Iris Liveness Detection Based on Quality Related Features

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Abstract

A new liveness detection scheme for iris based on quality related measures is presented. The novel anti-spoofing technique is tested on a database comprising over 1,600 real and fake (high quality printed images) iris samples proving to have a very high potential as an effective protection scheme against direct attacks. Furthermore, the liveness detection method presented has the added advantage over previously studied techniques of needing just one iris image (the same used for verification) to decide whether it comes from a real or fake eye.

1. Introduction

Over the last recent years important research efforts have been conducted to study the vulnerabilities of biometric systems to direct attacks to the sensor (also known as *spoofing attacks*) which are very difficult to detect as they are carried out in the analog domain using synthetic biometric traits such as high quality iris printed images or gummy fingers, so that the digital protection mechanisms (digital signature, watermarking, etc.) are not valid to prevent them.

Among the different existing biometric traits, iris has been traditionally regarded as one of the most reliable and accurate. This fact has led researchers to pay special attention to its vulnerabilities and in particular to analyze to what extent their security level may be compromised by spoofing attacks. These attacking methods consist on presenting a synthetically generated iris to the sensor so that it is recognized as the legitimate user and access is granted. The most common and simple approaches are those carried out with high quality iris printed images [17]. Finding an effective countermeasure against this type of attacking scheme is the problem addressed in the present paper. However, other more sophisticated threats have also been reported in the literature such as the use of contact lenses [18].

These research efforts in the study of the vulnerabilities of automatic recognition systems to direct attacks have clearly proven the necessity to propose and develop specific countermeasures against this type of security breach. In particular, different liveness detection methods have been presented through the past recent years. These algorithms are anti-spoofing techniques which use different physiological properties to distinguish between real and fake traits, thus improving the robustness of the system against direct attacks and increasing the security level offered to the final user. Iris liveness detection approaches can broadly be divided into: i)*software-based* techniques, in which the fake irises are detected once the sample has been acquired with a standard sensor (i.e., features used to distinguish between real and fake eyes are extracted from the iris image, and not from the eye itself), and ii) *hardware-based* techniques, in which some specific device is added to the sensor in order to detect particular properties of a living iris such as the eye hippus (which is the permanent oscillation that the eye pupil presents even under uniform lighting conditions) or the pupil response to a sudden lighting event (e.g., switching on a diode).

Although hardware-based approaches usually present a higher detection rate, the software-based techniques have the advantage of being less expensive (as no extra device in needed), and less intrusive for the user (very important characteristic for a practical liveness detection solution). In general, a combination of both type of anti-spoofing schemes would be the most desirable approach to increase the security level of biometric systems.

In the present work, we analyze the potential of quality assessment (already considered in the literature for multimodal fusion [15], or score rejection [2]) to identify real and fake iris samples acquired from a high quality printed image. It is not the first time quality assessment has been explored as a way to detect spoofing attacks. A similar strategy to the one proposed in the present paper based on quality related features has already been used for spoofing detection in fingerprint based recognition systems [7], achieving remarkable good results in the first International Fingerprint Liveness Detection Competition (LivDet 2009) [14]. Furthermore, some quality based features have also been used individually for liveness detection in traits such

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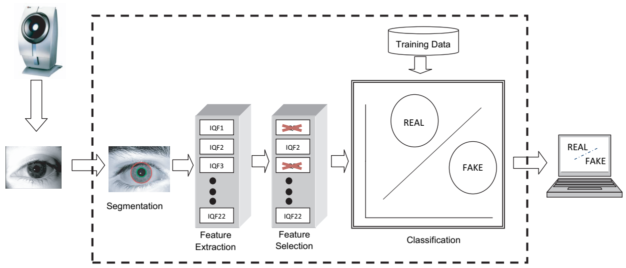

Figure 1. General diagram of the liveness detection system presented in this work.

as iris [11, 18] or face [12].

We propose a new parameterization based on quality related measures which is used in a global software-based solution for iris liveness detection. This novel strategy has the clear advantage over other previously proposed methods of needing just one iris image (i.e., the same iris image used for access) to extract the necessary features in order to determine if the eye presented to the sensor is real or fake. This fact shortens the acquisition process and reduces the inconvenience for the final user. The presented method is tested on an iris database which comprises 1,600 real and fake (high quality printed images) samples where it has proven its high potential as a countermeasure to prevent spoofing attacks. Different conclusions are also extracted regarding the most convenient types of quality features to be considered in liveness detection.

The rest of the paper is structured as follows. The liveness detection system is described in Sect. 2, with special attention to the different features used. In Sect. 3 the database and protocol used in the experiments is presented, and results are given in Sect. 4. Conclusions are finally drawn in Sect. 5.

2. Liveness Detection System

The problem of liveness detection can be seen as a two-class classification problem where an input iris image has to be assigned to one of two classes: real or fake. The key point of the process is to find a set of discriminant features which permits to build an appropriate classifier which gives the probability of the image vitality given the extracted set of features. In the present work we propose a novel parameterization using quality related measures which is tested on a complete liveness detection system.

A general diagram of the liveness detection system presented in this work is shown in Fig. 1. Just one input is given to the system: the iris image to be classified (the same one used for verification). In the first step the iris is segmented from the background, for this purpose, a circular Hough transform is used in order to detect the iris and pupil boundaries as proposed in [17]. Once the useful information of the total image has been separated, twenty-two different quality measures are extracted which will serve as the feature vector that will be used in the classification. Prior to the classification step, the best performing features are selected using the Sequential Floating Feature Selection (SFFS) algorithm [16]. Once the final feature vector has been generated the iris is classified as real (generated by a living eye), or fake (coming from a synthetic trait).

Class	**Features**
Focus	*IQF1*, *IQF4*, *IQF15*, *IQF16*
Motion	*IQF2*, *IQF5*, *IQF18*, *IQF20*
Occlusion	*IQF3*, *IQF6-12*, *IQF17*, *IQF19*, *IQF21*
Others	*IQF13*, *IQF14*, *IQF22*

Table 1. Summary of the 22 quality related features implemented in this paper classified according to the iris characteristic measured.

2.1. Feature Extraction

The parameterization proposed in the present work and applied to liveness detection comprises twenty-two quality-based features adapted from different parameters described in the literature. From a biometric point of view, the quality of iris images can be assessed by measuring one of the following properties: i) focus, ii) motion blur, iii) occlusion, and iv) others including the contrast or the dilation of the pupil. A number of sources of information are used to measure these properties such as the high frequency power spectrum, angle information provided by directional filters, pixel intensity of certain eye regions, or different ratios comparing the iris area to that of the image, or the iris and pupil sizes. Iris quality can be assessed either analyzing the image in a holistic manner, or combining the quality from local blocks of the image.

In the following, we give some details about the quality measures implemented in this paper, together with a short explanation of the rationale behind the use of those parameters in the proposed anti-spoofing system and why they may be useful, *a priori*, for a liveness detection problem such as the one addressed in the present work. A summary of the different quality features used in this work and the characteristic that they measure (i.e., class to which they may be assigned) is given in Table 1.

2.1.1 Focus features

Iris printed images are a 2D surface in opposition to the 3D volume of a real eye for which acquisition devices are thought. Thus, it is expected that the focus of a fake iris will differ from that of a genuine sample.

Intuitively, an image with good focus is a sharp image. Thus, defocus primarily attenuates high spatial frequencies,

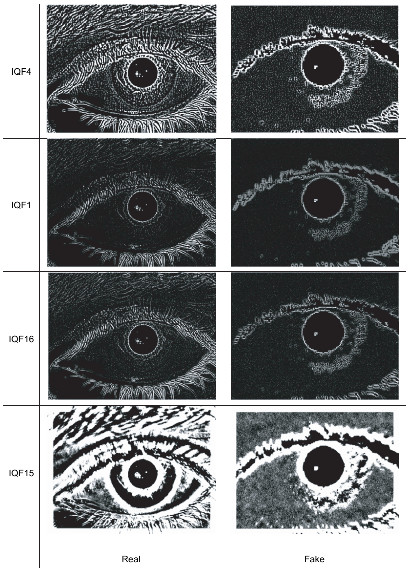

Figure 2. Example of the computation of the different focus quality features for a real and fake iris.

which means that almost all features estimating this property perform some measure of the high frequency content in the overall image or in the segmented iris region. The different focus estimators considered in this work are given below. In Fig. 2 an example of the computation of these features for a real and fake iris is shown.

- **High Frequency Power 1 (*IQF4*)** [5], which measures the energy concentration in the high frequency components of the spectrum using a high pass convolution kernel of 8×8.
- **High Frequency Power 2 (*IQF1*)** [19], very similar to the previous *IQF4* but uses a modified version of size 5×5 of the high pass filter proposed in [5].
- **High Frequency Power 3 (*IQF16*)** [19], analog to the previous *IQF1* but a new high-pass 5×5 convolution kernel is proposed.
- **High Frequency Power 4 (*IQF15*)** [1], it estimates the defocus of the image by computing the second order derivative (using a discrete approximation of the modified Laplacian) in order to high pass the iris images.

2.1.2 Motion features

It is expected that the degree of movement of an iris printed on a sheet of paper and held in front of a sensor will be different from that of a real eye where a more steady position can be maintained so that the small trembling usually observed in the first case should be almost imperceptible.

Figure 3. Power spectrum of a real and a fake iris images on its primary direction according to *IQF5*.

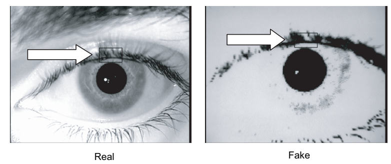

Figure 4. Region of interest used to estimate the iris occlusion according to *IQF3*.

Motion-related features try to estimate the image blur caused by motion (of the iris or of the sensor). The effect of motion is generally reflected on the directionality of the image, thus, these estimators are usually based on the computation of the preponderant directions within a given iris sample.

- **Vertical High Frequency Power 1 (*IQF2*)** [19], it uses a variation of the Sum Modulus Difference (SMD) filter proposed by Jarvis in [9] in order to measure the vertical high frequency power as indicator of the motion blur degree.
- **Vertical High Frequency Power 2 (*IQF18*)** [3], analog to the previous *IQF2* but using a new version of the vertical SMD filter.
- **Directional Strength (*IQF5*)** [10], it searches for the primary direction of movement in the iris images using directional masks (five degrees rotation between them) and computing the total power of the resulting filtered images. Then the final quality measure is taken as the strength of the Fourier coefficients which fall within a narrow window perpendicular to the previously estimated primary direction. In Fig. 3 we show the primary direction computation for a real and a fake iris.
- **Global Spectral Information (*IQF20*)** [20], it estimates the motion and defocus blurs simultaneously by considering the global spectral information and the image/iris ratio (see *IQF19*) of the segmented iris image.

2.1.3 Occlusion features

Fake iris samples captured from a printed image usually present a different contrast than real images, appearing in

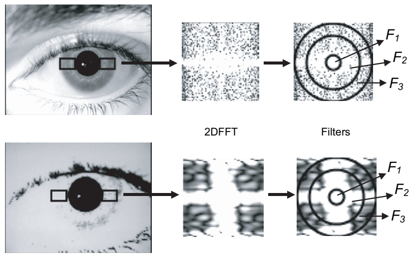

Figure 5. General process followed to estimate F_1, F_2 and F_3 for a real (top) and fake (bottom) iris. These parameters are then used for the computation of features *IQF6-12*.

the former very bright or dark sections which may be treated, in practice, as occluded areas. This can result in a different level of occlusion between real and fake samples.

Occlusion-related features try to detect those areas of the iris which are occluded by some external element such as the eyelids or the eyelashes. In this case different heterogeneous schemes have been proposed in the literature studying in general local characteristics of the iris image.

- **Region of Interest (*IQF3*)** [19], it analyzes the average value of the pixels in the region of interest, located 50 pixels above the pupil center and shown in Fig. 4.

- **Frequency Distribution Rates 1 (*IQF6-12*)** [13], these are different combinations (adding, substracting, multiplying or dividing) of three different parameters which consider respectively the power of the low (F_1), medium (F_2), and high (F_3) frequencies (computed according to the 2D Fourier Spectrum) of two local regions in iris images. The process followed to compute these three parameters is depicted in Fig. 5. Although here are included in the occlusion class, these quality descriptors may also be used to estimate other quality characteristics such as the motion or defocus blur.

- **Frequency Distribution Rates 2 (*IQF17*)** [4], similar to the previous quality features *IQF6-12* but in this case the iris is divided into multiple frequency regions (not just low, medium and high) and the spectrum is computed according to the 2D Continuous Wavelet Transform (2DCWT) which is more suited for deriving local quality measures.

- **Iris/Image Ratio (*IQF19*)** [20], it computes the ratio between the area of the segmented iris and the whole image. Depending on the sensor used for the acquisition, the distance from the trait to the device in order to capture a valid image can be different for a 2D surface (fake iris) than for a 3D volume (real iris). This may lead to significant differences between the two types of samples that can be useful in liveness detection.

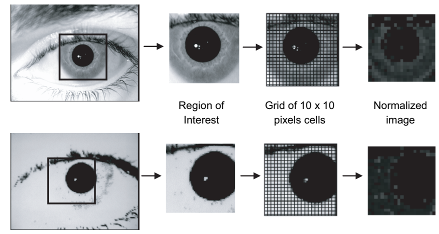

Figure 6. General process followed to compute *IQF13* for a real (top) and fake (bottom) iris image.

- **Binarization (*IQF21*)** [6], it estimates the iris area not occluded by eyelids, eyelashes and other elements by doing a binarization of the eye image.

2.1.4 Other features

In this category are included all those features measuring some different iris characteristic to those considered in the previous classes and which may be *a priori* useful for liveness detection. In particular, the two quality indicators taken into account here will be the contrast (similar to occlusion) and the pupil dilation:

- **Global Contrast (*IQF14*)** [1]. This parameter detects extremely bright or dark parts of the image (more common in fake iris samples). For images with 256 grey levels, pixels with very high or low values are set to a contrast value of 0 while the rest are normalized to a scale of 1-25.

- **Local Contrast (*IQF13*)**, this is a novel quality feature proposed in the present work is inspired in the technique presented in [1] for occlusion estimation. A square region covering the iris and pupil is divided into a 10×10 cell grid. Each cell is assigned a value which corresponds to the power of its medium frequencies. The final quality measure is obtained averaging the number of cells which value falls between 20 and 60 by the total number of cells. The general process to compute *IQF13* is depicted in Fig. 6.

- **Pupil Dilation (*IQF22*)** [6], it computes the ratio between the pupil and iris radios.

2.2. Feature Selection and Classifier

Due to the curse of dimensionality, it is possible that the best classifying results are not obtained using the set of twenty-two proposed features, but a subset of them. As we are dealing with a twenty-two dimensional problem there are $2^{22}-1$ possible feature subsets, which makes unfeasible to perform exhaustive search. For this reason Pudil's Sequential Floating Feature Selection (SFFS) algorithm [16] is used as feature selection method as it has proven before a

# features	Feature Subset	Class	ACE_{train} (%)	ACE_{test} (%)
1	*IQF6*	Occlusion	19.25	24.00
	IQF10	Occlusion	19.25	20.87
	IQF11	Occlusion	18.50	22.50
	IQF13	Contrast	5.75	7.37
	IQF19	Occlusion	4.25	10.5
	IQF21	Occlusion	14.75	14.62
2	*IQF19 + IQF4*	Occlusion + focus	2.25	5.00
	IQF19 + IQF13	Occlusion + contrast	0.25	3.00
	IQF19 + IQF14	Occlusion + contrast	2.75	6.50
	IQF19 + IQF15	Occlusion + focus	2.50	4.75
	IQF19 + IQF21	Occlusion + occlusion	4.00	5.37
	IQF19 + IQF22	Occlusion + dilation	0.00	0.00
3	*IQF19 + IQF22 + IQF13*	Occ. + dilat. + contrast	0.00	0.00
+ 3	*IQF19 + IQF22 + IQF13* + any	Occ. + dilat. + contrast + any	0.00	0.00

Table 2. Classification results for the best feature subsets. ACE_{train} and ACE_{test} represent respectively the Average Classification Error in the train and test sets.

very good performance compared to other feature selection techniques [8].

For classification we have used a standard quadratic classifier fitting the training data with multivariate normal densities with diagonal covariance estimates stratified by group.

3. Database

The database used in the experiments comprises real and fake iris images of 50 users of the BioSec baseline database. This fake iris database was acquired in the frame of a research work to evaluate the vulnerabilities of iris verification systems to direct attacks [17]. In that work, the spoofing attacks carried out on these data achieved a success rate of over 30% for all the different scenarios tested. The high performance of the direct attacks described in [17] proves that the fake samples considered in the present work pose a real threat to iris-based biometric systems.

The database follows the same structure as the original BioSec database, therefore, the data used in the experiments comprises 50 subjects $\times$ 2 eyes $\times$ 4 images $\times$ 2 sessions $=$ 800 fake iris images and its corresponding original samples. In the experiments both eyes of the same subject are considered as different users (i.e., $50 \times 2 = 100$ users). The acquisition of both real and fake samples was carried out using the LG IrisAccess EOU3000 sensor.

For the experiments the database is divided into a train set (comprising 200 real images and their corresponding fake samples corresponding to the first 25 users in the database) where the feature selection process and the classifier training are performed, and a totally independent test set (with the remaining 600 real and fake samples corresponding to the last 75 users of the database) to evaluate the performance of the proposed liveness detection approach.

4. Results

The first objective of the experiments is to find the optimal feature subsets (out of the proposed 22 feature set) for the considered database using the SFFS feature selection algorithm. The fitness function to be optimized by the algorithm for each of the subsets is the classification performance computed on the train set in terms of the Average Classification Error, which is defined as $\text{ACE} = (\text{FLR} + \text{FFR})/2$, where the FLR (False Living Rate) represents the percentage of fake irises misclassified as real, and the FFR (False Fake Rate) computes the percentage of real irises assigned to the fake class.

Once the optimal subsets have been found and evaluated using the train set, their performance is finally assessed on the test set (which has no overlap with the training samples) in order to obtain totally unbiased results about the discriminant capabilities of the system. In Table 2 we summarize the results obtained in the classification process. For clarity, only the best feature subsets in the training phase are given. The performance results shown correspond to the classification threshold where FLR=FFR=ACE.

Several observations may be extracted from the results shown in Table 2: i) the proposed system presents a very high potential as a new method to prevent direct attacks, reaching a 100% of correctly classified samples for the particular fake data considered; ii) for the fake samples taken into account (high quality iris printed images) and for the sensor used, the occlusion features seem to present the best single performance for liveness detection; iii) when several features are combined the best performance is reached for complementary parameters measuring each of them a different characteristic from the iris image (e.g., see the best combination for 3 or more features).

As was explained in the description of the occlusion parameters (see Sect. 1), some of these features measure the difference in illumination that exists between real 3D irises (uniform illumination) and fake 2D samples (very bright or dark areas). This fact can account for the very good individual behaviour presented by this type of quality measures in the liveness detection problem addressed.

5. Conclusions

A novel liveness detection scheme for iris, based on quality related measures has been presented. The proposed method was tested on an iris database which comprises 1,600 real and fake images, where it reached a total 100% of correctly classified (real or fake) samples, proving this way its high potential as a countermeasure to prevent direct attacks to the sensor. Furthermore, different conclusions have been extracted regarding the potential of the different types of quality features considered for liveness detection and the best way to combine them.

Although the results presented in this work have been obtained for a specific type of synthetic traits (i.e., high quality iris printed images), we firmly believe that the proposed method can also be used to detect other types of fake data (e.g., printed lenses) by selecting the subset of parameters that better adapts to the new anti-spoofing problem. Even though the very high performance shown for the tested database may not be generalized, we do think these results give an idea of the high potential of the proposed method. In fact, it should not be an easy task to generate such a synthetic trait that it possesses all the measured quality related features in the same degree as a real sample.

Liveness detection solutions such as the one presented in this work are of great importance in the biometric field as they help to prevent direct attacks (those carried out with synthetic traits, and very difficult to detect), enhancing this way the level of security offered to the user.

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