Comparison of Elliptical Unwrapping and Frontal Projection for Off-angle Iris Normalization

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ABSTRACT

Iris recognition is one of the most accurate biometric recognition techniques, however off-angle iris recognition has yet to have an established comprehensive recognition framework. This is due to the difficulties in the recognition of off-angle iris image inconsistencies within the iris patterns when gaze deviations are present. In this work, we investigate different iris normalization techniques and compare their performance. The two methods under investigation include elliptical normalization and circular normalization after frontal projection of off-angle iris recognition. Elliptical normalization samples the iris texture using elliptical segmentation parameters: x, y, r_1, r_2, θ where x, y are coordinates, r_1, r_2 are the radius, and θ is the orientation. Also, when investigating circular unwrapping, we will be using the ellipse segmentation parameters to estimate the gaze deviation. The image will be projected back to a frontal view using perspective transformation. Then, we segment the transformed image and normalize using the circular parameters: x, y, r where x, y are coordinates and r is the radius. We further investigate if: (i) elliptical normalization or circular unwrapping recognition performance is higher, and (ii) if the two segmentation methods in circular unwrapping increase the recognition efficiency.

Keywords - Iris recognition, segmentation, elliptical unwrapping, frontal projection, off-angle iris.

I. INTRODUCTION

Biometrics include physical and behavioral characters, the former include face, fingerprint, retinal and iris, and the ladder refers to voice or type cadence and scent signature. With technology continually evolving, there is an ever-pressing need for fast, secure, and accurate biometric recognition systems within the security field. Fast and reliable identification is essential with the ever-increasing need for access control of millions of people passing through secure areas. For this reason, there are several biometric systems present in our everyday life using biometric methodologies. Existing studies on these biometric systems have shown iris recognition as being the most unique, stable, and accurate biometric identifier [1][2][3]. Since 2001, iris recognition has become more prevalently used in areas such as passport control, criminal/terrorist identification, missing persons cases, and restricted military installments.

Due to the reliability of the distinctiveness and accuracy, iris recognition or a mix of iris recognition along with another biometric identifier are preferred methods of identification. Especially, at the time of the COVID-19 pandemic, iris recognition also provides a touchless biometric solution for those wearing protective masks and gloves. However, the quality of the captured iris image determines the accuracy of the recognition systems. For a majority of images, the quality of the image can be determined to be non-deal. Studies have presented algorithms that have successfully recognized these non-ideal images and improved performance of its predecessors [4][5].

With the development of the standoff biometric systems, iris images can be captured in a less restrictive environment where subjects can move around with more freedom. Therefore, standoff iris images are generally non-ideal images and may also include gaze angle and pupil dilation differences. Off-angle iris images, unlike frontal images, present several distortion issues. For example, Figure 1 shows an example of a frontal and off-angle iris image. Recent studies have derived robust algorithms and deep learning techniques to handle the distortions present. Convolutional neural networks have also been proposed to compensate for the degradations on iris segmentation [6]. Which has shown improvements in the segmentation of off-angle images. However, there is still not a comprehensive framework to handle the recognition of off-angle iris images. After segmentation, there are different approaches to normalize the iris image. In this paper, we compare two different normalization approaches to handle iris gaze deviations in off-angle iris images.

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(a) (b)

Figure 1: Example frontal and off-angle iris images at (a) frontal view, 0º and (b) off-angle gaze 50º.

The rest of this paper is structured as follows: Section II presents background and related works in iris recognition system. In Section III, two normalization approaches to off-angle iris images will be compared and discussed including elliptical unwrapping and frontal projection with circular unwrapping. Experiments and results are presented in Section IV. Finally, we conclude in Section V.

II. BACKGROUND AND RELATED WORKS

In the existing literature, there have been multiple algorithms designed and implemented to handle frontal iris recognition. These literature works have mainly segmented frontal iris images by fitting circles to the pupil and iris boundaries while using different approaches when fitting the circles to these boundaries. Daugman [7] in 2004 proposed the integro-differential operator which exhaustively searches three parameters of a circle (the radius r and center coordinates x, y) to maximize angular integral over the radial derivative of iris images. In order to handle occlusions such as eyelid and eyelashes, Eskandari, etc. [5] used subpattern-based pattern approaches (I.E., Principal Component Analysis (PCA), subpattern-based PCA (spPCA) and modular PCA (mPCA) methods) to extract such present features. Literature today has started to dive into deep learning technologies to segment frontal iris images. S. Bazrafkan and P. Corcoran [8] proposed a deep learning approach that generates ground truth segmentation using high-quality images acquired through outsourced database sets. This approach improved the accuracy of the best algorithms in literature presented.

Despite improvements toward off-angle iris recognition, there has yet to be a dedicated comprehensive recognition framework. This is due to difficulties in the recognition of off-angle iris image inconsistencies within the iris patterns when there are gaze deviations or angle deviations, occlusions, or other irregularities are present i.e.., corneal limbus, reflection spots, dilation. Therefore, traditional iris recognition systems have a harder time in successfully identifying and recognizing these types of errors in off-angle iris images. Karakaya, et. al. [2] proposed a segmentation algorithm which would use edge detection, edge elimination, edge classification, and ellipse fitting techniques for off-angle iris images, where ellipses are fitted to the inner and outer boundaries. This method improves the segmentation results for off-angle iris images by eliminating the outer regions that cannot be part of the pupil and iris boundaries.

After segmentation, the focus is the normalization of the segmented iris image, also known as iris unwrapping. There are different normalization techniques presented in past research. Two favored ways to normalize segmented iris images include (i) Daugman's elliptical unwrapping and (ii) Schukers et al. [9] perspective projection. Daugman's Rubber Sheet Model is used throughout research to normalize iris images [7]. This model takes the segmentation points and unwraps the iris counterclockwise. This model is used in both circular and elliptical unwrapping; shown in the flow chart in Figure 2. There have also been improvements to the Rubber Sheet Model since the original implementation date. Mohammed and Al-Gailani [10] proposed an algorithm based on Daugman's algorithm that improved the speed of the normalization step within the process of iris recognition. Perspective projection, aka. frontal projection compensates the off-angle degree to rotate the image back to its frontal view. After projection, the image is normalized using circular unwrapping in the newly developed frontal image [9]. Initial implementation of both resulted in poor recognition performance beyond that of 30º. These methods also did not handle light refraction at the cornea or limbus occlusions.

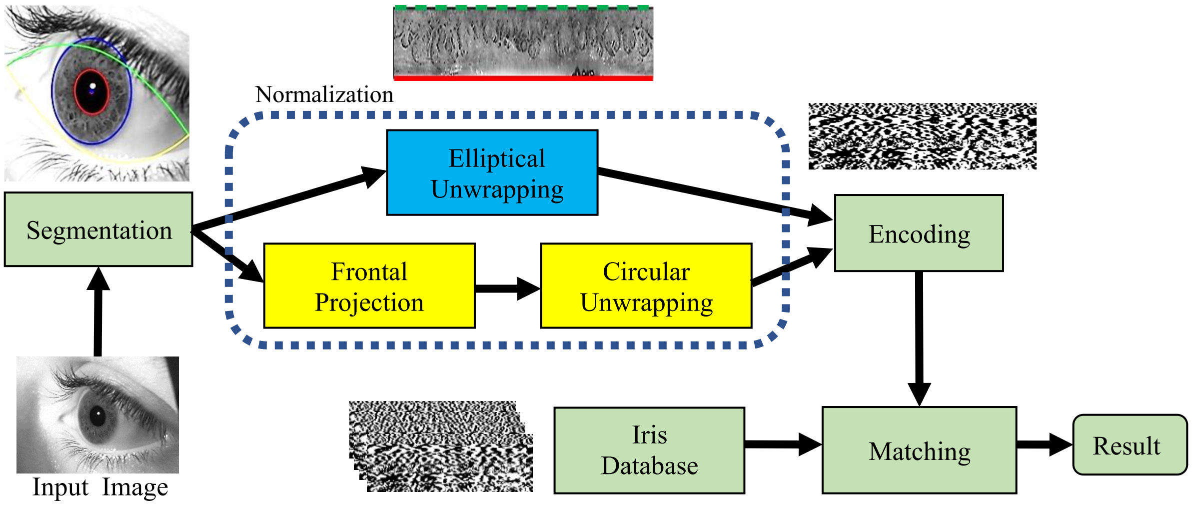


Figure 2: Flow chart representing two different approaches to recognize the off-angle iris images. Green boxes represent the traditional steps where both approaches follow. Blue box at the top of the fork represents elliptical unwrapping. Yellow boxes at the bottom of the fork represent the frontal projection with circular unwrapping.

III. METHODS

Traditional iris recognition systems generally use the circular unwrapping method to normalize the frontal iris images after segmenting the pupil and sclera boundaries as circles. However, the fitting of circles to boundaries to off-angle images is not feasible because the iris shapes change from circular to ellipses due to the gaze angle between camera and eye. Therefore, we cannot use the circular unwrapping directly to off-angle iris images. In this paper, we investigate two different approaches for off angle iris normalization including (1) elliptical unwrapping and (2) circular unwrapping with frontal projection. Figure 2 illustrates the flow chart of the two different approaches to recognition of off-angle iris images. Green boxes represent the traditional steps where each approach follows, such as the segmentation, encoding, and matching steps. The difference in these two approaches is mainly in the normalization step. The blue box at the top of the fork represents the elliptical unwrapping approach. While the yellow boxes at the bottom of the fork represent the frontal projection with circular unwrapping.

In the first approach, elliptical unwrapping uses the elliptical parameters being fitted to the inner and outer boundaries of the iris. The inner boundary, also called the pupil boundary, separates the pupil from the iris. The outer boundary separates the iris and sclera and is also known as the sclera boundary. The iris segmentation step fits an ellipse to the pupil and sclera boundaries where each ellipse consists of five parameters: the center coordinates x, y the radius of minor and major axis, r_1, r_2 and the orientation, θ. In this paper, we used our previous segmentation algorithm [2] to find the segmentation parameters of the off-angle iris images. This algorithm first finds the best ellipse for the inner and outer boundaries. Then, to ensure the ellipse parametrization is accurate, we segment manually using the ground-truth tool purposed in [11]. To validate the segmentation and reduce subjective decision making, the results from the above segmentation are controlled by at least two operators, [12]. The resulting segmentations are also used as ground truth variable for the frontal projection method. In elliptical unwrapping, the iris texture between the pupil and sclera boundaries are sampled using the rubber sheet-based approach. The size of the normalized image is set to 64x512 and we start sampling from 3 o-clock location with the origin at the sclera center. Therefore, 64 linear points are selected between the pupil and sclera boundaries with the same distance measurements, as shown in Figure 4(a). This procedure is repeated 512 times, increasing the sampling angle approximately 0.7^{o}.

The second approach for off-angle normalization is circular unwrapping with frontal projection. This approach consists of two steps including the frontal projection and circular unwrapping. The off-angle iris image is first converted back to its frontal view using frontal projection using the elliptical parameters of the iris boundaries. In the projected image, the boundaries of iris texture become circular in shape. Then, we normalized the projected image using circular unwrapping. Circular unwrapping also uses the rubber sheet-based approach as shown in Figure 4(b). For the normalized images set to 64x512, we select 64 linear points from the circular pupil boundary to the sclera boundary from every 0.7^{o} in angle rotation starting from the 3 o-clock location.

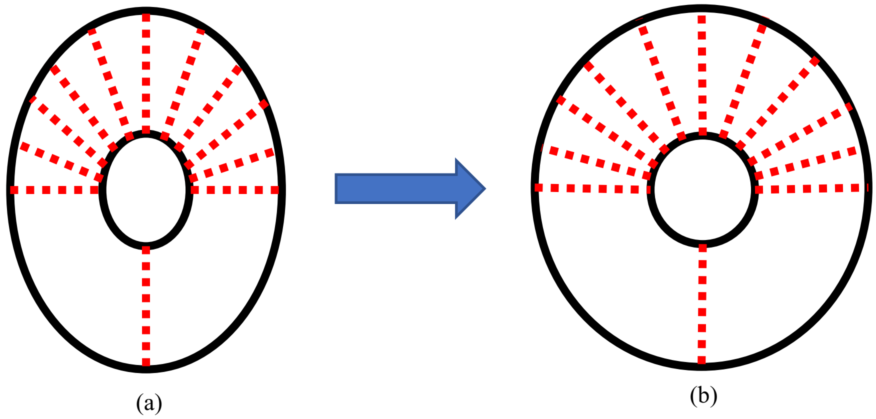


Figure 4: Rubber sheet-based sampling locations for different normalization approaches. (a) Elliptical unwrapping (b) circular unwrapping.

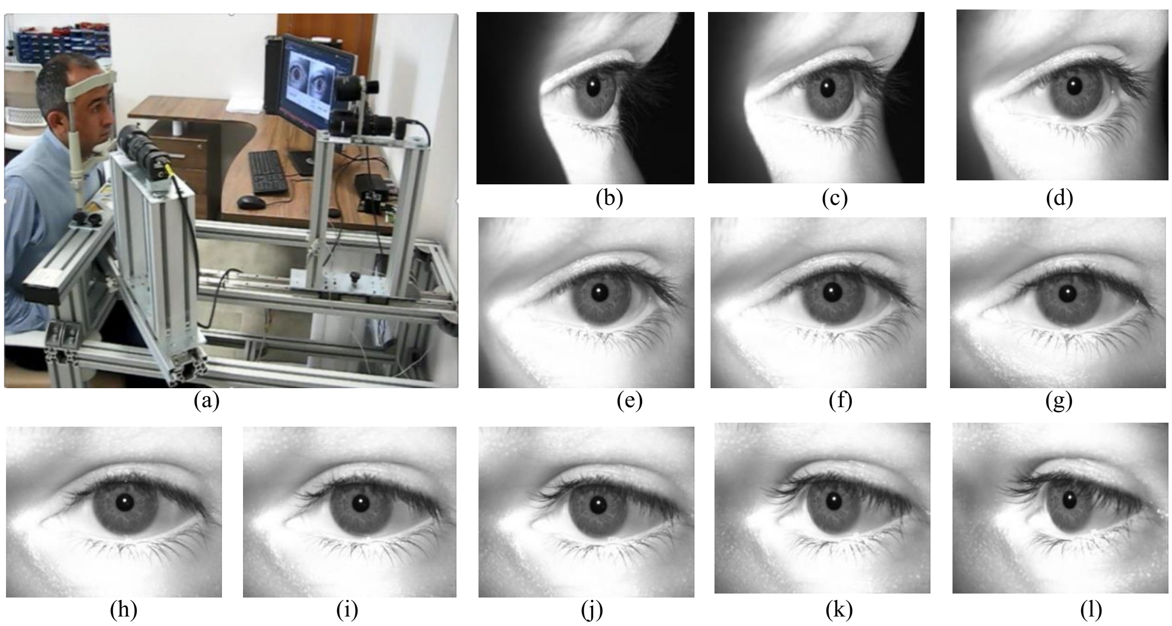
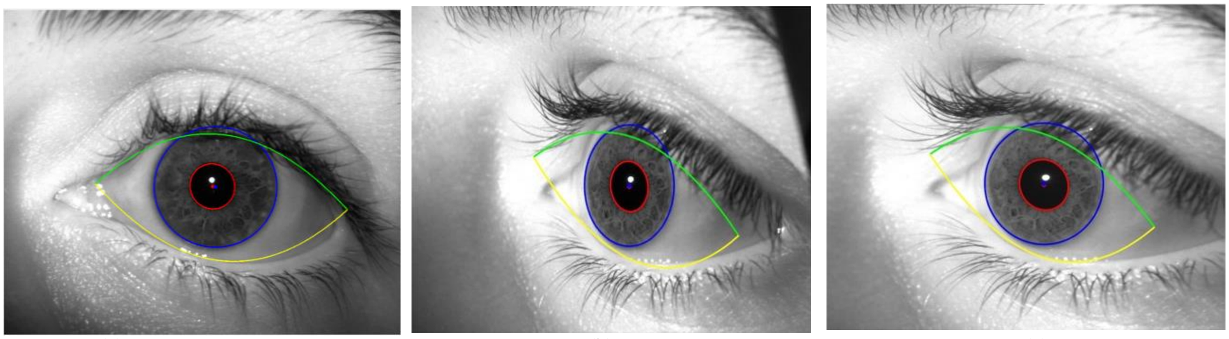


Figure 3: (a) Experimental setup of off-angle iris image capturing of off-angle iris dataset. Example images from off-angle iris databases, (b)+50° angle, (c)+40° angle, (d)+30° angle, (e)+20° angle, (f)+10° angle, (g) 0° angle, (h)-10° angle, (i)-20° angle, (j)-30° angle, (k)-40° angle, (l)-50° angle.

IV. EXPIRIMENTAL SETUP AND RESULTS

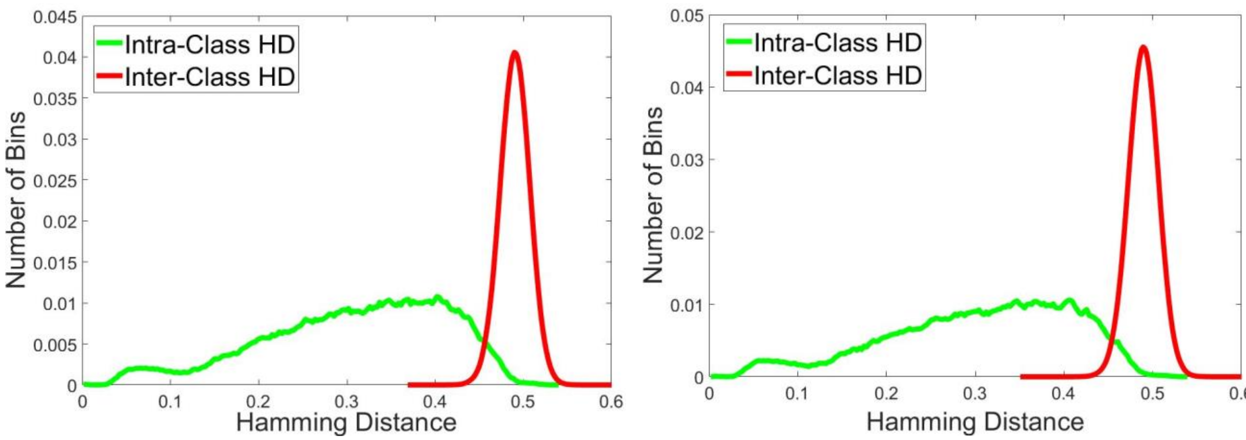
We performed our experiments on our off-angle iris dataset. The iris images were captured by two near-infrared sensitive IDS-UI-3240ML-NIR cameras as shown in Figure 3(a). The frontal camera is attached on a fixed arm and the off-angle camera is attached on a moving arm to capture the iris images. Each camera captures 10 iris images per angle, where 100 frontal and 110 off-angle iris images are captured for each subject. The frontal camera captures the eye images from the frontal view of the subjects at gaze angle of 0°. The off-angle camera captures off-angle iris images by shifting at increments of 10° horizontally from -50° to +50° angles, which can be seen in Figure 3(b-l). Readers can find more details about the off-angle iris dataset in [13]. In our experiments, we include frontal and off-angle iris images from left eye of 78 subjects. Since we excluded blinked eye images from the dataset, the total number of iris images is 8457.

To compare elliptical unwrapping and circular unwrapping with frontal project, we segmented each iris image, normalized them using both approaches, and calculated the Hamming distance between the frontal and off-angle iris images. Figure 5 shows frontal and off-angle iris images from the same subject and their results after using the elliptical



(a) (b) (c)

Figure 6: Sample frontal image with 0º gaze angle and off-angle images with 50º gaze angle. (a) Frontal image, (b) Off-angle image with elliptical unwrapping, and (c) Frontal projection of off-angle image to frontal view.



(a) (b)

Figure 5: Histogram distribution of Hamming distances for (a) Elliptical unwrapping and (b) Frontal projection with circular unwrapping.

unwrapping and frontal projection methods. The frontal iris image is shown in Figure 5(a) with its pupil and sclera boundaries and eyelid segmentation. Figure 5(b) shows the segmented off-angle image after the normalization technique elliptical unwrapping is performed. The frontal projection of the off-angle iris image from Figure 5(b) is shown in Figure 5(c). First, the elliptical parameters of the iris-sclera boundary in the off-angle iris image are used to calculate the projection parameters. Then, the off-angle iris image is projected to frontal view where the iris-sclera boundary then is transformed to a circle. After the frontal projection, circular unwrapping is then applied to normalize the projected image.

Figure 5 shows the intra-class and inter-class distributions of the Hamming distance comparisons. The intra-class distribution is shown as green lines for the comparisons of images between same subjects. The inter-class comparisons are shown as the red lines where scores are generated for images between different subjects. Figure 5(a) shows the intra-class and inter-class comparisons of the elliptical unwrapping approach. The comparison of frontal projection is shown in Figure 5(b). We observed a left shift when comparing frontal projection to elliptical unwrapping. We also observed that the intra-class HD has a mean of 0.309 and standard deviation of 0.102 for elliptical unwrapping. Its inter-class hamming distance has a mean of 0.490 and standard deviation of 0.017. For frontal projection, intra-class distribution has a mean of 0.307 and standard deviation of 0.102 and its inter-class hamming distance has a mean of 0.489 and standard deviation of 0.017. As a result, the frontal projection method has shifted the Hamming distance distributions of intra and inter classes to the left when compared with elliptical unwrapping.

Figure 7 displays the receiver operator characteristic (ROC) curve for elliptical unwrapping and circular unwrapping with the frontal projection. It demonstrates the true position rate (TPR) and false positive rate (FPR) for different HD thresholds. When the points along the graph present a curve that is closer to the upper left corner of the graph indicates better performance. Equal error rate (EER) is plotted with black line and its intersection with ROC curve shows each

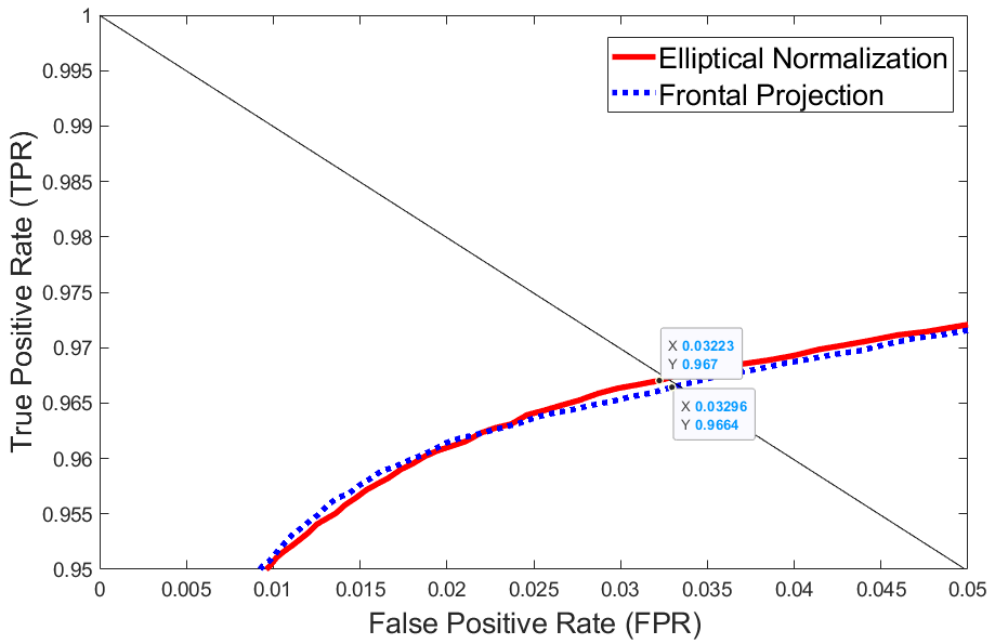


Figure 7: Receiver Operator Characteristic (ROC) curves for bother Elliptical unwrapping (red) and Circular unwrapping with frontal projection (blue)

equal error points for ROC curves. The result for elliptical unwrapping is shown with a red curve within the ROC graph where the equal error rate (EER) is achieved at 0.032 and its TPR is 96.7%. The blue curve represents the circular unwrapping with frontal projection results with an EER of 0.033 where TPR equals to 96.6%. Based on these results, the elliptical normalization method shows slightly better recognition performance in off-angle iris images with 2.2% decrement in the equal error rate.

V. CONCLUSION

In this paper, we investigate two different iris normalization techniques (1) elliptical normalization and (2) circular normalization with frontal projection. In our research, we first investigate elliptical normalization where the inner and outer boundaries of off-angle iris images are segmented by fitting the best ellipses to these boundaries. After the best fit ellipse has been found, we then go in and validate and fix errors using the Ground Truth Tool. We then go on to investigate perspective projection, where the inner and outer boundaries are transmuted to a frontal projection. Our experiments were performed on off-angle iris dataset with gaze angles ranging from -50 to +50. We examine how the Hamming distance distribution changes between the two methods of off-angle iris segmentation. Based on out experimental results, we found that the perspective projection has shifted the distributions of intra and inter class Hamming distances to the left and that elliptical normalization equal error rate decrease by 2.2%.

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