Input Images in Iris Recognition Systems: A Case Study

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Abstract—**Iris pattern is a unique, stable and non-invasive biometric feature, suitable for individual recognition purposes. There are several and very diverse iris recognition algorithms, but in most cases, a collaborative environment and ideal conditions are required when capturing the system input image. To overcome these constraints and increase the number of domains in which iris recognition systems can be used, it is essential to develop robust algorithms that work in non-collaborative environments, but in order to do this in a correct way, it is important to previously analyse the different situations that can occur in such environments. In this context, different noisy and artificial iris images are analysed in this paper in order to determine its influence in iris recognition systems performance.**

Keywords—artificial iris images; biometrics; fake iris images; noisy iris images; system performance.

I. Introduction

Iris patterns, which begin to form in the third month of gestation and are completed by the eighth month, are unique, regardless of whether they are related or not. In fact, although genetically identical, both iris patterns of the same individual are unique and structurally different. Human iris is also stable and not changeable, except in cases of injury. Because of these two important characteristics, uniqueness and stability, among others, iris recognition is considered a reliable method of identification.

When consulting literature related to iris recognition, it is easy to find several and very diverse algorithms [1-7], but in most cases, the individual cooperation and ideal environmental conditions are required for the system to work properly. Specifically, most current systems require subjects to stand close to the capture device and stare at it during a few seconds until the input image is obtained. In addition, these systems are usually used in controlled environments, under homogeneous lighting conditions. Such necessity of both the subject cooperation and controlled image acquisition conditions restricts the usage of this type of systems. The development of robust algorithms that work in non-collaborative environments is essential to overcome these constraints.

In order to design robust iris recognition algorithms for non-collaborative environments and determine the requirements of the systems when working under non-controlled conditions, it is necessary to previously analyse the different input images that could be acquired in such environments. Two different types of potential input images are analysed in this paper: noisy and artificial iris images.

The proposed analysis method consists of determining the distance between the noisy or artificial sample and the corresponding sample captured in ideal conditions. In the case of noisy images, by observing the distance it is possible to determine how and how much noise affects the system performance, something that has to be controlled, especially considering that it can occur that distance changes enough as to make the system falsely reject a genuine user. Regarding artificial images, when a person uses any kind of artificial iris, both for cosmetic or health reasons, or because this person intents to cheat the recognition system, it is important that the system knows that the sample corresponds to an artificial iris, so that the appropriate measures can be taken, like using an extra automatic recognition system or even change to a manual recognition system (e.g. police checkpoints in airports). In this context, the distance analysis makes possible to determine if artificial iris images are detected as such with no need of implementing any countermeasure.

In order to calculate the distance between samples, OSIRIS [8] system has been used. OSIRIS (Open Source for Iris) is an open source iris recognition system developed in the framework of the BioSecure Network of Excellence. It is inspired by Daugman works [1] and it consists basically of two steps: segmentation and classification. The segmentation part uses the circular Hough transform and an active contour approach to detect the contours of the iris, and the classification part is based on Gabor phase demodulation and Hamming distance classification. This way, Hamming distance is the one chosen in this case to carry out the distance analysis.

II. Database Development

It is difficult to find public databases of noisy, artificial or fake iris images nowadays. Nevertheless, this kind of databases is essential to develop robust and/or antifraud iris recognition systems.

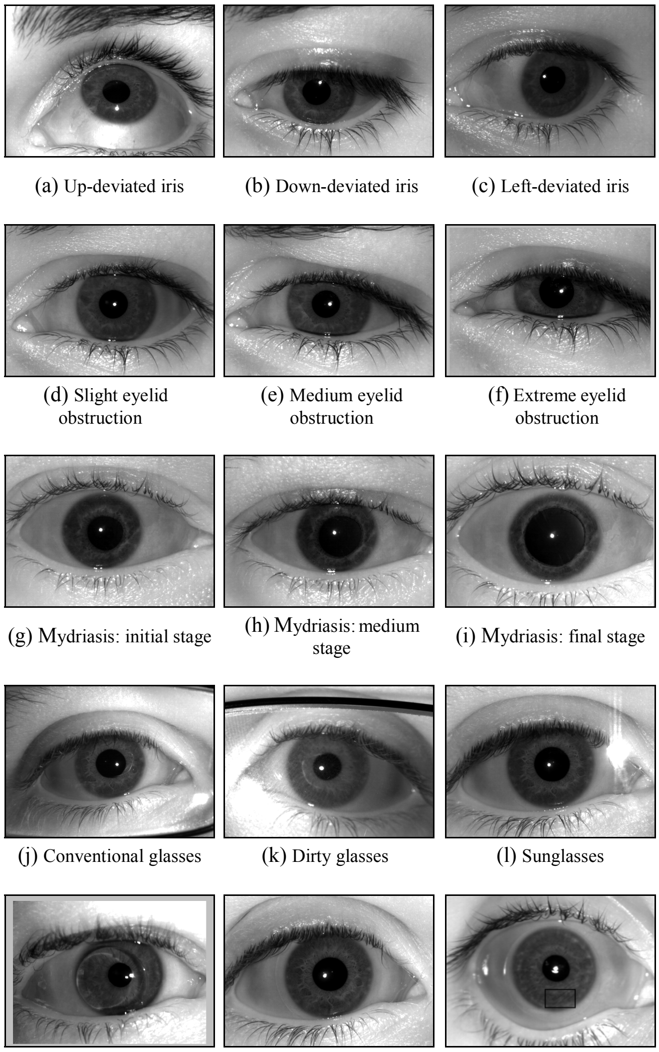
In order to generate the database that has been used in this case, a total number of 40 subjects between the ages of 16 and 70 years old have been considered. The total number of images of the database is 1600. Considering that the aim of this paper is to analyse the influence of different iris input images captured in non-collaborative environments, the images of the database have been taken in different scenarios, under several different lighting conditions. For the same reason, no image has been rejected, except those with an extremely poor quality.

III. NOISY IRIS IMAGES

In iris recognition systems, input samples are iris images. In this context, a noise source can be defined as anything that modifies the input image in such a way that the conditions for recognition are not optimal. In the case of iris, there are some noise sources associated to the existing conditions when the image is obtained. This way, blinking, a slight gaze deviation in the moment of capturing the image or an iris anomaly due to surgery or physiological reasons, are noise sources that make recognition difficult or even impossible. Another kind of noise sources, such glasses or contact lenses, are tangible.

Five different groups of noisy images have been analysed in this paper. In the first three groups, noise is provoked by non-tangible causes, while in the last two groups, tangible elements like glasses or lenses are needed (see Fig. 1).

- *Gaze deviation*. When acquiring the image, if not controlled, it is possible that the gaze is deviated to any direction. Depending on how off-axis the iris is, it can be directly processed or not. Gaze deviation can be corrected by using trigonometry to estimate the gaze angle and make a transformation to rotate the eye until it looks straight ahead [9].
- *Eyelid obstruction*. One of the most frequent noise sources in iris images is eyelid and eyelashes obstruction due to blinking. In this case, a logical mask must be set to prevent the non-valid pixels from affecting the iris-code. Also the amount of iris occluded must be taken into account, in order not to consider too little valid information.
- *Mydriasis*. Mydriasis is an excessive dilation of the pupil due to disease, trauma or the use of drugs or alcohol. Mydriasis can be also artificially provoked by using a mydriatic in the form of eyedrops. In the case of mydriasis, non-elastic deformations of the iris occur as the pupil dilates. Due to this kind of deformations, the iris circular shape is affected. If mydriasis is in an advanced stage, recognition systems performance could be affected.
- *Glasses*. Considering that a big percentage of the population wears glasses, it is important that this noise source does not affect the iris recognition systems performance. Reflections are one of the adverse effects of glasses. If these reflections cover part of the iris, a logical mask must be set to prevent the non-valid pixels from affecting the iris-code, just as occurs with eyelids and eyelashes.
- *Contact lenses*. Due to certain pros of contact lenses, its use has become widespread. Depending on the kind of lens, iris recognition systems can be influenced in more or less extent. Conventional contact lenses are generally categorized as hard or soft lenses. As the name implies, hard contact lenses are manufactured from a rigid material, polymethylmethacrylate or PMMA, often combined with other plastics to increase the oxygen permeability. The general name of this kind of lenses is rigid gas permeable (RGP) lenses (see Fig. 1m). On the contrary, soft contact lenses are made from a plastic hydrogel polymer, hydroxyethylmethacrylate or HEMA, and have high water content. Some soft contact lenses show a printed mark (e.g. "AV" or "123") to ensure a proper insertion (see Fig. 1o).



(a) Up-deviated iris (b) Down-deviated iris (c) Left-deviated iris
(d) Slight eyelid obstruction (e) Medium eyelid obstruction (f) Extreme eyelid obstruction
(g) Mydriasis: initial stage (h) Mydriasis: medium stage (i) Mydriasis: final stage
(j) Conventional glasses (k) Dirty glasses (l) Sunglasses
(m) Hard lens (n) Soft lens (o) Soft lens with numbers ("123") printed on it

Figure 1. Examples of noisy images used in the analysis.

Considering that the images under study are noisy versions of a genuine iris, any robust iris recognition system should identify the user correctly. Nevertheless, as previously commented, it is not so common that all iris systems can work properly in non-collaborative environments in which noisy samples are more frequent.

In Table I, the OSIRIS Hamming distances between the different noisy samples and the corresponding sample captured in ideal conditions are shown. In order to analyse the results, it is necessary to indicate that, with the database used, mean intra and interclass distances obtained with OSIRIS system are respectively 0.2788 and 0.4505. The threshold value to make the system work properly can be fixed to 0.38. This way, in spite of noise, any genuine sample should show a distance lower than the threshold, not to be falsely rejected by the system.

TABLE I. MEAN HAMMING DISTANCE BETWEEN NOISY SAMPLES AND THE CORRESPONDING NON-NOISY SAMPLES CALCULATED WITH OSIRIS SYSTEM

Noise source	*Case under analysis*	*OSIRIS Hamming distance*
Gaze Deviation	Up	0.431590
	Down	0.451397
	Left	0.453464
	Right	0.427321
Eyelid Obstruction	Slight	0.292528
	Medium	0.322854
	Severe	0.416084
Mydriasis	Initial Stage	0.366837
	Medium Stage	0.414967
	Final Stage	0.468786
Glasses	Conventional	0.274279
	Dirty	0.279250
	Sunglasses	0.210000
Contact Lenses	Hard	0.306194
	Soft	0.285266
	Soft + “123”	0.281218

Bearing the intraclass, interclass and threshold values in mind, it can be stated that, as expected, glasses and contact lenses are not very problematic, as hardly affect the system. It is not the same, however, with gaze deviation and severe cases of eyelid obstruction. In these two cases, most samples are falsely rejected, so in order to make the system more robust, extra algorithms must be considered. As previously commented, one possibility in the case of gaze deviation is implementing a correction by using trigonometry to estimate the gaze angle and make a transformation to rotate the eye until it looks straight ahead. In the case of severe eyelid obstruction, a logical mask must be set to prevent the non-valid pixels from affecting the iris-code, but even if this mask is implemented, it can occur that the system fails. This is due to the amount of iris occluded. If occlusion is too severe and there is not enough information, individuals’ recognition is not possible, and this problem cannot be solved regardless of how robust the algorithm is. Capturing a new image if possible or applying an extra recognition method would be the only options.

Mydriasis is quite a special case, because it is not very common and it specially affects in its final stage. How mydriasis and, in general, pupil dilatation affect an iris recognition system is not simple to describe and quantify. According to certain studies [10], if the degree of dilation is similar at enrollment and recognition, comparisons involving highly dilated pupils result in worse recognition performance than comparisons involving constricted pupils. If the matched images have similarly highly dilated pupils, the mean intraclass Hamming distance increases and the mean interclass Hamming distance decreases, increasing the probability of false rejection. Finally, if larger differences in pupil dilation exist, there are higher template dissimilarities and the probability of false rejection increases notably. This last case is the one which best fits in the case under study, and it is reasonable to think that the reason why this occurs is that there is less iris area visible, and with less data available, iris is more poorly characterized and recognition performance gets worse.

IV. ARTIFICIAL IRIS IMAGES

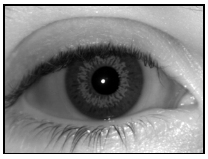
Regarding artificial images, two different approaches have to be considered. On the one hand, it is possible that a person uses any kind of artificial iris for cosmetic or health reasons, but it is also possible that the person intents to cheat the recognition system with such artificial iris. In both cases, it is important the system knows that the sample corresponds to an artificial iris, so that the appropriate measures can be taken. When focusing on spoofing, it is important to mention that thanks to research work related to fraud [11,12] it has been proved that there are many possibilities to try to spoof automatic iris recognition systems by using, for example, certain lenses or printed iris photographs. This way, it is essential to analyse potential iris forgeries in order to avoid spoofing in this kind of systems.

In this paper, a distance analysis of different artificial iris images has been carried out in order to determine if any of them can be directly detected as artificial image, or if, on the contrary, any extra algorithm is required to do so. The same analysis also helps to determine if the artificial images under study can be used as a forgery. Specifically, six different groups of artificial iris images have been analysed (see Fig.2).

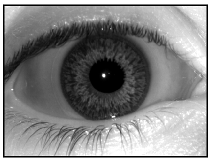
- *Cosmetic lenses.* These lenses are commonly used with purely cosmetic purposes, to change the eye appearance. Among them, color and fantasy lenses are particularly common. In most cases, color cosmetic lenses are the result of the combination of two or three layers of color pigment, simulating the limbal and pupillary rings, as well as the radial iris coloration, in order to achieve a natural appearance. Unlike color contact lenses, fantasy lenses are used to achieve an unreal physical appearance. In both cases, lenses are opaque and cover the iris completely, so it is not possible to recognize the person by the iris.

- *Non-integrated prosthetic eyes.* Ocular prostheses are used to replace an absent natural eye. They take the shape of a convex shell and fit over an orbital implant under the eyelids. Non-integrated prosthetic eyes are usually fixed to the eyelids, so no movement is allowed. For this reason, they are quite uncommon nowadays and have been replaced by integrated prosthetic eyes.

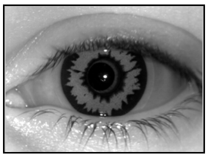
- *Integrated prosthetic eyes.* Integrated prosthetic eyes take also the shape of a convex shell and fit over an orbital implant under the eyelids, but unlike non-integrated prosthesis, direct mechanical coupling between implant and prosthesis exists and mobility improves. There are different ways to reproduce the iris in the shell. It can be directly painted in one layer or in three layers, reproducing a different part of the iris in each layer in order to achieve a sense of depth.



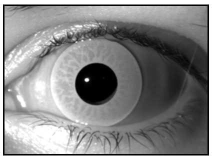
(a) Green cosmetic lens



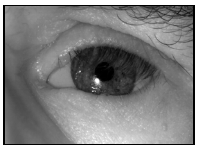
(b) Blue cosmetic lens



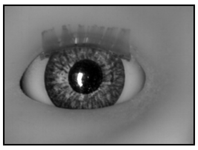
(c) Fantasy cosmetic lens Model *Wolf black*



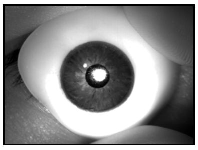
(d) Fantasy cosmetic lens Model *Blood shot*



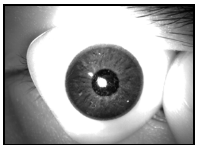
(e) Human non-integrated prosthetic eye



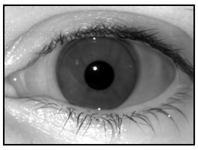
(f) Doll non-integrated prosthetic eye



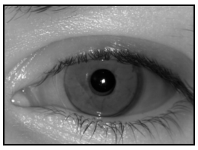
(g) 1-layer integrated prosthetic eye



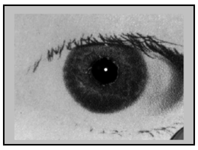
(h) 3-layers integrated prosthetic eye



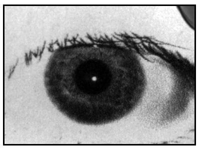
(i) Prosthetic lense with black pupil



(j) Prosthetic lense with transparent pupil



(k) Printed photo with cut-out pupil



(l) Printed photo with non-cut-out pupil

Figure 2. Examples of artificial images used in the analysis

- *Prosthetic lenses.* Prosthetic contact lenses are usually used to mask flaws and improve the appearance of an eye disfigured from a birth defect, trauma or disease. Similarly to regular contact lenses, prosthetic contact lenses can be hard or soft. They are hand-painted and try to reproduce all the details of a healthy eye. They can be made with black or transparent pupil. As occurs with the cosmetic lenses, they are opaque and cover the iris completely, so the subject recognition is not possible.
- *Printed photographs.* One simple way of trying to cheat an iris recognition system consists of taking a high resolution photograph of a genuine eye and printing it, to later place it over the impostor eye. In some cases in which the capture system implements aliveness detection mechanisms, it is necessary to cut out the pupil. The idea under this kind of images is slightly different than that of the previous cases, in which not only fraud purposes, but cosmetic or health purposes could exist.

TABLE II. MEAN HAMMING DISTANCE BETWEEN ARTIFICIAL SAMPLES AND THE CORRESPONDING NATURAL SAMPLES CALCULATED WITH OSIRIS SYSTEM

Artificial iris	*Case under analysis*	*OSIRIS Hamming distance*
Color Cosmetic Lenses	Green	0.428500
	Blue	0.482415
Fantasy Cosmetic Lenses	*Wolf black* model	0.469089
	Blood shot model	0.463317
Non-integrated Prosthetic Eye	Human	0.454876
	Doll	0.483836
Integrated Prosthetic Eye	1-layer	0.472718
	3-layers	0.470179
Prosthetic Lenses	Black pupil	0.455186
	Transparent pupil	0.448387
Printed photographs	Cut-out pupil	0.472885
	Non-cut-out pupil	0.395349

Table 2 shows the different Hamming distances between the artificial samples and the corresponding natural samples calculated with OSIRIS system. Considering that mean intra and interclass Hamming distances are respectively 0.2788 and 0.4505, the main conclusion that can be drawn is that the distance between a genuine iris and an artificial iris is very similar to the distance between a genuine iris and a common impostor iris (i.e. a natural iris from any different person than the genuine user). This means that it is quite difficult to distinguish between an artificial iris and the natural iris from an impostor by only taking into account the Hamming distance.

Being this the situation, alternative algorithms should be included in iris recognition systems that allow them to know when the iris captured is an artificial one. There already exist several algorithms to detect artificial iris images and most of them exploit the idea that there are important textural differences between counterfeit iris images and alive iris images. This way, most algorithms are based on texture analysis, as occurs e.g. with Daugman´s proposal [13], consisting of detecting printed iris patterns using spurious energy in 2D Fourier spectra, or with other proposals like He et al. [14] or Wei et al. [15], which use different texture-based features to detect fake iris images.

V. CONCLUSIONS

In this paper, different types of noisy and artificial iris images have been described, and the way they influence iris recognition systems has been analysed in order to determine what is needed to develop robust algorithms that can work properly in non-collaborative environments.

Regarding noise sources, it has been observed that glasses and conventional contact lenses hardly affect iris recognition systems, something very positive considering that a big percentage of the population wears any of them. Other sources like gaze deviation or severe eyelid obstruction are more damaging, and cause that most genuine samples are falsely rejected by the system. In this case, in order to make recognition systems more robust, extra algorithms must be considered.

In the case of artificial iris images, there are some problems to solve. On the one hand, elements like cosmetic or prosthetic lenses make identification impossible, as they are opaque and hide the iris completely. In a similar way, prosthetic eyes are also a problem. In such cases, alternative recognition methods have to be used to identify the individual. In addition to the previous drawback, the distance between a genuine iris and an artificial iris is very similar to the distance between a genuine iris and a common impostor iris, which means that it is quite difficult to distinguish between an artificial iris and the natural iris from an impostor by only taking into account the Hamming distance. This way, extra algorithms must also be implemented to avoid this problem. Finally, regarding spoofing, it is essential to keep in mind that as technology progresses, iris reproductions in prosthesis or lenses improve, and the probability of cheating recognition systems increases. In the face of such threat, the necessity of robust algorithms which implement anti-spoofing countermeasures is clear.

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