Contact Lenses: Handle with Care for Iris Recognition

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***Abstract*— Many iris recognition systems operate under the assumption that non-cosmetic contact lenses will not affect match quality and the convenience of the system. In this paper we show results opposing this belief with a study of 51 contact lens wearing subjects and 64 non contact lens wearing subjects. Our experimental results show that contacts lens wearers are 14 times more likely to be falsely rejected by an iris recognition system at a Hamming distance threshold of 0.32 than non contact lens wearers. We further classify contact lens wearers into four categories according to the type of lens and its visibility in the iris image. The false reject rate varies with different types of contacts and the artifacts they produce on iris images.**

***Index Terms*— iris biometrics, contact lenses, match distribution stability**

I. Introduction

Approximately 28 to 38 million people wear contact lenses in the United States and about 125 million wear them worldwide [7]; it is a multi-billion dollar industry. As iris recognition becomes more widespread, it is necessary to create a system that is flexible in dealing with large and varying populations while also maintaining appropriate security precautions. The large number of contact lens wearers in the general population requires recognition systems to operate well for individuals wearing varying types of lenses. In this paper we challenge the widely accepted belief that prescription contact lenses have little or no effect on recognition.

Some contact lenses leave significant artifacts visible on the iris. These distortions of the iris texture result in the increased likelihood of two images of the same iris being falsely declared to be a non-match. On visual inspection, other lenses appear to cause no distortion of the iris texture. We explore whether these contacts nonetheless affect recognition results.

Section 2 discusses related work of the effect certain lenses have on recognition. Section 3 outlines our experimental materials and methods as well as our categorizations of subjects based on their contact lenses. Section 4 presents our results. Section 5 further illustrates the regions of the iris affected by contact lenses. Lastly, section 6 discusses these results and future work.

II. Related Work

Cosmetic or patterned contact lenses are known to cause a disturbance in iris recognition. It has been shown that the use of such lenses can in fact allow an imposter to invade a system with the use of a contact lens of an alternate texture [6]. Daugman presents a method to detect cosmetic contact lenses manufactured with a “dot-matrix” type process, thus preempting any such invasion.

Many iris recognition algorithms account for hard contacts. Daugman’s algorithm detects the boundaries of such contacts and ignores these regions as artifacts [10] [1]. However, soft contacts are usually ignored and treated as having no effect on verification.

Some Acuvue [9] contact lenses have an “AV” or “1-2-3” indicator printed on the lenses in order to ensure proper application and insertion. Researchers in this group have previously reported degradation of the Hamming distance and increased false reject rate due to significant artifacts such as an “AV” printed on contact lenses [12]. However, to our knowledge, no work has been done to show the effect of the general case of contact lenses, specifically those without registration indicators or cosmetic patterns.

III. Experimental Materials and Methods

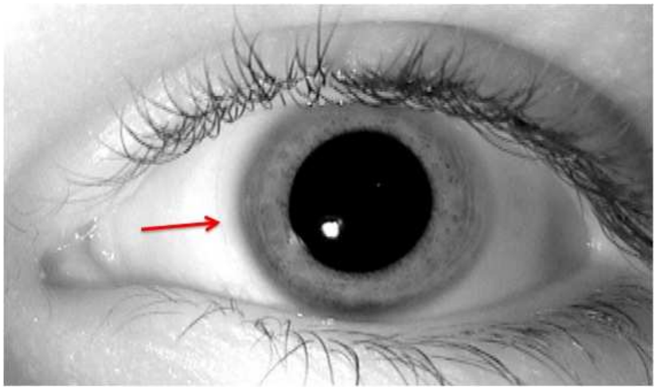
This section describes the iris image dataset, the iris biometrics software and the categorization of the types of contact lenses and their resulting artifacts on iris images used in this study.

A. Image Data set

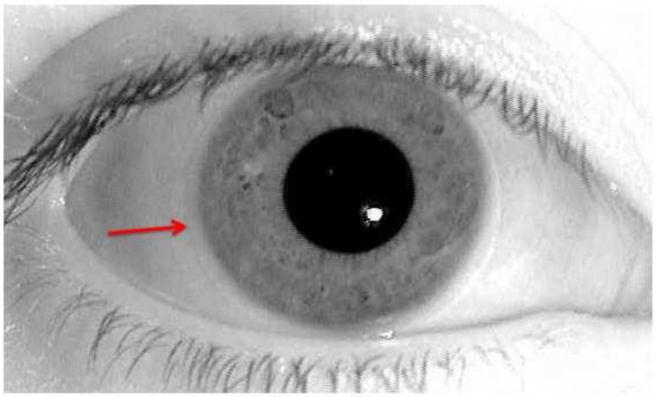
The images used in this study are from the Iris Challenge Evaluation 2005 (ICE) [5] data set and were acquired using an LG 2200 iris imaging system [2]. Image acquisition was performed in the same studio with the same ambient indoor lighting. We visually inspected all images considered for use in this study and rejected any of noticeably low quality, as well as those for which the iris segmentation results were noticeably poor.

We consider 51 subjects wearing contact lenses and 64 subjects without contact lenses. For the 51 contact lens subjects (102 irises), we have approximately 3100 images with an average of 60 images per subject. For the 64 non contact lens subjects (128 irises), we have approximately 3700 images with an average of 60 images per subject. We visually inspected all images to ensure all those in the contact lens category showed a visible contact lens and all those in the non contact lens category were indeed without any visible lens.

In this study we used our modified version of the open source IrisBEE system to locate and segment the iris and report match scores as a fractional Hamming distance between 0 and 1 [5] [3]. Our software also outputs the number of bits used in computing the Hamming distance. We implemented

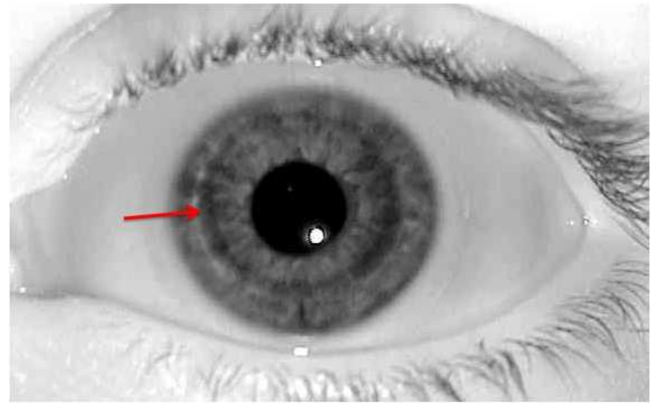


(a) 04312d593

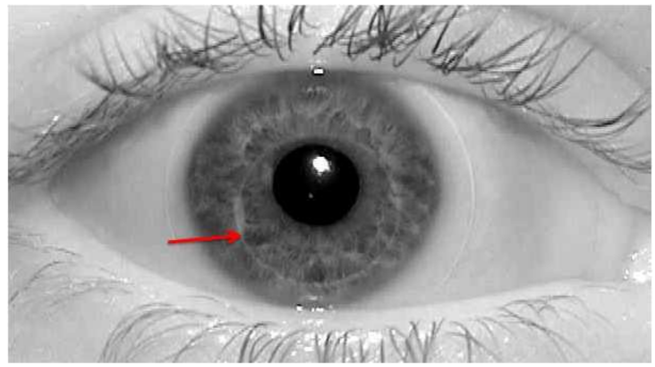


(b) 04408d479

Fig. 1. Examples of Category 1 Contact Lens Images. We observe little or no contact lens artifact in the iris region. The arrow points to visible evidence of the contact lens



(a) 04456d363



(b) 04613d893

Fig. 2. Examples of Category 2 Contact Lens Images. We observe a circular boundary line of the contact lens in the iris region in addition to the circular boundary on the sclera.

score normalization as suggested by Daugman [8] in order to control for differences in the number of bits.

We initially considered all contact lens images as one set and compared match and non match distributions for this set to match and non match distributions for the non contact lens image set.

However, as we note, various types of contact lenses are available and affect match quality differently. We categorized the contact lens images into four main categories. In our visual inspection of the iris images, we observed regularity within a subject in the type of artifact resulting from a contact lens on the iris image; each of the contact wearing subjects consistently showed qualities of one of the four categories.

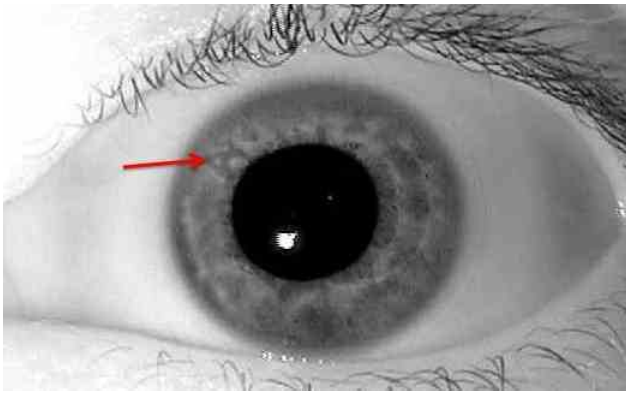
B. Categorization of Contact Lenses

The first category we found were subjects with a visible contact lens that left little or no visible artifact on the iris (see Fig. 1). The boundary of these lenses can be seen in the sclera, but no artifact is apparent in the iris itself. We placed 23 subjects (46 irises) into this category. We noted the images for these subjects consistently showed this same trend of little lens presence in the iris.

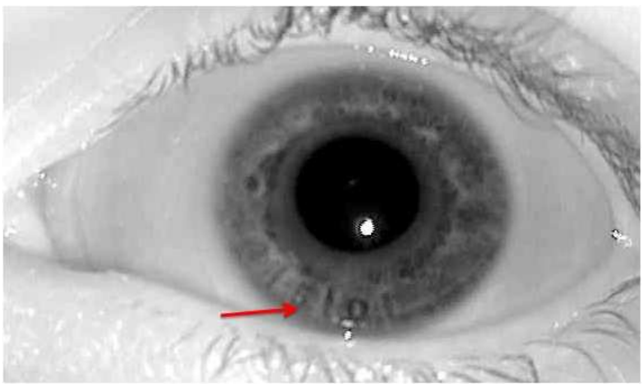
The second category we used was subjects with a visible contact lens that resulted in a light or dark circular outline in the iris itself as well as on the sclera (see Fig. 2). Some contact lenses (e.g. toric lenses designed to compensate for astigmatism) have boundaries between the outer portion of the eye surface and the inner part of the lens that actually creates the prescribed visual correction. These boundaries cause the lines observed. We placed 14 subjects (28 irises) into this category. Again, we found consistency within subjects whose iris images displayed this circular boundary.

The third category contains subjects whose contacts resulted in a large visible artifact on the iris. This large artifact may be an “AV” logo (see Fig. 3(a)) or numbers, such as “1-2-3” (see Fig. 3(b)), printed on the iris for ease of insertion. We have two subjects in our data set with the “AV” and one with the “1-2-3” printed on the lenses. We also placed in this category subjects who regularly had other large artifacts present in their iris such as those in Figs. 3(c) and 3(d). These artifacts can result from an ill-fitting lens where a portion of the rim of the lens does not properly sit on the surface of the eye. We ascertained from the subject in Fig. 3(c) that the contact lenses worn at the time of these image acquisition did not fit well on their eye. The seven subjects placed in the third category due to these large artifacts did not necessarily always demonstrate such an artifact. However, we did observe this effect in the majority of their images. We placed a total of 10 subjects (20 irises) into this category.

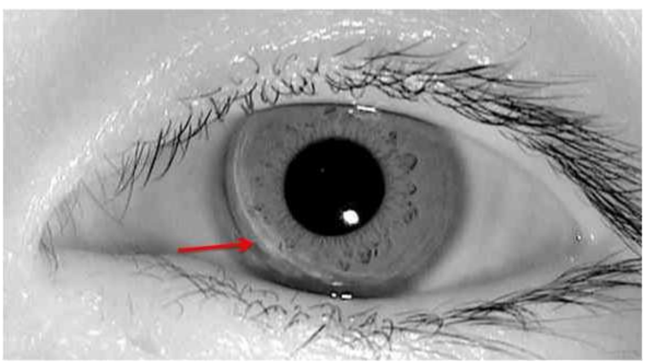
Finally, we considered the three subjects in our data set



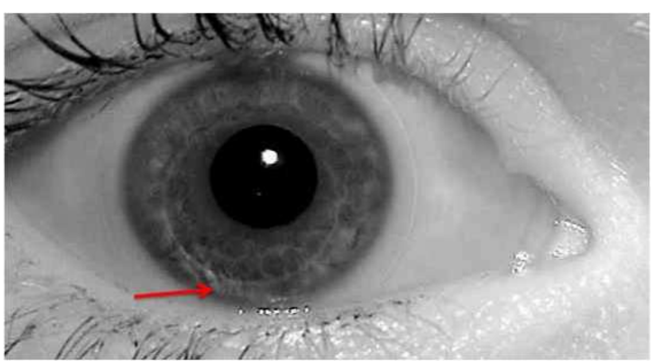
(a) Example iris image with AV on the contact lens - 04349d909



(b) Example iris image with numbers on the contact lens - 04869d84

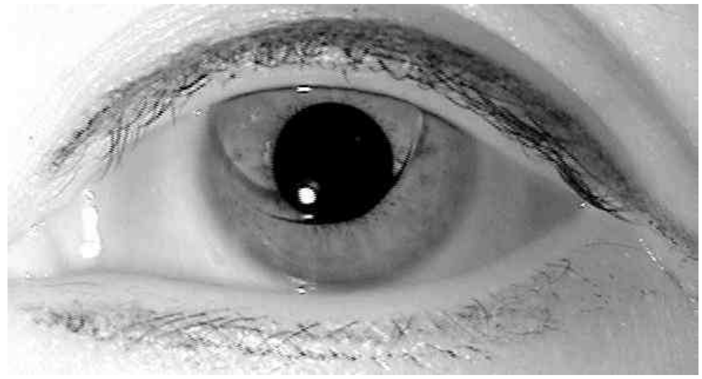


(c) Example iris image with a significant artifact on the iris from the lens - 04221d1382

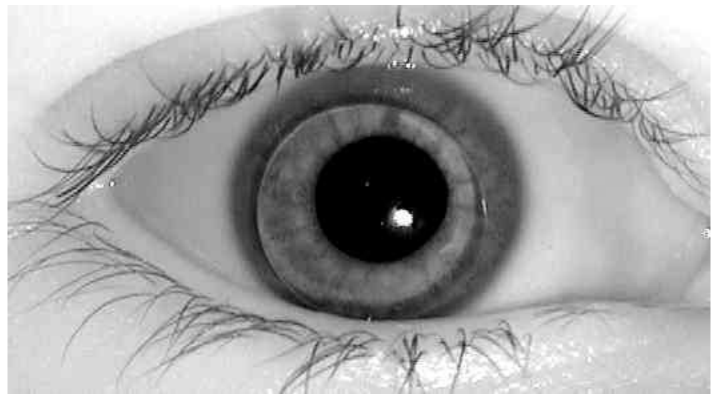


(d) Example iris image with a significant artifact on the bottom left region of the iris from the lens - 04885d111

Fig. 3. Examples of Category 3 Contact Lens Images. We observe significant artifacts from the contact lens in the iris region.



(a) 04593d633



(b) 04622d629

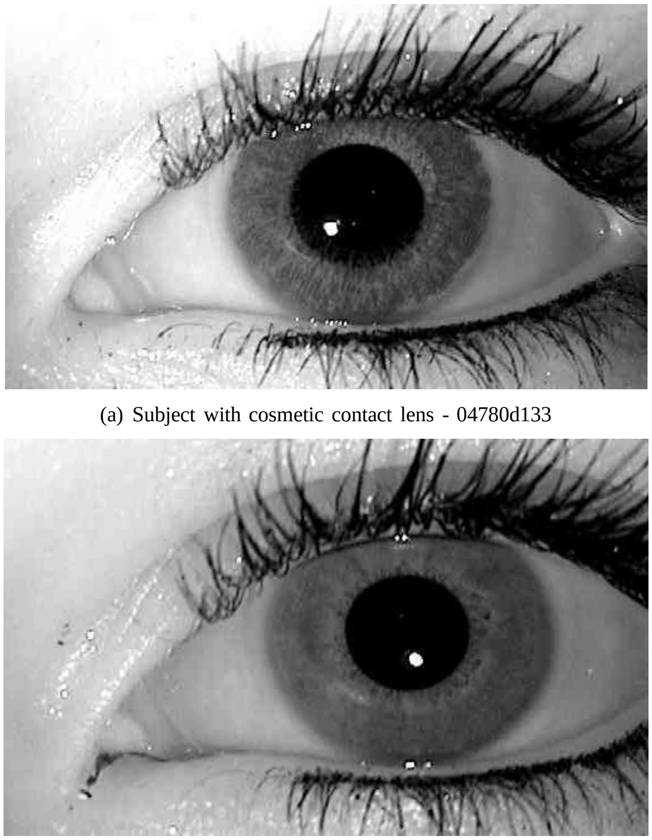
Fig. 4. Examples iris images with hard contact Lenses

who wore hard contacts (see Fig. 4). It is widely accepted that hard contacts cause a degradation in iris match quality and increase the false reject rate. Many algorithms attempt to detect and ignore the boundaries created by this type of contact lens. We use this fourth category to determine empirically how much of an effect hard contact lenses have on recognition.

We have one subject with cosmetic contact lenses. This subject wore these cosmetic lenses in some acquisitions, but also wore regular contact lenses in other sessions (see Fig. 5). While the effect of cosmetic contact lenses is well known and many algorithms are available to detect such lenses, we qualify their effect by considering three sets of matches for this subject: 1) we consider matches between images where both are of the subject wearing the cosmetic contact lenses, 2) we consider matches between images where both are of the subject wearing regular contact lenses, and 3) we consider matches between images where in one the subject is wearing the cosmetic lens and in the other the subject is wearing regular lenses.

IV. Experimental Results

We present results of two different experiments on the effect of contact lenses. First, we show the general effect of contact lenses where we compare the match distributions of all contact lens subjects and the non contact lens subjects. Second, we show the effects of the four different categories



(a) Subject with cosmetic contact lens - 04780d133

(b) Subject without cosmetic contact lens - 04780d140

Fig. 5. Example of subject 04780 with and without a cosmetic lens

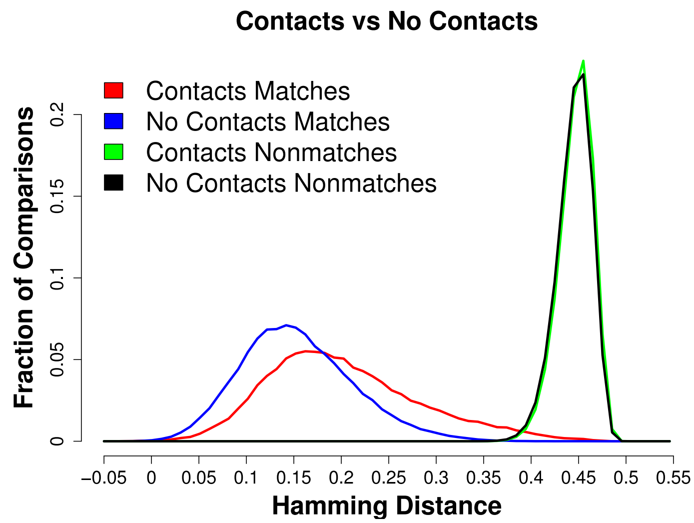


Fig. 6. Match and Non Match Distributions

of contact lenses as outlined in Section III-B. We again compare these four categories to the non contact lens subjects. For both experiments we explore the contact lenses' effect on the false reject rate and the false accept rate.

A. General Contact Lens Subjects vs. Non Contact Lens Subjects

We initially consider all contact lens wearers as one subject pool and all non contact lens wearers as a second subject pool. We computed match scores for an all versus all match of the images within each set of subjects. The match scores are reported as a fractional Hamming distance where a score of 0 indicates a perfect match and a score of 0.5 represents random matching.

The mean Hamming distance for all match pairs from subjects wearing contact lenses is 0.2052 with a median of 0.1945. The mean Hamming distance for all match pairs from non contact lens wearing subjects is 0.1564 with a median of 0.1517. This change in mean Hamming distance of approximately 0.04 reflects an 8% degradation. We applied a Student's t test to test the null hypothesis that these two sets of Hamming distances comes from match distributions with the same mean against the alternative hypothesis that they are from match distributions with different means. The null hypothesis was rejected at a 5% significance level ($p < 0.00001$). Fig. 6 displays these distributions and clearly illustrates that the contact wearing subjects' match distribution is shifted to the right of the non contact wearing subjects' distribution.

The mean non match Hamming distance for all subjects wearing contact lenses is 0.4471 with a median of 0.4491 and the mean non match Hamming distance for all non contact lens wearing subjects is 0.4453 with a median of 0.4472. The difference is not statistically significant.

The false reject rate (FRR) (percentage of false non matches) and false accept rate (FAR) (percentage of false matches) were calculated at a 0.32 Hamming distance threshold. The FRR for contact lens subjects was 9.42% meaning approximately 1 in 11 true matches would be reported as a non match. However, the FRR for non contact lens subjects was only 0.719% meaning that approximately 1 in 140 true matches would be reported as a non match. This presents a 14-fold increase for contact lens subjects versus non contact lens subjects. The FAR at the 0.32 threshold was 0.0000753% for contact lens subjects and 0% for non contact lens subjects. Contact lenses do not significantly affect the FAR.

B. Categorized Contact Lens Subjects

We computed Hamming distances for all pairs of images within each category of contact lenses and computed the mean and median Hamming distances. We present these means and medians as well as the false reject and false accept rates at a 0.32 Hamming distance threshold in Table I. Fig. 7 shows the match distributions for each of these categories and Fig. 9 shows the non match distributions for each of these categories.

The best performing category of contact lenses is category two, where the lens produces a circular boundary in the iris. This type of contact yielded an approximate 0.02 increase in Hamming distance, which is a 4% increase. A subject wearing this type of contact lens will experience a false reject rate approximately 10 times that of a subject not wearing a

TABLE I

MATCH AND NON MATCH MEAN AND MEDIAN HAMMING DISTANCES AND FRR AND FAR FOR CATEGORIES OF CONTACT LENS SUBJECTS

	Number of Subjects	Match Mean	Match Median	Non Match Mean	Non Match Median	FRR	FAR
No Contacts	64	0.1395	0.1323	0.4257	0.4283	0.273%	0.0000753%
Category 1	23	0.2286	0.2289	0.4457	0.4477	10.64%	0%
Category 2	14	0.1839	0.1753	0.4449	0.4467	3.90%	0%
Category 3	10	0.2184	0.2125	0.4502	0.4521	14.37%	0%
Hard	3	0.3238	0.3255	0.4525	0.4544	45.44%	0%

contact lens.

As expected, the worst performing category of contact lenses is the Hard contacts category. While these results represent only three subjects, they strongly demonstrate a significant shift in the Hamming distance for hard contact lens subjects. The mean Hamming distance increases by approximately 0.18 or 36% for these subjects. Additionally, the false reject rate is an astounding 45.4%, which is approximately 200 times that of a subject without any contact lens. At a Hamming distance threshold of 0.32, a subject wearing hard contacts is almost equally as likely to be falsely declared an imposter by the system as they are to be correctly matched.

The results shown for category one seem somewhat surprising, as this category consisted of the subjects whose iris images showed little, if any, artifact from the contact lens on the iris. Perhaps this type of contact lens magnifies the iris in such a way that it disturbs the texture and recognition but is not apparent to the human eye. This type of contact results in an approximate 0.06 or 12% increase in Hamming distance for matches. Additionally, for subjects wearing this type of contact lens, we observe a false reject rate approximately 20 times that of subjects without contact lenses.

The third category's results are not surprising, as this category includes subjects with significant artifacts on their iris from their contact lenses. The lenses with the printed "AV" or "1-2-3" will rarely have these markings on the same location of the iris in any two images. Thus, these markings alone will result in areas of mismatching. Additionally, matches involving subjects with these types of contacts are likely to also experience complications observed in the contacts from category one or two. The same conclusions can be drawn for subjects with artifacts due to ill-fitting contact lenses. Similar to subjects in category 2, subjects with these significant artifacts will experience an approximate 12% increase in Hamming distance. However, the false reject rate for these subjects increases to 14.37%, thus a subject with a significant visible artifact due to a contact lens is approximately 55 times more likely to be rejected by an iris recognition system than a person without any contact lenses. It is important to note that unlike hard contact lenses, most current systems have no mechanism to detect this type of artifact.

Fig. 8 clearly shows the false reject rates at various Hamming distance thresholds for the categories of contacts. All types of categories have rates well above that of no contacts. Hard contacts are clearly troublesome as they dramatically increase the false reject rate.

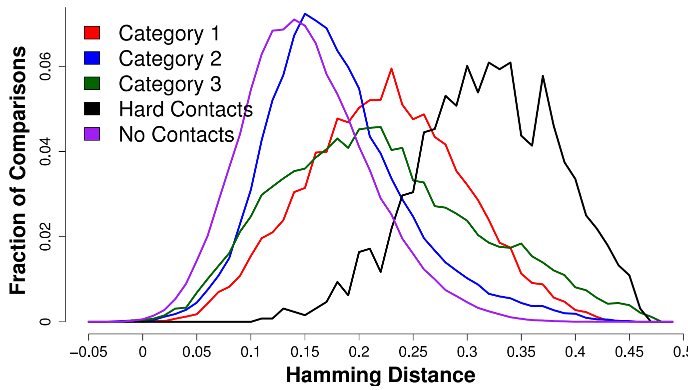


Fig. 7. Match Distribution for Categories of Contacts

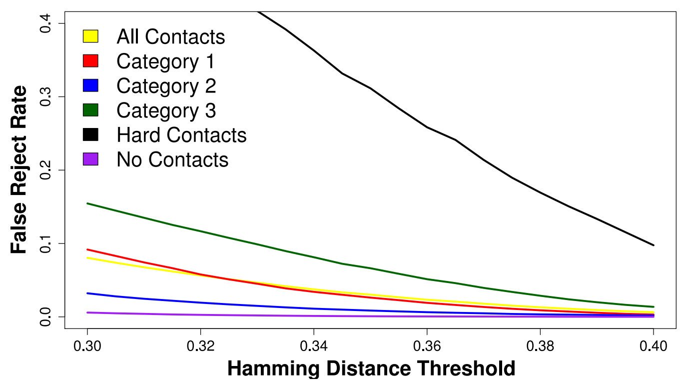


Fig. 8. False Reject Rates for Different Categories of Contacts at varying Hamming Distance Thresholds

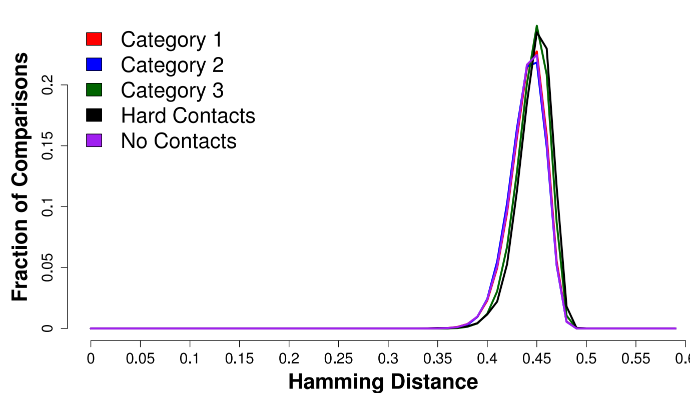


Fig. 9. Non Match Distribution for Categories of Contacts

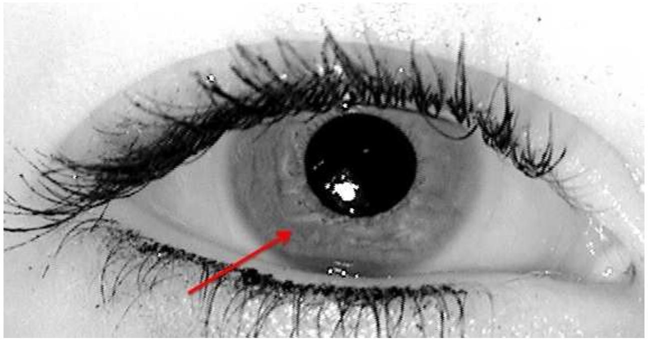


Fig. 10. Image of the cosmetic contact lens subject with regular contact lenses but with a significant artifact - 04780d192

We observe very little change in the non match Hamming distances for the various categories of contact lens subjects. Similarly, the false accept rates for the categories of contact lenses are not significantly different.

C. Cosmetic Contact Lens Effects

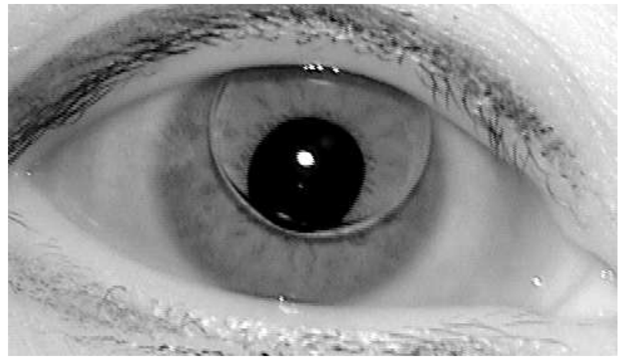
In order to determine the effect of cosmetic contact lenses, we consider our only subject with such lenses. We used 20 images of this subject with their cosmetic contact lenses and 26 images without these lenses. In the 26 images without the lenses, several of the images showed a significant artifact caused by their regular contact lenses (see fig. 10). If we were to categorize this subject based on their regular lenses, they would have been classified as a category 3 subject.

We compared pairs of cosmetic contact lens images for this subject and found the mean Hamming distance was 0.4213 and the median was 0.4444. The false reject rate for cosmetic lens versus cosmetic lens was 91.5%. Comparing pairs of regular contact lens images for this subject, we found the mean Hamming distance was 0.3090 and the median was 0.3141. The false reject rate for not cosmetic versus not cosmetic was 45.22%. This FRR is quite a bit higher than we would normally expect. However, given the very few matches produced due to the low number of images and the rather significant artifact found in several of this subject's images, it is not altogether surprising. Finally, we compared pairs of images where in one, the subject wore a cosmetic lens, and in the other the subject wore a regular contact lens. For these pairings, we found the mean Hamming distance was 0.4150 and the median was 0.4213. The false reject rate for this set was 98.13%.

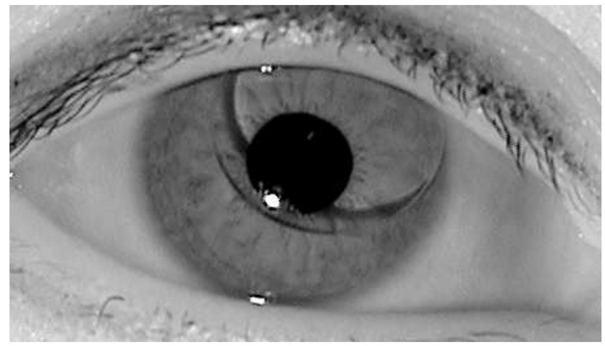
Clearly, the cosmetic lenses cause a tremendous degradation in match quality and make it nearly impossible to identify a person correctly. The high false reject rate for cosmetic versus cosmetic indicates that it is difficult to match a cosmetic lens to itself. The explanation is likely that the lens overlays a texture onto the natural iris texture, so that the observed texture is variable between images.

V. Visible Effects of Contact Lenses

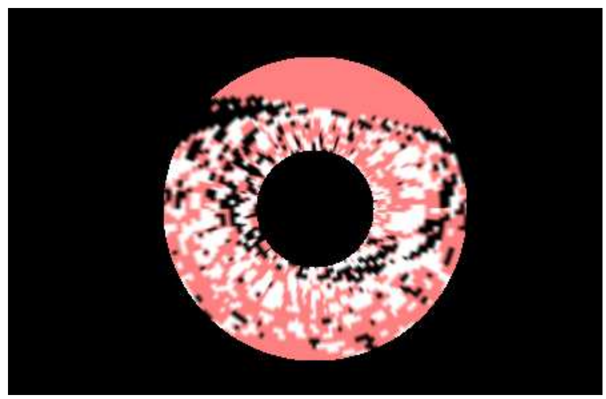
In this section we present our work to more precisely pinpoint the effect of certain contact lenses. We compare



(a) Gallery Image - 04593d617



(b) Probe Image - 04593d624



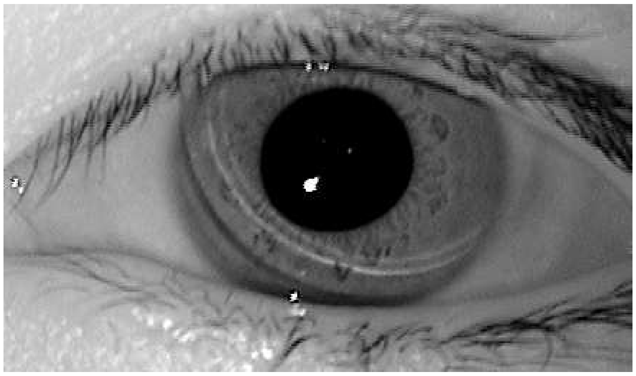
(c) Disagreeable Bits in match

Fig. 11. The black regions represent bits that did not agree in the match between Image 04593d617 and 04593d624. The red regions are bits that were masked in one or both of the images during the segmentation and the white regions represent bits that did agree in the match. With the exception of some eyelid occlusions, the black regions are around the contact lens boundary. This pair of images resulted in a Hamming distance of 0.315.

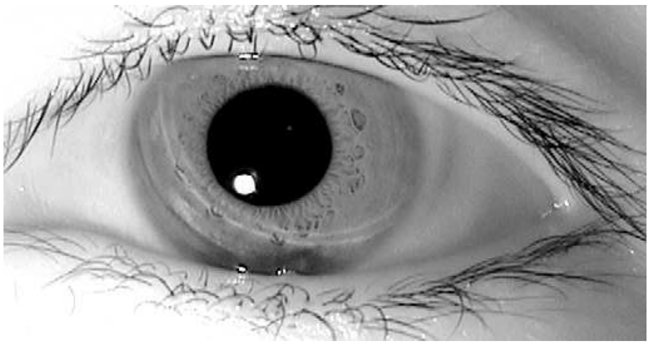
the aligned iris codes for two images from the same iris and find the locations of the bits that do not agree. We mark all bits that were masked by one or both of the images as red, all bits that agree as white, and all bits that disagree as black. We present the results of this for two subjects.

Subject 04593 wears hard contacts and as fig. 11 shows, the hard contacts mostly affect the iris code along its boundary. We do note that we do have some eyelid occlusion causing some bits to disagree in those regions as well. The region of the iris covered by the lens is mostly unaffected.

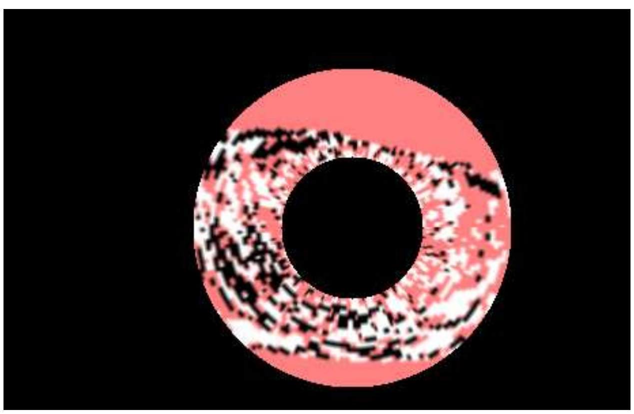
Subject 04221 had ill-fitting contact lenses that left a



(a) Gallery Image - 04221d1067



(b) Probe Image - 04221d1070



(c) Disagreeable Bits in match

Fig. 12. The black regions represent bits that did not agree in the match between image 04221d1067 and 04221d1070. The red regions are bits that were masked in one or both of the images during the segmentation and the white regions represent bits that did agree in the match. With the exception of some eyelid occlusions, the black regions mostly are found near the artifact caused by the contact lens. This pair of images resulted in a Hamming distance of 0.364.

substantial artifact on their iris. As fig. 12 shows, this artifact significantly affected the match score. Again, we observe some disagreeable bits due to eyelid occlusion, but the regions of the contact lens' artifact are largely disagreeable.

In both of these figures, the images used for comparison were acquired in the same acquisition session within seconds of each other. Comparing images from different acquisition sessions shows an even more noticeable effect as the contact lens (and its resulting artifact) will not be in the same general location as they are in these pairings.

VI. Discussion and Future Work

The results presented here show that contact lenses of all types, not just hard or cosmetic lenses, cause significant degradation in iris match quality. Additionally, we have shown that the degree of degradation and the increase in the false reject rate varies with different types of contact lenses. The false accept rate is not affected by the contact lenses.

In order to reduce the rate of false non matches for contact lens subjects, it may be possible to implement new algorithms to detect lenses and mask the bits around the boundaries they present in the iris. However, as we showed with the category one contact lenses, some lenses produce no visible artifact on the iris, yet they clearly effect the texture in some way to degrade match quality. Therefore, some technique may be required to overcome the effect these lenses have on match quality. Additionally, the artifacts due to ill-fitting contacts would be difficult to detect as they are more inconsistent within a subject's images.

It is important to extend this study on a larger subject pool and perhaps further distinguish the categorizations of contact lenses. We also would like to more closely examine the actual iris regions affected by contact lenses on the match score. This may be especially pertinent for the category one contact lenses as we cannot visually distinguish the effect of the lens on the iris image. The images in the other categories all exhibit obvious disturbances in the iris. Thus, as we have shown, we can predict that the increased Hamming distance results from bits not likely to match around these regions of disturbance.

Many individuals choose not to wear their prescribed contact lenses at all times. Thus, it is important to consider scenarios where we compare contact and non contact lens images of the same subject. It is possible that the contact lenses may magnify or alter the texture of the iris in such a way as to further increase the match scores between the contact lens and non contact lens images.

VII. Acknowledgement

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