Pupil Dilation at Synthetic Off-angle Iris Images

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Abstract: With the development technology, the conventional stand-on iris recognition system is giving its place to a new biometrics research area; a stand-off iris recognition system. Previously encountered non-ideal images, which are captured from a controlled or constrained environment unintentionally, are put in the center of the new system. Thus; some degradation factors that affect the accuracy and performance of iris recognition system, such as pupil dilation, image acquisition angle, corneal refraction, focus, depth of blur, complex 3D iris texture, and limbus impact have come into prominence. In this paper, we investigate how pupil dilation variations affect the Hamming distance changes for different gaze angles. Based on the results from simulated experiments with the real iris textures, it is proven that pupil dilation effect has an influence on the Hamming distance score as the angle of iris images varies between frontal and off-angle.

Keywords: Iris recognition, pupil dilation, off-angle images, biometrics.

1 Introduction

Advanced technology has recently brought hot topic in front us a more complicated scenario; stand-off iris recognition. To come into a small-size, low-power and affordable stand-off identification systems with wireless communication capabilities, *non-ideal,* mostly off-angle images are become crucial. Of course, there is still some work to develop more robust, truthful methods in traditional iris recognition systems for *ideal* iris images, but a new trend certainly will be fresh methods for *non-ideal* iris images, which are frequently captured from intelligent stand-off systems. Especially off-angle iris images in stand-off systems bring potential serious challenges; pupil dilation, occlusion, image quality, image acquisition angle, focus, blur, specular reflections, complex 3D iris texture, limbus impact and illumination variations. These are encountered burning questions and cause the decrement in accuracy and performance of iris recognition. Examples of frontal and off-angle iris images of the same eye with various dilation levels are shown in Fig. 1.

There are few attempts in biometrics literature to solve these issues for stand-off iris recognition systems. Daugman [Da07], Schukers et al. [Sc07] and Li et al. [Li13] proposed some approaches to improve the accuracy of the recognition system for off-angle iris images. Their approaches such as affine transformations, elliptical unwrapping and perspective transform only concentrate on perspective geometric distortion by ignoring challenging issues. Despite the improvement in the recognition performance;

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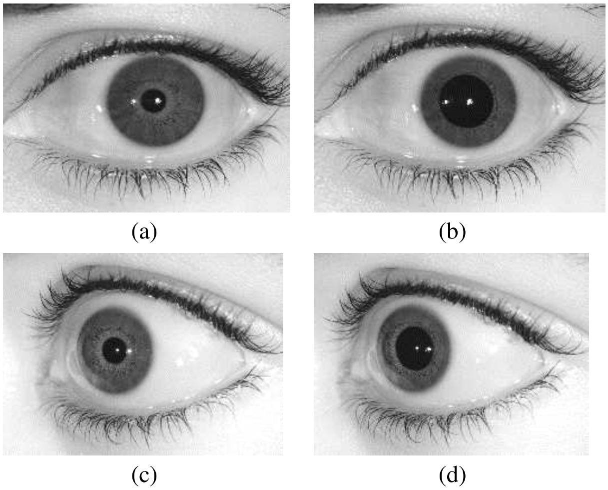

Fig. 1. (a-b) frontal iris images with 0.26 and 0.58 dilation levels, respectively. (c-d) 40° off-angle iris images with 0.30 and 0.50 dilation levels, respectively.

pupil dilation, corneal refraction of light, 3D iris textures, depth of field blur and limbus effect are still influencing important factors beyond 30°. Frigerio et al. [Fr12] and Santos-Villalobos et al. [Sa12] focused on corneal refraction effect at off-angle iris images. Karakaya et al. [Ka13] remarked limbus effect on off-angle iris images that degrades the performance of stand-off systems distinguishably.

Moreover, the influence of the change of the pupil's dimension is one of the most active research subjects both in stand-on and in stand-off systems. There are some pioneer works examining the effects of pupil dilation for only frontal iris images. Wyatt [Wy00] revealed in 2000 a very important biological analysis regarding the variations of the iris and pupil. Alongside the non-linear influence of the changing pupil on radial distance, he claimed that it also has an angular influence. Daugman's [Da04] approach uses a 'rubber-sheet' model to show the modification of pupil and its' dimension. In 2005 X. Yuan et al. [YS05] developed a normalization technique using linear and non-linear methods at the same time. Ma et al. [Ma04], Thorton et al. [TSK07], and Kerekes et al. [Ke07] highlighted how the pupil variations of iris images have effects on the false non-matches.

Hollingsworth et al. [HBF09] carried out a study on Daugman's rubber-sheet model that if the dilation level is the same as the compared image, the identification of images with small pupil is more successful; however, if the images are off-angle, similar comparisons have given unexpected, inconsistent results. And, the National Institute of Standards on Technology (NIST) [Gr09] conducted a larger study on iris recognition systems and also verified the results of [HBF09]. They were in agreement that variations of pupil dilation degrade the system performance. Ortiz and Bowyer [OB11] developed a strategy on the enrollment stage that could sense the eye images and their modifications to increase the performance of iris recognition systems. Tomeo-Reyes et al. [To15] showed that dilation is not a linear process and to improve the accuracy of the iris recognition under different degrees of pupil dilation, nonlinear normalization scheme is needed.

In this paper, we study the pupil dilation effect on the off-angle iris images by using the biometric eye model with real iris textures at various levels of pupil dilations. We present how Hamming distance changes for different off-angle iris images where they are coming from the same or different subjects.

2 The Effect of Pupil Dilation

The human eye is a complex and only visible internal organ that remarkably demonstrates the architectural wonders of the human body. Like a camera, the eye is able to refract light and produce a focused image that can stimulate neural responses and enable to see. The pupil is the transparent area and its black appearance is attributed to the fact that light rays entering through the pupil are either absorbed directly by the retina or absorbed after diffuse reflections within the eye. Several factors have an impact on pupil size, including the degree of retinal illuminance, accommodative state of the eye, individual's age and also emotional conditions. One difficulty is that the size of the pupil changes involuntarily and deforms iris shape non-linearly. A sphincter muscle and a set of dilator muscles control the size of the iris together to adjust the amount of incoming light through the pupil. Optical coherence tomography (OCT), a medical imaging technique, is used to capture the image of the eye structures and to determine their parameters such as thickness, height and shape. Fig. 2 shows the OCT image of the same eye with constricted and dilated irises from their vertical cross-sections. We can observe that length of the dilated iris is smaller than the constricted iris with almost same height due to the intertwining sphincter and dilator muscles. Also, we observed that iris region close to pupillary boundary is deformed more than limbus boundary as discussed in [To15]. Therefore, limbus occlusion becomes more severe in dilated iris images because more percentage of the iris region become occluded in dilated iris images. Karakaya et al. [Ka13] showed that limbus occlusion causes significant degradation in off-angle iris recognition performance. In order to illustrate the effect of the pupil dilation on off-angle iris images, we used a biometric eye model as designed in [Sa12]. This eye model includes the cornea, aqueous humor, limbus, iris and sclera with their approximate geometry of eye anatomy and utilizes a ray tracing method (POV-Ray).

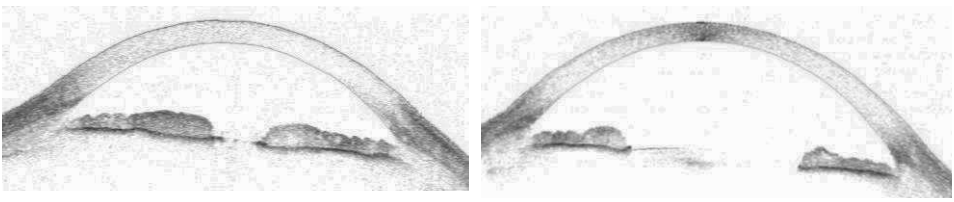

Fig. 2. OCT image of same eye with (left) constricted and (right) dilation irises.

In general,ray tracing techniques can generate an eye image to compute the refraction of the entering and outgoing lights which strike on the iris texture with regard to its angle to the cornea. For the reconstruction of the frontal projection of an off-angle iris image, Persistence of Vision Ray-tracer is used to trace light rays from the camera's sensor to the iris plane of the eye model. For better visualisation, we first generate iris images by using the eye model with a circular patterns covered on the 2D iris plane at different dilation. Fig. 3 and Fig. 4 shows both frontal and off-angle images of eye models are captured from 0° and 50° in angle and with 0.23 and 0.53 dilation levels and their normalized iris images, respectively. The circular iris 2D texture which is between the inner and the outer boundary, is unwrapped and normalized by an elliptical linear rubber-sheet model with fixed intervals. The iris is unwrapped from three o'clock position in clock-wise direction and the pupillary part corresponds to the upper part of the normalized image. The circular iris texture is composed of six groups and each group has five different colors where it has totally 30 circles encircle one and other.

Fig. 3(a, c) shows the frontal iris images with 0.23 and 0.53 dilation levels, respectively. Despite of the whole circular patterns are visible in Fig. 3(a), 4 circles disappeared in Fig. 3(c) because the increment in dilation level cause the limbus occlusion at the iris pattern close to the limbus boundary. However, the limbus occlusion due to the dilation in frontal iris images affects equally at every sides of the limbus boundary. This effect can be observed easily normalized iris images in Fig. 3(b, d) where circular iris patterns in both frontal iris images with different dilation levels appear as nearly (with some distortions, like wrinkles) straight lines. Therefore, the effect of the pupil dilation in frontal iris images can be minimized by normalizing the iris images using linear rubber-sheet model. Due to the limbus occlusion, linear unwrapping could not fully eliminate the pupil dilation effect but it will tolerate the small dilation difference in two iris images as discussed in the biometric literature [HBF09]. Fig. 4(a, c) demonstrates off-angle iris images captured at 50° in angle with 0.23 and 0.53 dilation levels, respectively. Compared with frontal iris images at the 0.23 dilation levels, we observed that limbus occludes more iris texture on the left side than other sides for off-angle iris images and causes optical distortion and data loss.

Since limbus occlusion is unevenly changes at different sides of the iris pattern, traditional linear unwrapping method stretched the normalized iris images differently as shown in Fig. 4(b). When the dilation level of the off-angle iris images increased, the impact of pupil dilation on the off-angle iris images can be viewed clearly in wavy normalized iris image as shown in Fig. 4(d).Combination of camera capturing angle and increment in dilation level cause significant distortions at circular iris patterns in the central region of the normalized off-angle iris images. Therefore, in order to remove the effect of the pupil dilation in off-angle iris images, linear rubber-sheet model is not sufficient.Using the traditional iris matching system on these kind of images produces a Hamming distance of 0.45 which is well within the impostor distribution. Reasons for this dissimilarity are not only the corneal refraction distortion and the effect of three-dimensional structures in iris but also the limbus occlusion and pupil dilation.

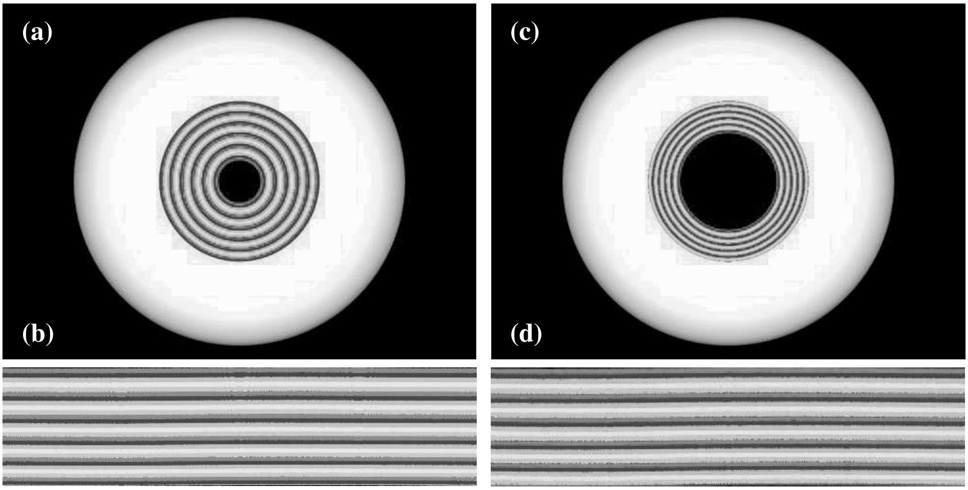

Fig. 3. (a, c) Frontal image of the eye model with circular iris texture at different dilation levels (b,d) their normalized image by using the elliptical rubber-sheet unwrapping model.

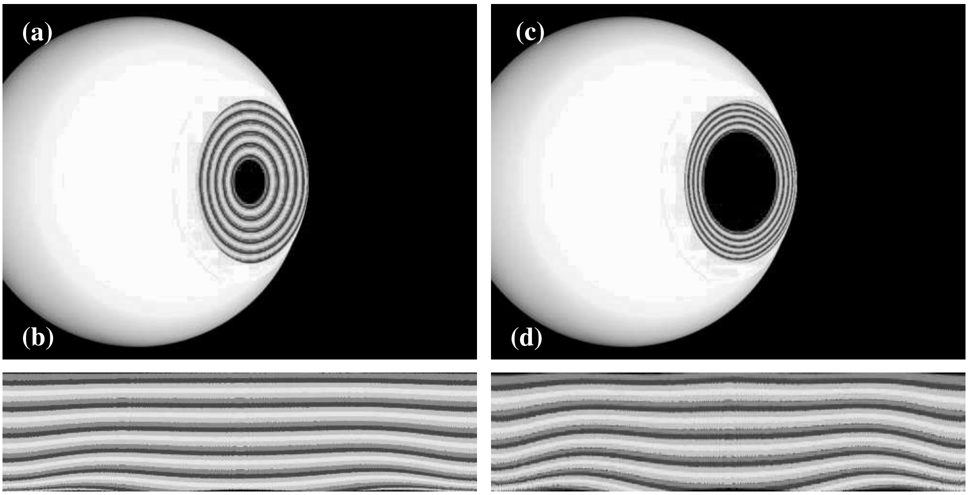

Fig. 4. (a, c) Off-angle image of the eye model with circular iris texture at different dilation levels (b, d) their normalized image by using the elliptical rubber-sheet unwrapping model.

3 Experiments and Results

The construction of a set of synthetic eye images as a dataset involves the extraction of the real iris textures with different dilation levels from each subject's acquired eye images. We generate the synthetic iris image datasets by using a biometric eye model

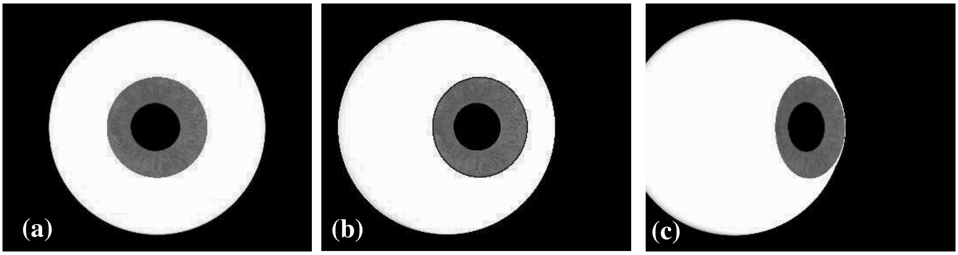

Fig. 5. Rendered sample iris images by (a) frontal camera and (b-c) off-angle camera from 20° and 50° angles, respectively where dilation level is fixed at 0.38.

described in [Sa12] with real iris patterns. The textures of the iris images with different dilation levels are extracted from 14 different individuals at Oak Ridge National Laboratory Iris Dataset. Each iris pattern at different dilation levels is cropped from pupillary boundary to sclera boundary and feed into the biometric eye model to render synthetic iris images from different angles. Dilation levels of each subject range from 0.23 to 0.53 with 0.05 step size and angle of image acquisition range from 0° to 50° with 10° step. Sample rendered iris images as shown in Fig. 5 by changing the gaze angle of image at 0.38 fixed dilation level. Although the nearly same amount of iris area (the right and the left side) for frontal iris image in Fig. 5(a), off-angle iris images' both sides of iris plane are totally different from each other in Fig. 5(b-c) as and discussed earlier. After the segmentation step, iris images captured from different angles at different dilation levels is normalized based on the elliptical pupillary boundary and visible iris boundary by using linear elliptical unwrapping that samples the iris image with respect to the iris center to account for iris eccentricity, shifted centers, and rotation. Then, OSIRIS's phase-quadrant demodulation [Kr09] is used to generate the iris codes. After, Hamming distance scores between frontal and off-angle iris images were calculated to measure the similarity of the iris images. In this dataset each subject hasn't got every dilation levels, unfortunately. Thus, our work has been limited between 0.23 and 0.53 for inter-class Hamming distance. For intra-class Hamming distance, we average the results of each subject with its available dilation levels. Fig. 6 shows the Hamming distance scores between frontal and off-angle iris images of the same subject with camera angle ranging from 0 to 50 degrees in angle and dilation level ranging from 0.23 to 0.53. Each line represents different gaze angles and each gaze angle is compared with iris images with the frontal iris image at 0.23 dilation level. In this figure, we first observed that even if gaze angle is fixed, all average Hamming distance scores at the inter-class distribution increase as the dilation level increases. For example, the matching scores between frontal iris images at different dilation levels increase from 0 to 0.35 based on the dilation level difference. Since the Hamming distance score is less than the defined threshold, the linear rubber-sheet model can be used to eliminate the effect of the pupil dilation for the frontal iris images. Second, we observed that the Hamming distance increases from 0 to 0.40 as the image acquisition angle increases even if the pupil dilation is fixed at 0.23. This result shows us how the gaze angle affects the performance of the iris recognition without the effect of the pupil dilation. The main reason is that

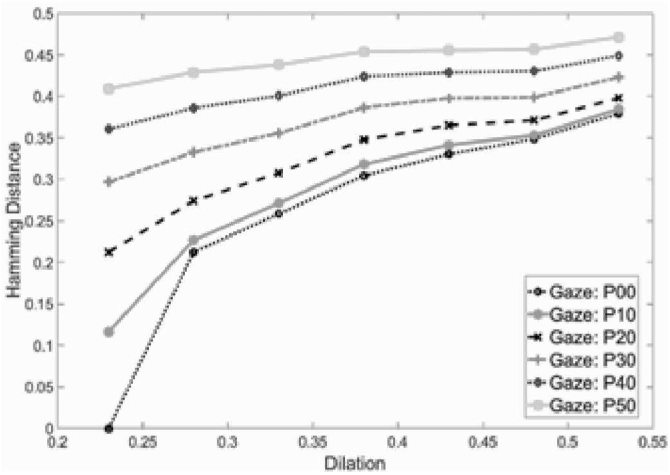

Fig. 6. Intra-class Hamming distance scores between frontal and off-angle iris images with dilation ranging from 0.23 to 0.53.

corneal refraction and limbus occlusion exhibits distortion on the off-angle image even when there is dilation change and the amount of distortion increases as angle increases. The result with dilation fixed at 0.23 provides us a baseline to determine how much additional error introduced by dilation exclusively from corneal distortion and limbus occlusion for other off-angle images. Third, we observe that irises with large pupil dilation are affected for off-angle data capture where Hamming distance between frontal and off-angle images increases ranging from 0.1 to 0.47 depending upon the pupil dilation level. This shows why the linear rubber-sheet model is not adequate to remove the effect of the pupil dilation in off-angle iris images. Compared to the iris images captured from large gaze angles, subjects with the frontal shot have better performance in off-angle iris recognition due to less corneal refraction and limbus occlusion.

4 Conclusions and Future Work

The goal of this study was to characterize quantitatively how pupil dilation is important in terms of the performance and accuracy on the stand-off iris recognition systems. We approached to bring out into the open this challenge using the anatomically approximate model of the human eye in a ray-tracing algorithm. This method provided our experiments with well-controlled so that we could focus only on the effect of pupil dilation on frontal and off-angle iris images. Based on our results, difference in pupil dilation level can cause significant errors at the performance and accuracy of stand-off iris recognition systems. We will study on to reduce the impact of pupil dilation for the stand-off iris recognition systems and to find comprehensive solution by using eye model to eliminate all these challenging issues together.

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