Revisiting Iris Recognition with Color Cosmetic Contact Lenses

Naman Kohli[*] Daksha Yadav[*] Mayank Vatsa, Richa Singh
IIIT - Delhi
Email: {naman09027, daksha09019, mayank, rsingh}@iiitd.ac.in

Abstract

Over the years, iris recognition has gained importance in the biometrics applications and is being used in several large scale nationwide projects. Though iris patterns are unique, they may be affected by external factors such as illumination, camera-eye angle, and sensor interoperability. The presence of contact lens, particularly color cosmetic lens, may also pose a challenge to iris biometrics as it obfuscates the iris patterns and changes the inter and intra-class distributions. This paper presents an in-depth analysis of the effect of contact lens on iris recognition performance. We also present the IIIT-D Contact Lens Iris database with over 6500 images pertaining to 101 subjects. For each subject, images are captured without lens,transparent (prescription) lens, and color cosmetic lens (textured) using two different iris sensors. The results computed using VeriEye suggest that color cosmetic lens significantly increases the false rejection at a fixed false acceptance rate. Also, the experiments on four existing lens detection algorithms suggest that incorporating lens detection helps in maintaining the iris recognition performance. However, further research is required to build sophisticated lens detection algorithm that can improve iris recognition.

1. Introduction

Iris is one of the most promising biometric modalities which is being used in several large scale applications such as UAE port of entry and India's UIDAI (Aadhar). Though iris features are considered to be unique, recent research results suggest that they are affected by several covariates such as pupil dilation [8] and sensor interoperability [1, 4]. Another factor that may affect iris recognition and has received less attention, is the presence of *transparent and textured color cosmetic lenses*. With recent developments in technology and low cost, the use of contact lens is becoming more prevalent. According to Nichols [10], the worldwide contact lens market in 2011 is estimated to be about 6.8 billions. Contact lens are generally used to correct eyesight as a replacement for spectacles/glasses. They are however, increasingly being used for cosmetic reasons also where texture and color of iris region is superimposed with a thin textured lens. As shown in Figure 1 (iris images with and without color cosmetic lens), it is apparent that the use of color cosmetic lens changes the appearance/texture of an eye in both visible and near infrared spectrums. Therefore, we be-

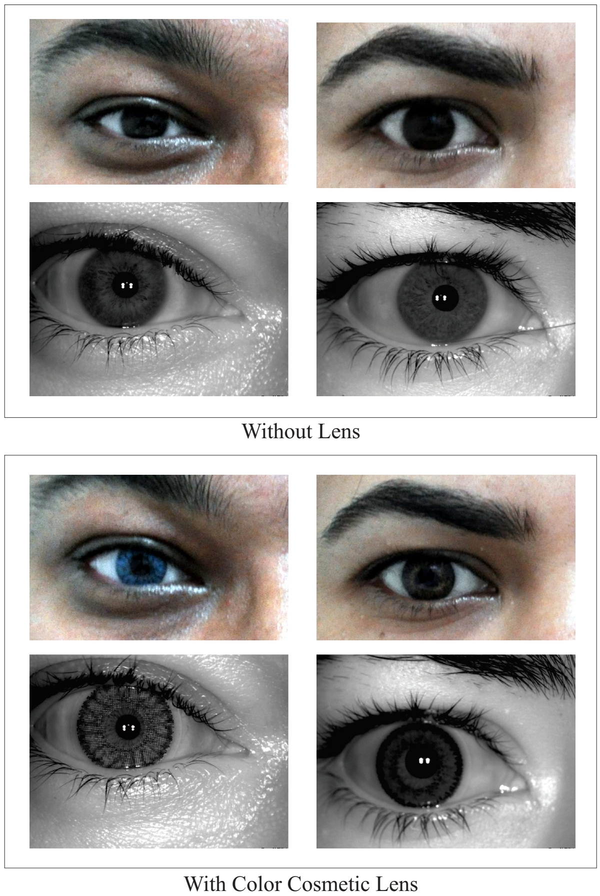


Figure 1. Illustrating the variations due to color cosmetic lenses. The first row in both the figures contain images in visible spectrum and the second row contains examples under near infrared spectrum.

[*]Equal contributions by student authors, N. Kohli and D. Yadav.

lieve that it is important to understand (1) the effect of contact lens on the performance of iris recognition algorithms and (2) how this effect can be mitigated.

The discussion about fake iris images and images with contact lens effect was first initiated by Daugman [5] where frequency spectrum analysis was proposed to countermeasure against subterfuge. Lee et al. [9] later proposed a method to distinguish between genuine and fake iris based on the Purkinje image. On the other hand, He et al. [7] used four features (mean and standard deviation of pixel values, contrast and the angular momentum) of the gray level co-occurrence matrix (GLCM) as a feature vector and Support Vector Machine (SVM) classifier for predicting if the iris image contained colored contact lens or not. Ring and Bowyer [11] analyzed the iris bit code to detect regions of local distortions which can be due to contact lenses or occlusions. Wei et al. [14] used three different features to detect lens in iris images. The first method is the edge sharpness detection where the sum of intensity values of inner boundary of the iris is subtracted from that of the outer boundary. The second feature is Iris-Textons computed using Gabor filters along with KMeans algorithm and counterfeit iris classification is performed using SVM. The third approach utilizes GLCM features and SVM classification for the same task. Among the three approaches, the authors report that Iris-Textons and GLCM features are able to perform better classification. Baker et al. [2], on a database of 51 subjects wearing non-cosmetic contact lens and 64 subjects without lens, suggest that the lens wearers have 14 times higher false rejection rate compared to non-contact lens wearers. However, the number of users in the database per lens type is small and the variability among lenses is also not sufficient to statistically establish any results. Zhang et al. [15] used weighted Local Binary Pattern (LBP) encoding with SIFT descriptor and SVM for classification of lens and non-lens iris images. On a database of 72 users, a correct classification accuracy of over 99% is achieved. Using 12,003 images from 87 non-cosmetic contact-lens-wearing subjects and 9,697 images pertaining to 124 non-contact lens wearing subjects, Baker et al. [3] concluded that the lenses that produce larger artifacts on the iris yield more degraded performance.

The current literature primarily focuses on transparent contact lenses and limited studies with colored cosmetic lenses. Further, many of the results reported in literature are not evaluated using any state-of-the-art commercial systems. To the best of our knowledge, the databases used in these studies are not publicly available except the one used by Baker et al. [3] that contains non-cosmetic lenses. Finally, the lens detection approaches are not evaluated with respect to improvement in iris recognition performance. Doyle et al. [6] conducted a three class lens detection problem, in which an ensemble of 14 classifiers was learnt to achieve 97% accuracy. However, the accuracy of classifying an iris image into soft lens or no lens category was low. Also, the number of users per type of lens were less. In this research, we attempt to bridge these gaps and present:

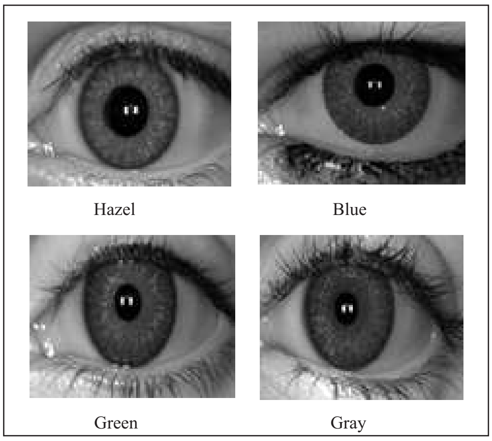


Figure 2. Iris images with four different types of colored lenses from CIBA vision.

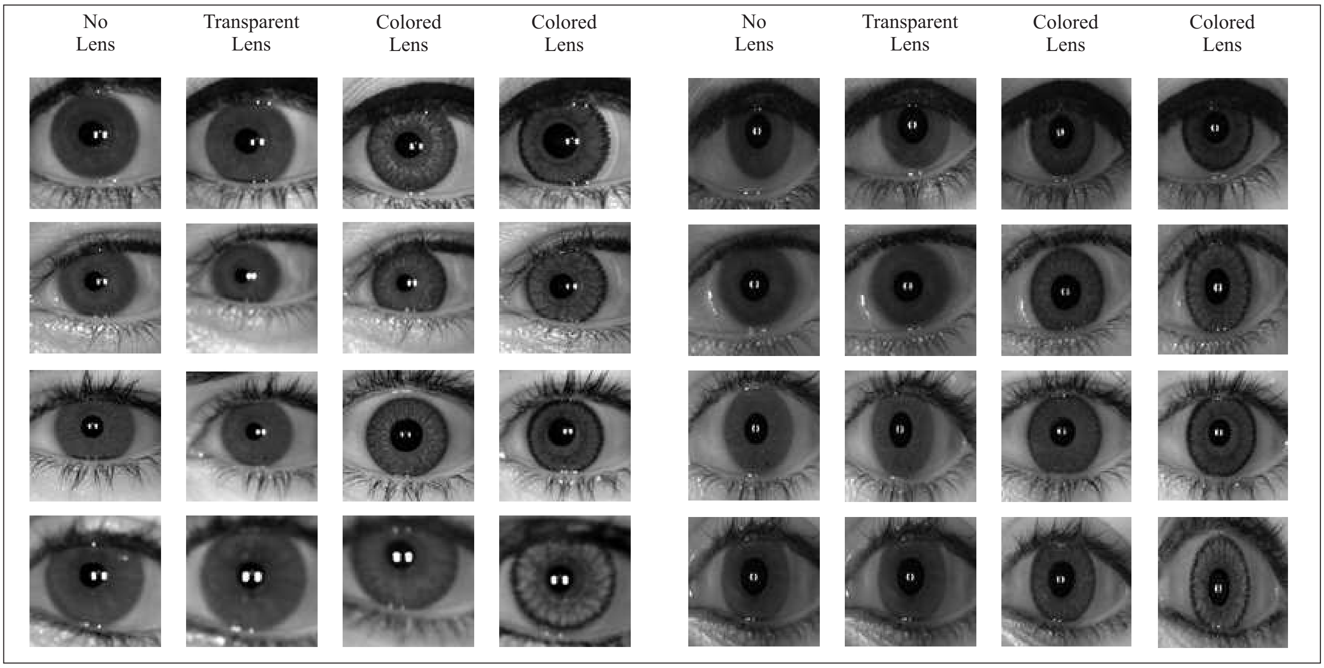
1. a new benchmark database that contains iris images with different kinds of contact lenses. This database is unique in terms of the types of images per subject, number of subjects, acquisition devices, contact lens colors, and manufacturers,
2. baseline verification accuracies using a commercial iris recognition system to understand the effect of transparent and colored cosmetic lenses. We also present inter and intra class performance analysis of contact lenses and effect of different iris sensors,
3. performance comparison of existing lens detection algorithms across different lens types and iris sensors.

2. Effect of Contact Lenses on Iris Recognition

With the increasing use of contact lenses, multiple types and colors of lenses are available with different textures by several manufacturers. To the best of our knowledge, there is no database that captures the variations across colors and textures in lenses. Further, different lens manufacturers may have different technologies for contact lens creation. To analyze the effect of these parameters on iris recognition, we have prepared the *IIIT-D Contact Lens Iris* (CLI) database. This section presents the details of the database and the performance evaluation of a commercial iris recognition system in both presence and absence of contact lenses.

2.1. IIIT-D Contact Lens Iris Database

The IIIT-D CLI database is prepared with three objectives: (1) capture images pertaining to at least 100 subjects, (2) for each individual, capture images without lens,



(a) (b)

Figure 3. Iris images in IIIT-D Contact Lens Iris Database (a) images captured using Cogent iris sensor and (b) images captured using Vista iris sensor. The two color lenses used here are from CIBA Vision in third column and Bausch & Lomb in fourth column.

Number of subjects (classes)	101 (202)
Types of contact lens	Without lens, transparent, and colored
Lens manufactures	CIBA Vision and Bausch & Lomb
Lens colors	Blue, Gray, Hazel and Green
Number of subjects per colored lens type	Blue (20), Gray (29), Green (30) and Hazel (22)
Iris sensors used for acquisition	Cogent dual iris sensor and VistaFA2E iris sensor
Number of images per subject per lens type	Minimum 5 images per eye class, per lens type
Total number of image in the database	6570

Table 1. Details of the IIIT-D Contact Lens Iris Database.

with transparent (prescription) lens, and with color cosmetic lens, and (3) capture images with variations in iris sensors and lenses (colors and manufacturers). Table 1 summarizes the characteristics of the IIIT-D CLI database which comprises of 6570 iris images pertaining to 101 subjects. Both left and right iris images of each subject are captured and therefore, there are 202 iris classes. The lenses used in the database are soft lenses manufactured by either CIBA Vision or Bausch and Lomb. For color cosmetic lenses, four colors are used and Figure 2 shows some iris images with different color lenses from CIBA Vision. To study the effect of acquisition device on contact lenses, iris images are captured using two iris sensors: (1) Cogent dual iris sensor (CIS 202) and (2) VistaFA2E single iris sensor. The database contains minimum five images of each iris class in each of the above mentioned lens categories for both the iris sensors.

2.2. Performance Evaluation of Iris Recognition

VeriEye [13], a commercial software, is used to understand the effect of contact lenses on iris verification. Two sets of experiments are performed on the IIIT-D CLI database to evaluate the iris verification performance:

1. *Effect of color and transparent lenses*: By varying the gallery probe combinations, the effect of different types of lenses on iris recognition is analyzed.

2. *Effect of acquisition device*: This experiment is performed to analyze whether iris acquisition using different sensors has any effect on the performance with contact lens variations. Three experiments are performed:

   (a) both the gallery and probe images are captured using the Cogent sensor

   (b) both the gallery and probe images are captured using the Vista sensor

(c) cross sensor gallery - probe verification experiment.

The verification accuracies of VeriEye are computed for the above mentioned protocols and the results are shown in Figure 4 and Tables 2 and 3. The key results are summarized as follows:

Lens type/ Sensor (Gallery/Probe)	Cogent	Vista	Cross Sensor
Normal - Normal	**98.9**	**99.8**	**97.9**
Normal - Transparent	96.1	59.9	95.0
Normal - Color	22.1	36.4	23.4
Transparent - Transparent	96.4	99.8	47.3
Transparent - Normal	96.1	57.4	48.8
Transparent - Color	22.9	33.8	22.5
Color - Color	50.4	63.3	5.0
Color - Normal	23.0	38.2	20.4
Color - Transparent	22.8	32.8	17.3

Table 2. Verification results with variations in acquisition device and lens type. The verification accuracy is reported at 0.01% FAR.

- The Receiver Operating Characteristic (ROC) curves in Figure 4 show that at 0.01% false accept rate (FAR), the best performance is achieved when both the gallery and probe images are without lens (normal irises). Matching images without lens and with transparent lens also show similar trends except when both the probe and gallery belong to Vista sensor. The fact could be attributed to the acquisition technology of Vista sensor, but since its a proprietary technology we cannot claim to it. However, the performance reduces significantly when either one of the gallery or probe image is with colored lens and the other is without lens or with transparent lens. It is also interesting to note that when both gallery and probe images are with colored lenses, the verification accuracy reduces to only 50-60%.

- It can also be observed from Figure 4 that different acquisition devices affect the iris verification performance with variations in contact lenses. ROC curves in Figure 4 re-establish the challenge of sensor interoperablity - without lens gallery probe images with cross sensor matching yields 1̃% lower verification accuracy than with same sensor matching. Similarly, as shown in Table 2, for other combinations of gallery probe pairs, the verification accuracy at 0.01% FAR is affected by cross sensor matching. With color gallery probe combination, the verification accuracy drops to 5%.

- VeriEye gives a score of *zero* for impostor matches and any score greater than zero denotes a genuine match.

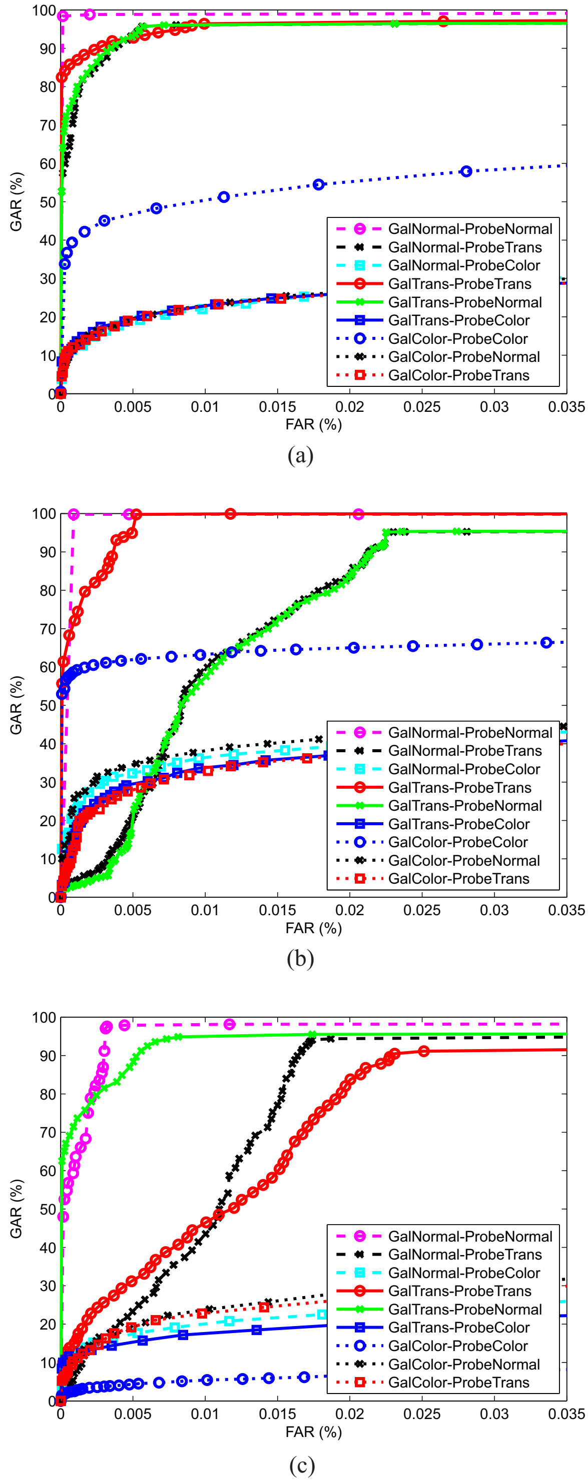


Figure 4. ROC curves for various experiments using VeriEye: (a) both the gallery and probe images are captured using the Cogent sensor, (b) both the gallery and probe images are captured using the Vista sensor, and (c) cross sensor matching.

Lens	Genuine		Impostor	
	[Min, Max]	Mean	[Min, Max]	Mean
Normal	[0, 1550]	653.19	[0, 87]	0.02
Transparent	[0, 1345]	472.99	[0, 447]	0.03
Blue Color	[0, 180]	31.76	[0, 77]	0.03
Hazel Color	[0, 129]	20.66	[0, 67]	0.01
Green Color	[0, 166]	22.86	[0, 79]	0.01
Gray Color	[0, 160]	17.82	[0, 96]	0.03

Table 3. Minimum, maximum, mean genuine, and mean impostor scores obtained from VeriEye [13] for different lens types.

The higher the match score, the greater is the confidence that the match pair belongs to the same user. To understand the variation in match scores due to the presence of contact lens, we further analyze the distribution of genuine and impostor scores obtained from VeriEye. For this experiment, the gallery constitutes of images without lens while the probe is varied from without lens to color lens iris images. Table 3 presents the mean of genuine and impostor scores along with minimum and maximum scores obtained for different colors lenses individually. It is observed that when color cosmetic lenses are used, the inter-class similarity increases while the intra-class similarity reduces significantly for many of the genuine pairs. In this database, blue colored lenses show maximum variation from normal iris. The results shown here are computed for the Cogent sensor and similar performance is observed for the Vista sensor as well.

- To ensure that the reduction in performance is due to the presence of lens only and not because of some other factors such as poor image quality or blurriness, we analyze the images that are wrongly accepted or rejected by the matchers. Figure 5 shows that when two good quality normal iris images (without any lens) are matched, VeriEye produces a high similarity score. However, when the iris of the same subject while wearing colored contact lens is matched with the normal image, it produces zero similarity score. This clearly indicates that the presence of contact lens alters the appearance of iris texture and may lead to incorrect verification results. Similarly, for impostor pairs, as shown in Figure 5, we observe high match scores which suggest that color cosmetic lenses increase the inter-class similarity.

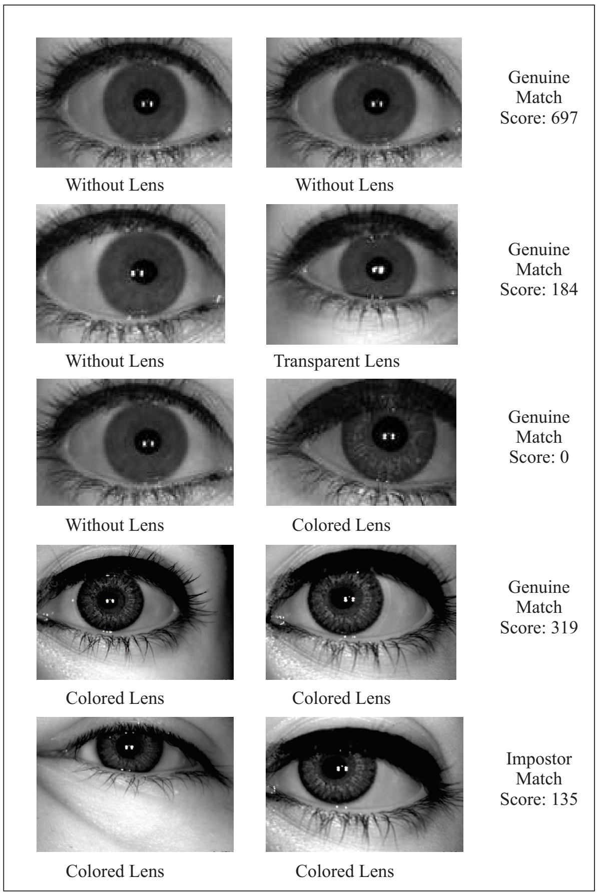


Figure 5. Illustrating the effect of contact lenses on iris matching performance.

3. Effect of Lens Detection on Iris Recognition

From the results shown in the previous section, it can be inferred that contact lens, especially color cosmetic lens, reduces the performance of iris recognition systems. It is our hypothesis that applying a lens detection algorithm to first reject the cases with *obfuscated* patterns and allowing only without lens (as well as with transparent lens) iris images can potentially improve the performance of iris recognition algorithms and reduce the false matches at higher verification rates. To test this hypothesis, we have evaluated the performance of four existing techniques: (1) iris edge sharpness [14], (2) textural features based on co-occurrence matrix [14], (3) GLCM based analysis [7], and (4) local binary pattern (LBP) and SVM based classification. The first three techniques are existing lens detection techniques while the fourth one is a standard texture classification algorithm. These lens detection algorithms require segmented iris image as input. Since the commercial systems do not provide the flexibility of extracting the active contour based segmentation of iris regions, we have used the algorithm proposed in [12].

The problem of lens detection in an iris image is approached as a three class classification problem: without lens (or normal), transparent lens, and colored lens. However, the iris edge sharpness utilizes thresholding for classification and therefore, the three-class lens classification for this approach is converted into a two-class classification

	Colored	Remaining	Total
Colored	1085	372	1457
Remaining	65	231	296
Total	1150	603	1753

Table 4. Confusion matrix for colored lens classification problem using edge sharpness [14].

	Normal	Remaining	Total
Normal	693	370	1063
Remaining	479	211	690
Total	1172	581	1753

Table 5. Confusion matrix for normal (without lens) classification problem using edge sharpness [14].

	Normal	Colored	Transparent	Total
Normal	195	157	234	586
Colored	80	469	54	603
Transparent	184	139	241	564
Total	459	765	529	1753

Table 6. Confusion matrix of lens detection using the textural features [14].

	Normal	Colored	Transparent	Total
Normal	192	215	179	586
Colored	205	274	124	603
Transparent	197	179	188	564
Total	594	668	491	1753

Table 7. Confusion matrix for lens detection using the GLCM features [7].

	Normal	Colored	Transparent	Total
Normal	384	37	165	586
Colored	30	539	34	603
Transparent	297	26	241	564
Total	711	602	440	1753

Table 8. Confusion matrix for lens detection using LBP features and SVM.

problem. To perform the experiments, images pertaining to the first 50 subjects are used for training and the remaining 51 subjects are used for testing. The classifiers (or parameters of lens detection algorithms) are first trained on the training set and the trained classifiers are used to classify the input image into one of the three classes. The test set is used to evaluate the performance of the trained classifiers on unseen images. With this experimental protocol, Tables 4 to 8 summarize the results of the four lens detection algorithms for images captured using the Cogent sensor. Similar confusion matrices are obtained for the Vista sensor as well. These results suggest that colored lenses are relatively easier to detect compared to transparent lenses. However, differentiating between without lens and transparent lens images is a challenging problem. Further, among

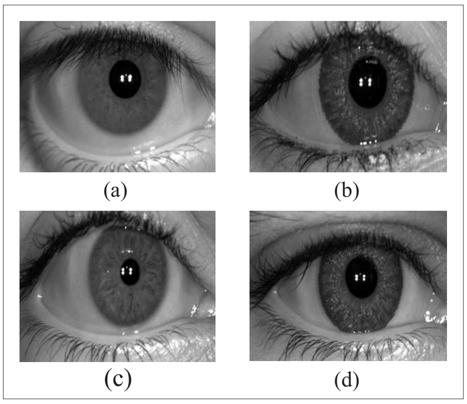


Figure 6. Examples of correct (a: without lens and b: colored lens) and incorrect classifications (c: without lens as colored lens and d: colored lens as without lens) using co-occurrence matrix [14].

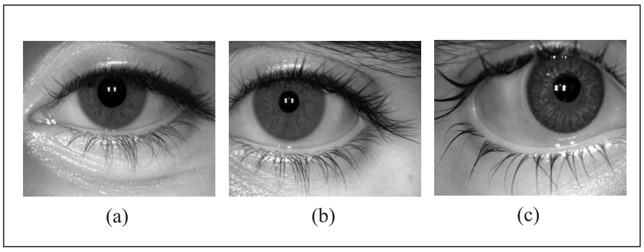


Figure 7. Misclassification by LBP and SVM classification: (a) without lens image classified as image with transparent lens, (b) image with transparent lens classified as without lens, and (c) image with colored lens classified as image with transparent lens.

all four lens detection algorithms, LBP with SVM classifier yields the best classification performance. As shown in confusion matrices (Tables 4 to 8) and examples in Figures 6 and 7, there are several instances when an image with colored/transparent lens is classified as either without lens (normal) or transparent lens and vice versa. This suggests that there is a need for a better lens classification approach that can delineate different lens classes correctly.

To evaluate the hypothesis that "detecting and rejecting the iris samples with color cosmetic contact lens can improve the performance of iris recognition algorithms", another experiment is performed in which the output of lens classification algorithm is provided as input to the iris recognition system. For this, LBP with SVM classifier based lens-detection approach is utilized and the same training-testing partitions are used. In this experiment, the gallery contains iris images without lens and the probe contains images without lens, with transparent lens, and with colored lens separately. During probe verification, the images classified as colored lens are declared as "failure to process". Figure 8 shows the ROC curves obtained with this protocol and its comparison with the results obtained when the gallery image is without lens and all the probe images are considered without lens classification. It also

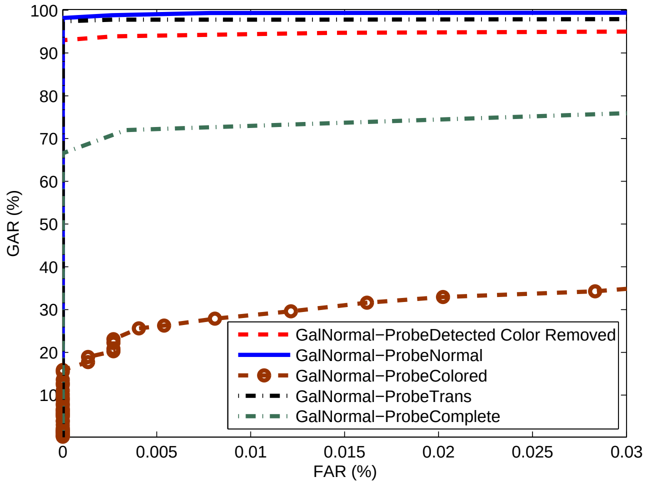


Figure 8. ROC curves demonstrating the effectiveness of incorporating lens detection algorithm (LBP features and SVM) with VeriEye.

compares the performance when probe is only without any lens (normal), only transparent lens (without classification), and only colored lens (without classification). At 0.01% FAR, normal gallery-probe images yield 99.36% verification accuracy, whereas with lens classification, all the probe images yield 72.95% accuracy. By applying lens detection algorithm, the accuracy improves to 94.41%. The results suggest that the removal of contact lens leads to increase in the recognition accuracy as compared to without lens classification. However, it is still lower than the accuracy of normal-normal and transparent-normal gallery probe pairs due to less accurate lens detection algorithm.

4. Conclusion and Future Work

Contact lenses, especially color cosmetic lenses, obfuscate the iris texture and can be viewed as "disguise" for iris biometrics. This can potentially be an important covariate of iris recognition systems. This paper analyzes the effect of contact lenses on the performance of iris recognition using the IIIT-D Contact Lens Iris database, prepared by the authors. The results computed using VeriEye suggest that both transparent (prescription) and color cosmetic lens (textured) affect the verification accuracy significantly. Analyzing the existing lens detection algorithms suggest that, though incorporating lens detection algorithms may improve the verification performance, designing better and improved lens detection algorithm is of paramount interest. It is also important to conduct the research in developing contact lens invariant feature extraction and matching algorithms. It is our assertion that with the availability of the IIIT-D CLI database, other researchers may also undertake research in these directions.

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