. The correction algorithm proposed includes a first modeling phase of the human eye, a segmentation of the acquired image, and a simulation phase where the acquisition geometry is reproduced and the distortions are evaluated. Finally we obtain an image which does not contain the distorting effects due to jumps in the refractive index. We show how this correction process reduce the intra-class variations for off-angle iris images.

Index Terms— Biometrics, Nonideal iris recognition, Intra-class variation, Eikonal equation

1. INTRODUCTION

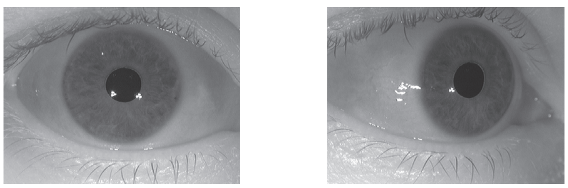
Biometrics uses physical, biological and behavioral traits to automatically identify and verify a person. The human iris, an annular portion between the pupil and the white sclera, has an extraordinary structure and provides many minute interlacing characteristics such as freckles, coronas, stripes and the collarette area, which are unique to each subject [1]. The unique structure of iris, the stability of iris pattern throughout the person's lifetime, the non invasiveness of the system (iris is an internal organ as well as an externally visible organ), the public acceptance and a wide range of applications influence the increased interest in the iris as one of the most reliable biometric technologies in recent years. Most of the literature is focused on processing of ideal iris images, acquired in typical quite constrained scenarios: subjects stop and stare relatively close to the acquisition device while their eyes are illuminated by a near-infrared light source, enabling the acquisition of high-quality data.

Several researchers are currently working on lowering these constraints without significantly impacting performance while increasing system usability. These include processing and encoding of a "nonideal iris" that is defined as accounting for the off-angle, occluded, blurred and noisy images, and "iris at a distance" that is defined as a snapshot of an iris captured from a moving individual at a large distance (more than a meter) [2]. Under a nonideal situation, traditional iris recognition systems would not work well. We focalize our attention on compensating off-angle iris images. It is not practical to assume that a user always aligns his/her optical axis with the camera's optical axis. Previous techniques for nonideal iris recognition do not specifically adjust for the iris images that are captured off-angle. Exceptions are the early work of Sung *et al.* [3], where they apply an inner eye corner detector in combination with a Sobel edge detector and a least square elliptical fit, and the work of Takano *et al.* [4], that use a rotation-spreading neural network. Santos *et. al.* propose a novel fusion of different recognition approaches [5] and describe how it can contribute to more reliable noncooperative iris recognition. The limitation of these papers is that the datasets used for testing did not specifically include the off-angle images. Li [6], Dorairaj *et al.* [7] and Schuckers *et al.* [2] use the West Virginia University database, specifically developed to address this issue. The limitation of all these papers is that homographic transformations are applied to the distorted images in order to obtain a synthetic frontal view with iris having circular boundaries. Our approach uses a 3D iris model and a ray-tracing algorithm in order to compensate also the distortions introduced by transparent surface layers and obtain a more reasonable iris frontal view. Moreover we propose a method that can help transform traditional iris recognition systems to work on the off-angle situation without a costly update. This method does not change the core parts of the traditional systems but add additional software modules in order to compensate geometric distortions due to jumps in the refractive index of the external transparent layers.

The rest of the paper is organized as follow. Section 2 describes the 3D eye model used. Section 3 introduces the correction algorithm. Experimental results (Section 4) and conclusions (Section 5) end the paper.

2. 3D EYE MODEL

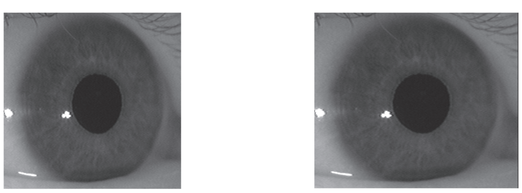
Regarding the image acquisition, we consider two cases (see Fig.1): frontal and off-angle acquisition. In the frontal acquisition case the camera optical axis is aligned with the user's optical axis. Iris and pupil boundaries are well approximated as having circular boundaries. In the off-angle acquisition case the camera and the eyes are at the same height but the user is looking at a different horizontal direction respect to the camera optical axis. Iris and pupil boundaries could be approximated as ellipses, whose long and short axes are parallel to the vertical and the horizontal directions [6].



(a) (b)

Fig. 1. Sample images from the WVU off-angle iris database. (a) 0^o angle; (b) 30^o off-angle.

Considering the off-angle image we can make a first correction compensating the distortions associated with the off-angle acquisition. We restore the circular shape of the iris and pupil acting directly on the image by changing the shape of the image content without considering how the distortions are effectively introduced on the image during its acquisition (see Fig.2). Moreover we can observe a loss of horizontal resolution due to the interpolation of a greater number of pixels.



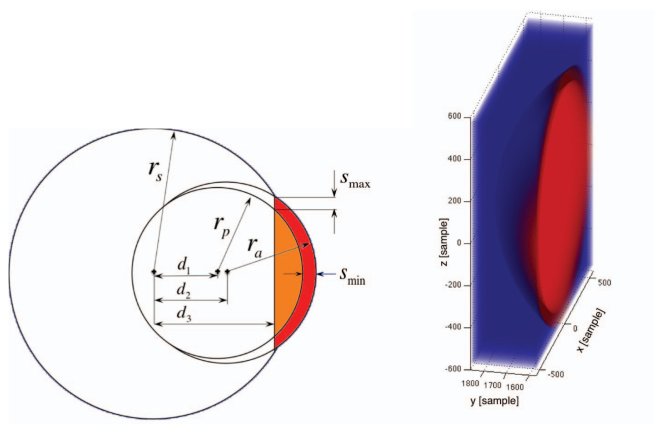
(a) (b)

Fig. 2. (a) Example of image acquired with 30^o off-angle. (b) Image obtained after rotation around the vertical axis.

Taking into account the morphology and the properties that characterize the superficial layers that protect the iris, distortions that are present in the acquired image could be effectively corrected, both for frontal than for off-angle acquisitions. The transparent surface layers, cornea and aqueous humor, have different refractive indices and refract incident light, focusing it on the retina. The way in which a generic ray of light is refracted by an interface between two media depends on the incident angle and the interface properties. As a result of the refraction indexes jumps and of the cornea curvature, the iris in the image appears always distorted. The idea behind the implemented method is to determine and compensate the distortions introduced on the iris image, due to both the off-angle acquisition condition and the refraction generated by cornea and aqueous humor. We use a 3D model of the human eye, shown in Fig.3(a), that takes inspiration from the model proposed by Liou *et al.* [8]:

- cornea is modeled by a meniscus with: anterior radius $r_a = 7.2mm$; distance between sclera center and anterior corneal center of curvature $d_2 = 5.62mm$; posterior radius $r_p = 6.8mm$; distance between sclera center and posterior corneal center of curvature $d_1 = 5.54mm$; minimum thickness $s_{min} = 0.5mm$; maximum thickness $s_{max} = 0.65mm$; refraction index $n_c = 1.376$;
- iris is assumed to be planar and with constant thickness. Its radius is $r_i = 5.75mm$ and the distance between sclera center and iris is $d_3 = 9.95mm$;
- aqueous humor is the spherical cap between the iris and posterior part of the cornea. Its refraction index is $n_a = 1.336$:
- sclera has radius $r_s = 11.5mm$;
- pupil is assumed to be planar with mean radius $r_{pp} = 2.75mm$.

In agreement with the geometry of the 3D model, a refractive map was created to define refraction index values for each point belonging to cornea and aqueous humor (Fig.3(b)).



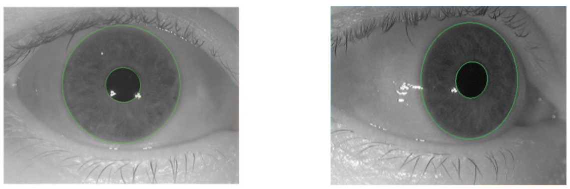
(a) (b)

Fig. 3. (a) Geometry of the considered model. (b) Refraction index map.

3. CORRECTION ALGORITHM

The first step of our correction algorithm is to segment the acquired image. The frontal images are segmented using the Circular Hough transform [9] through which the circular contours of iris and pupil could be estimated. The off-angle images are segmented making the fitting of ellipses on the binary edge map, following the algorithm proposed by Fitzgibbon *et al.* [10]. There are several approaches focused on localization of non-circular iris boundaries ([11]-[12]). In our case we can take advantages considering only off-angle acquisitions, that means that the ellipses must have long and short axes parallel to vertical and horizontal directions.

The segmentation process (see Fig.4), as well as extracting the iris region, is useful to obtain a metric relationship between the model size, the camera distance and the acquired iris. This allows to consistently evaluate, during the simulation, the effect of refraction indices jumps and of the acquisition angle of the image.



(a) (b)

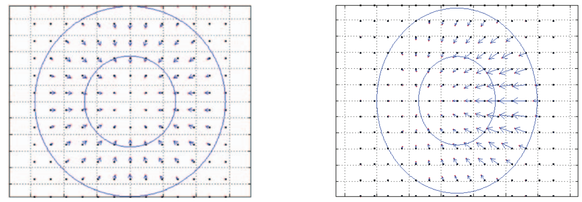
Fig. 4. Segmented iris images from the WVU off-angle iris database. (a) 0^o angle; (b) 30^o off-angle.

The next step is the analysis of the introduced distortions: knowing the camera position, a grid of equally spaced points is placed on the iris in the model and the angles of each ray connecting the camera center and each point of the grid, in the absence of discontinuities, are computed. In literature there are several approaches to estimate the acquisition angle. For example Dorairaj *et al.* [7] use two objective functions to estimate the gaze direction: Hamming distance and Daugmans integro-differential operator and determine an estimated angle by picking the value that optimizes the selected objective function. In this case we assume that the off-angle is known.

We used the Eikonal equation in order to determine the trajectory of each ray that, starting from the optical center, is refracted by the cornea and then by aqueous humor before impact on iris. We found that this method is more useful that apply the Snell equation when we work with a trajectory meeting two interfaces: air versus cornea first and cornea versus aqueous humor after. Using the Eikonal equation, we are able to determine the trajectories of the rays that, emitted from a point source, propagate up to discontinuities that characterize the surface layers of the eyeball, where are refracted, and then impact on the iris or pupil. The Eikonal equation could be written as:

$$\frac{dT}{dl} = s(\vec{x}) \quad (1)$$

where $T(\vec{x})$ is the phase of the wave, l is the distance along the ray trajectory and $s(\vec{x}) = n(\vec{x})/c_0$ is the slowness of the medium. We indicate with c_0 the light speed in vacuum and with $n(\vec{x})$ the refraction indexes distribution in the model. The eq. 1 states that, moving along the ray trajectory, the phase derivative varies according to the slowness of the medium at the point considered $\vec{x}$. We use the Runge-Kutta method [13] in order to estimate all the trajectories from the camera center to the iris.



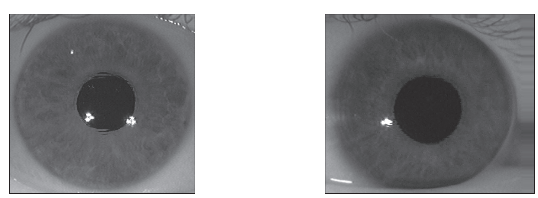
(a) (b)

Fig. 5. Original and distorted grids for iris images acquired under (a) 0^o angle; (b) 30^o off-angle.

Downstream the ray-tracing step, we obtain a new grid of points on the iris, distorted non-linearly due to the refraction introduced by the discontinuity that precede the iris from the outside toward the interior. The iris image is considered as a spatially uniform sampling of the distorted grid obtained with ray-tracing, as shown in Fig.5 with points (representing the pixels centers) and arrows (representing the distorted grid) for images with 0^o and 30^o acquisition angles. It can be seen that in the frontal case the grid is compressed toward the pupil center symmetrically, while in the off-angle case the compression is symmetric only respect to the horizontal axis. In both cases the distortion is bigger for points further away from pupil center that, because of cornea radius of curvature, undergo refraction with a bigger angle. The intensity value of each point of the distorted grid is estimated interpolating the values of the 4 nearest pixels on the acquired images:

$$\hat{I}_j = \frac{\sum_{i=1}^{4} \frac{1}{d_{i,j}^2} I_i}{\sum_{i=1}^{4} \frac{1}{d_{i,j}^2}} \quad (2)$$

where $I_i (i = 1, ...4)$ represents the intensity values of the 4 nearest pixels, $\hat{I}_j$ represents the interpolated intensity value on the distorted grid computed downstream the ray-tracing and $d_{i,j}$ is the distance between the point in pixel unit. The corrected image is obtained by giving to the equal spaced points on the grid in the 3D model (built independently of the cornea and aqueous humor) the intensity estimated on the distorted grid on the iris image. Two examples of corrected images are shown in Fig.6



(a) (b)

Fig. 6. Corrected iris images from the WVU off-angle iris database. (a) 0^o angle; (b) 30^o off-angle.

4. RESULTS

To verify our correction method we used part of the WVU off-angle iris database, considering 2 acquisitions at different angles of view (0^o and of 30^o) of 20 human eyes. After correcting iris images, we test our approach in an identity verification scenario. We assume that the frontal image is the reference image and we compare the other image with it. We apply the classical Daugman algorithm [14] to compute the distance between two images of the same iris both applying only the geometrical correction and correcting also the distortions introduced by cornea and aqueous humor. In all the tested cases we can observe a decreased Hamming-distance and in most cases, this decrease fall below the typical detection threshold (equal to 0.36) experimentally founded by Daugman for frontal images from the CASIA databases. We obtain a reduction of the mean distance from 0.39075 till 0.3615. At the same time inter-class variation does not decrease, but remains, in mean, unchanged till the third decimal place ($= 0.460$). If only the homographic transform is applied, as illustrated in Fig.2, a less decrease of the mean intra-class distance is obtained ($= 0.3802$), unable to reduce the false non-matching rate.

5. CONCLUSION

In this paper we proposed a novel approach to correct off-angle iris images. In particular, through the study and modeling of human eye discontinuities, it is possible to introduce a correction method for iris acquired both frontal and off-angle. It can be seen from Fig.6 how, after the correction process, the circular shape of iris and pupil is obtained also for images acquired with angle of view different from 0^o. This correction method, added in a traditional iris recognition system, allows to obtain a reduction of the Hamming distance between templates belonging to the same subject but acquired with different angles of view. This effectively decrease the intra-class variation, fundamental for reducing false non-matching rate and that is shown to increase when working with off-angle iris [6]. At the same time inter-class variation does not decrease, maintaining a low false acceptance rate.

6. REFERENCES

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