Unconstrained Visible Spectrum Iris with Textured Contact Lens Variations: Database and Benchmarking

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Abstract

Iris recognition in visible spectrum has developed into an active area of research. This has elevated the importance of efficient presentation attack detection algorithms, particularly in security based critical applications. In this paper, we present the first detailed analysis of the effect of contact lenses on iris recognition in visible spectrum. We introduce the first contact lens database in visible spectrum, Unconstrained Visible Contact Lens Iris (UVCLI) Database, containing samples from 70 classes with subjects wearing textured contact lenses in indoor and outdoor environments across multiple sessions. We observe that textured contact lenses degrade the visible spectrum iris recognition performance by over 25% and thus, may be utilized intentionally or unintentionally to attack existing iris recognition systems. Next, three iris presentation attack detection (PAD) algorithms are evaluated on the proposed database and highest PAD accuracy of 82.85% is observed. This illustrates that there is a significant scope of improvement in developing efficient PAD algorithms for detection of textured contact lenses in unconstrained visible spectrum iris images.

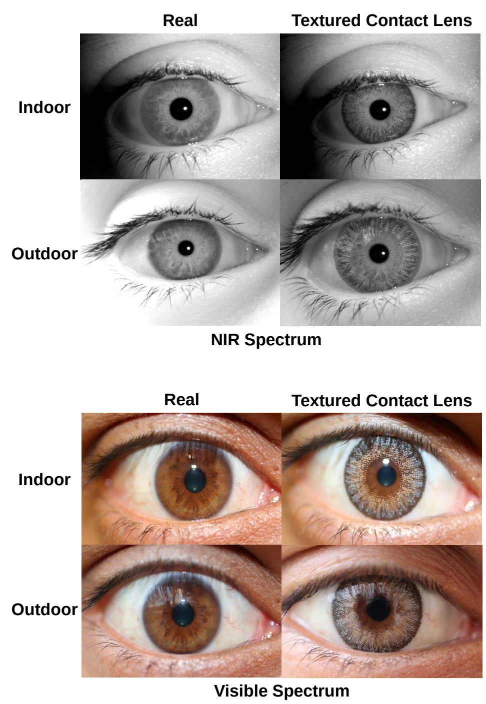


Figure 1: Illustrating the variations due to textured contact lenses and environmental variations in near-infrared (NIR) and visible spectrum iris images. (Best viewed in color)

1. Introduction

Surge of iris biometrics in authentication applications such as banking and e-commerce sectors has increased concerns about the ease of subversion of these systems by determined adversaries. In the literature, researchers have demonstrated the impact of variety of presentation attacks on near-infrared (NIR) spectrum based iris recognition systems such as print/scan attacks [3], textured contact lens [5], and synthetic irises [16]. Studies have also focused on developing algorithms for detection of contact lenses in iris images captured in NIR spectrum [1, 7, 20].

Research in visible spectrum iris recognition [4, 10, 11, 18] has witnessed significant growth in recent years and is being actively explored. Iris recognition in visible spectrum can be utilized for applications such as authentication in outdoor environments where near-infrared iris images may be difficult to acquire. Visible spectrum iris recognition has also gained popularity due to its potential application in the field of mobile biometrics [15, 19].

Various visible spectrum iris databases exist in the literature such as UBIRIS.v2 [12], MICHE [8], mobile phone-based [19], and VSSIRIS [15]. However, there is a distinct lack of attention towards the probability of presentation attacks in visible spectrum based iris recognition and very few relevant studies exist. Recently, Raghavendra and Busch [13] have demonstrated a video-replay presentation attack for iris recognition in the visible spectrum using printed

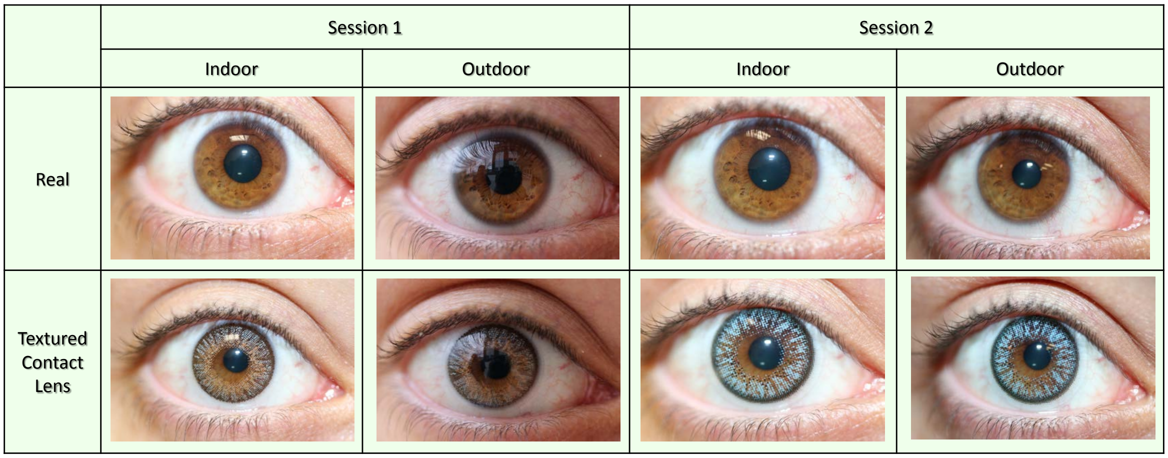


Figure 2: Sample images of a subject from the proposed Unconstrained Visible Contact Lens Iris (UVCLI) database demonstrating the variations due to textured contact lens, environmental conditions, and multi-session acquisition. (Best viewed in color)

photos and electronic displays. Even though, textured contact lens are becoming more popular with developments in low-cost technology, their influence on iris recognition in visible spectrum has not been explored. The problem is compounded by the non-existence of any visible spectrum iris database with annotated information regarding subjects wearing textured contact lens. Moreover, it is imperative to evaluate the effectiveness of these algorithms in detecting contact lenses in iris images captured in unconstrained scenarios. Figure 1 highlights the transformations in the iris texture patterns in both NIR and visible spectrum.

In this paper, we present a novel visible spectrum iris database comprising 70 classes with textured contact lens iris images and real iris images. The images in the database have been acquired in varying environmental scenarios. We also analyze the effect of textured contact lenses on visible spectrum iris recognition and the performance of existing iris presentation attack detection (PAD) algorithms is evaluated on the proposed database. The key contributions of this paper are:

- Introducing a new benchmark unconstrained visible spectrum contact lens iris database termed as Unconstrained Visible Spectrum Contact Lens Iris (UVCLI) Database[1]. The proposed database consists of over 3,800 images, both real and with textured contact lenses, pertaining to 70 iris classes. This database comprises multi-session images of subjects captured in a controlled indoor environment as well as in an unconstrained outdoor environment with variations in illumination. To the best of our knowledge, this is the first such publicly available visible spectrum database. Figure 2 shows sample images from the proposed database. Since the database contains multiple images per class, it can also be utilized to create better iris recognition algorithms in visible spectrum.
- Evaluating the effect of wearing textured contact lenses on the performance of existing visible spectrum iris recognition algorithm with the proposed database. The influence of environmental variations at the time of image acquisition is also analyzed. Therefore, the influence of two confounding variables: textured contact lenses and environmental variations on iris recognition performance is demonstrated.
- Benchmarking the performance of existing iris presentation attack detection algorithms on the proposed UVCLI benchmark database in detecting contact lenses in the visible spectrum.

[1]The database will be available at http://iab-rubric.org/resources.html#iris

2. Unconstrained Visible Spectrum Contact Lens Iris (UVCLI) Database

The increasing popularity of contact lens has led to the advent of technology for developing user-friendly contact lens by different manufacturers. These contact lenses may be utilized inadvertently or intentionally to attack iris recognition systems. Currently, prominent contact lens manufacturers offer a variety of options for textured contact lenses which vary with respect to the color of the textured contact lens and replacement frequency (daily or disposable). These variations may impact the performance of visible iris recognition systems differently. Furthermore, due to the advantages in deployment of visible spectrum iris recognition in outdoor environments, it is crucial to understand how unconstrained nature of visible spectrum images captured in outdoor environment influences the performance. To the best of our knowledge, there is no database which

Table 1: Characteristics of the proposed Unconstrained Visible Contact Lens Iris (UVCLI) database.

Spectrum	Visible
Environmental Variations	Multi-Session Acquisition Indoors and Outdoors
Total Number of Images	3,802
Types of Images	Real (1,877) & Textured Contact Lens (1,925)
Contact Lens Brands	CIBA Vision Freshlook Colorblends; CIBA Vision Dailies; Bausch & Lomb Lacelle; Aryan; and Celebration
Number of Subjects (Classes)	35 (70)
Participant Gender	Females (17) & Males (18)

captures these diverse variations in visible spectrum. Therefore, to evaluate the influence of these variations, we introduce the Unconstrained Visible Contact Lens Iris (UVCLI) Database.

The proposed UVCLI database consists of 3,802 iris images captured in visible spectrum at two locations: indoors (with controlled illumination) and outdoors (with varying environmental scenarios) in two sessions. These images have been captured one at a time using EOS 60D DSLR Canon camera with EFS 60mm f/2.8 Macro USM Fixed lens. In each session of data acquisition, a minimum of six images of each eye when wearing textured contact lens and a minimum of six images of each eye without any lens (real) are acquired. These images are captured indoors and this process is repeated in the outdoor environment. Outdoor images have been collected at varying times of the day (such as afternoon and night) and varying weather conditions (such as sunny and cloudy). Majority of the first session outdoor data collection is conducted during the daytime.

The textured contact lenses utilized in this database belong to five different types: CIBA Vision FreshLook Dailies[2], CIBA Vision Freshlook Colorblends, Bausch & Lomb Lacelle[3], Aryan 3-Tone, and Celebration. Varying colors such as pure hazel, turquoise, amethyst, and gray have been selected to create a medley of texture patterns. Also, each participant is provided with color lens from different manufacturers in different sessions.

In total, the database comprises of iris samples from 35 subjects (70 classes) with 17 females and 18 males between the age of 18-38 years. The database has participants belonging to diverse ethnicities such as Asian, Caucasian, and Hispanic. Table 1 summarizes the characteristics of the proposed UVCLI database and Figure 1 illustrates sample images of an individual from the database.

This new database can be utilized by the research community for visible iris recognition in unconstrained scenarios and textured contact lens detection in visible spectrum. In the following sections, we present baseline experiments on the proposed UVCLI database for analyzing the effect of textured contact lenses on visible spectrum iris recognition. We also benchmark the performance of existing iris presentation attack detection algorithms on this database.

3. Effect of Textured Contact Lens on Unconstrained Visible Spectrum Iris Recognition

In this section, we investigate the effect of textured contact lens on the performance of iris recognition. As the texture patterns of the contact lens may conceal the original iris patterns, they may be used for intentional or unintentional iris presentation attacks. Hence, it is imperative to evaluate how textured contact lens degrade the accuracy of iris recognition systems.

3.1. Iris Recognition Algorithms for Evaluation

The first step in the iris recognition pipeline is the segmentation of the iris region. For this purpose, three existing algorithms are utilized: OSIRIS v4.1 [17], total variation (TV) based algorithm [22], and IrisSeg [2]. OSIRIS V4.1 [17] is an open-source iris recognition software and has been employed for visible spectrum iris segmentation by Raja et al. in [14]. TV based segmentation algorithm [22] is proposed by Zhao and Kumar for segmenting unconstrained iris images including visible spectrum and they have demonstrated superior performance on databases such as UBIRIS.v2 [12] as compared to other approaches. IrisSeg [2] has been recently introduced specifically for segmenting non-ideal irises. Out of these three approaches, TV based algorithm yields the best segmentation outputs. Both OSIRIS and IrisSeg are not able to detect the iris-pupil boundary, particularly, the images that were captured outdoors. It should be noted that various color channels were also explored to enhance the segmentation outputs. It is observed that there is a significant decrease in the overall contrast between the pupil and iris region in the images collected in the visible spectrum. This significantly reduces the segmentation performance of the tested algorithms and in many cases, the entire iris region is marked as the pupil region. Hence, there is a need to develop better iris segmentation algorithms for unconstrained visible spectrum iris images.

As the goal of this experiment is to compute baseline iris recognition performance due to the presence of textured

[2]http://www.freshlookcontacts.com/all-color-contacts/

[3]http://www.bausch.com.my/en/our-products/contact-lenses/cosmetic-lenses/lacelle/

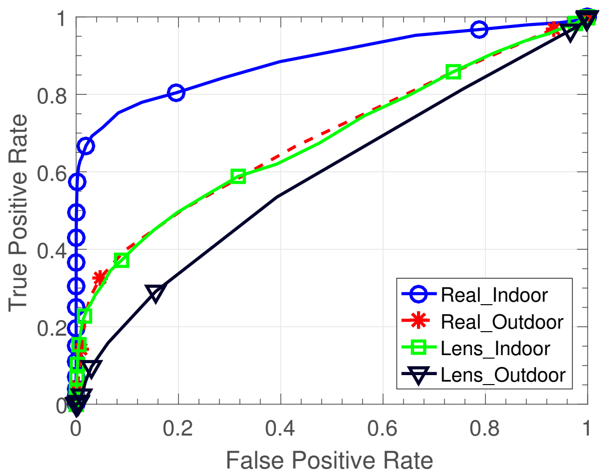


Figure 3: ROC curves showing the performance of visible iris recognition on the proposed UVCLI database (Session 1 and Session 2 combined).

contact lens and environmental variations, feature extraction and matching are performed using the classical iris recognition approach by Masek and Kovesi [9] after segmenting the iris region. This is similar to the approach followed by Zhao and Kumar [22] for visible spectrum iris recognition. Feature extraction is performed by normalizing the segmented iris into rectangular images followed by computation of 1D log-Gabor filters. The templates are created by quantization of these features to four levels and are matched using Hamming distance. For investigating the performance of unconstrained visible spectrum iris recognition, commercial-off-the-shelf system (VeriEye) is also utilized. However, it failed to segment the iris region in majority of the images.

3.2. Iris Recognition Experimental Protocol

The proposed UVCLI database has real and textured contact lens images of each subject captured indoors and outdoors across two sessions. An experimental protocol is designed to evaluate the effect of textured contact lenses on the performance of iris recognition system. In this experiment, one real (without contact lens) image per class which are acquired indoors in the first session are combined to form the gallery. This experiment simulates the scenario where the iris images used for enrollment are acquired in controlled illumination setting. The remaining visible spectrum iris images are utilized to form the probe set to analyze the impact of textured contact lenses on visible iris recognition.

3.3. Iris Recognition Experimental Results

Table 2 and Figure 3 show the iris recognition accuracy on the experimental protocol described above and the results are analyzed subsequently.

Table 2: Iris recognition performance (EER%) on the proposed UVCLI database.

Session	**Environment**	**Real**	**Textured Contact Lens**
Combined	Indoor	19.55	38.35
	Outdoor	37.65	42.57
Session 1	Indoor	13.44	40.70
	Outdoor	43.39	40.97
Session 2	Indoor	19.97	37.76
	Outdoor	33.55	39.70

As seen in Figure 3 and the *Combined* row of Table 2, the best iris recognition performance is observed when the probe contains real images. On further analysis, it is observed that the probe containing images captured indoors in the same session as the gallery (first session) yields EER of 13.44%. This result serves as the baseline for the remaining comparisons as the gallery-probe set pair is expected to have minimum intra-class variations.

On the other hand, if the real gallery images captured indoors are matched with real probe images captured in outdoor environment, there is a drastic decrease in the iris recognition performance. We observe approximately 30% increase in EER (session 1 real outdoor) and 20% increase in EER (session 2 real outdoor) in these cases with respect to the baseline. This highlights the challenging nature of iris images captured in outdoor environment due to factors such as specular reflection and varying illumination. The 10% EER increase in session 1 outdoor real images probe as compared to session 2 outdoor real images probe can be attributed to the fact that majority of session 1 outdoor samples are acquired in daylight, which can lead to specular reflections and other illumination issues in the images.

Next, we analyze the effect of the presence of textured contact lens in the probe set and the accuracy for the same is shown in the rightmost column of Table 2. It is observed that textured contact lenses reduce the performance of visible spectrum iris recognition system as compared to the baseline. The EER of textured contact lenses probe images ranged from 37.76% to 40.97% EER in different environments and sessions. This result illustrates that textured contact lenses significantly conceal the original iris pattern which in turn, can be utilized by individuals to conceal their identity.

In summary, these experiments highlight that textured contact lens significantly degrades the performance of iris recognition system in visible spectrum. This can lead to intentional or unintentional concealment of identity. Additionally, it is very challenging to segment visible spectrum iris images acquired in outdoor environment due to varying illumination conditions and future visible spectrum iris recognition algorithms need to account for these challenges.

4. Iris Presentation Attack Detection in Unconstrained Visible Spectrum

The previous section highlights that textured contact lens significantly reduces the accuracy of iris recognition system in visible spectrum and hence, can be considered as a *iris presentation attack*. Thus, it is crucial to design algorithms for detecting textured contact lens in a given visible spectrum iris image. In this section, we investigate the performance of the three existing PAD algorithms:

- DESIST [6]: DEtection of iriS spoofIng using Structural and Textural feature (DESIST) framework is proposed by Kohli et al. [6] for detecting multiple iris presentation attacks such as textured contact lens and print attacks in NIR spectrum. DESIST is the state-of-the-art in detecting NIR based multiple iris presentation attacks.
- Multiscale BSIF [13]: Raghavendra and Busch [13] have developed this framework for detecting photo print and screen attacks in visible spectrum iris images. They have utilized multiscale Binarized Statistical Image Features (BSIF) and Support Vector Machine (SVM). This framework uses segmented iris image using OSIRIS [17] and whole iris image to detect presentation attack in visible spectrum. As mentioned earlier that on the proposed database OSIRIS does not yield good segmentation performance; therefore, the experiments are performed on the whole iris image.
- Weighted LBP [21]: For classifying textured contact lens iris images in NIR spectrum, Zhang et al. [21] have utilized Weighted Local Binary Patterns (Weighted LBP) in conjunction with SVM classifier.

4.1. Visible Spectrum Iris PAD Experimental Setup

For the purpose of iris presentation attack detection, five-fold cross validation is performed on the proposed UVCLI database such that the subjects in the training and testing partitions are unseen. Two experimental protocols are developed which are explained subsequently:

Real vs Attack Iris Detection: In this experiment, all visible spectrum real and textured contact lens (attack) images of the training partition subjects are used for training the PAD models. Similarly, all the images of the subjects in the testing partitions are utilized for evaluating the PAD performance.

Effect of Environment: The objective of this experiment is to evaluate the efficacy of iris presentation attack detection algorithms which are trained only with constrained iris images captured indoors. In this experiment, the training set comprises indoor real and attack images captured in the first session, while the testing set comprises first session outdoor, second session indoor, and second session outdoor images of testing partition subjects.

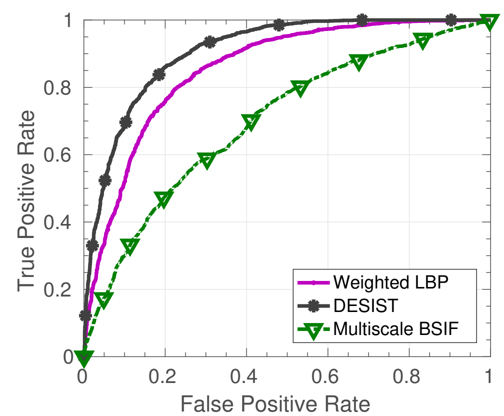
Table 3: Iris Presentation Attack Detection Performance on the proposed UVCLI database.

(a) Results of *Real vs Attack Iris Detection*

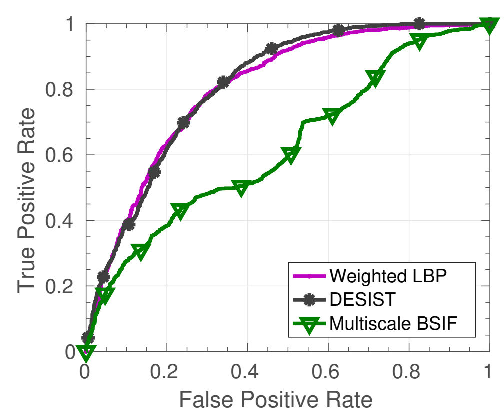
Algorithm	Mean PAD Accuracy (%)
DESIST [6]	**82.85 ± 3.73**
Weighted LBP [21]	78.49 ± 3.15
Multiscale BSIF [13]	63.30 ± 3.31

(b) Results of *Effect of Environment*

Algorithm	Mean PAD Accuracy (%)
DESIST [6]	**74.60 ± 5.33**
Weighted LBP [21]	73.88 ± 2.17
Multiscale BSIF [13]	56.29 ± 8.28



(a) *Real vs Attack Iris Detection*



(b) *Effect of Environment*

Figure 4: ROC curves showing the performance of visible spectrum iris PAD algorithms on the proposed UVCLI database.

4.2. Visible Spectrum Iris PAD Results

The results of iris presentation attack detection on the proposed UVCLI database are summarized in Table 3 and Receiver Operating Characteristic (ROC) curves are presented in Figure 4.

4.2.1 Results of *Real vs Attack Iris Detection*

Upon analyzing the results of experiment *Real vs Attack Iris Detection* in Table 3a and Figure 4a, we observe that DESIST framework [6] outperforms other approaches by at least 4% in distinguishing between visible spectrum real and attack (textured contact lens) images. The combination of structural and textural features in DESIST is able to encode discriminatory information for iris presentation attack detection.

The performance of iris PAD algorithms are further analyzed with respect to the percentage of real and textured contact lens (attack) images correctly classified in *Real vs Attack Iris Detection* experiment. Using DESIST, 85.00% of the real images are correctly classified as compared to 79.31% and 62.07% by multiscale BSIF and weighted LBP, respectively. On the other hand, 80.79% of attack images are correctly classified by DESIST. In other words, around 20% of attack images may be incorrectly classified as real by the state-of-the-art iris PAD algorithm.

4.2.2 Results of *Effect of Environment*

For analyzing the effect of environmental variations in visible spectrum iris PAD, we evaluate the results of *Effect of Environment*. In this experiment, the training set consists of only real and textured contact lens images captured in indoor setting with controlled illumination. Table 3b and Figure 4b illustrate the results of this experiment. It is observed that PAD performance of all three algorithms decreases by 5-8% in *Effect of Environment* experiment. This can be attributed to the fact that the algorithms are not trained on visible samples that have been acquired in outdoor environment and did not account for variations such as considerable illumination changes. This showcases that iris PAD algorithms need to be trained with real-world unconstrained iris images.

Additionally, iris PAD analysis of DESIST is performed on session-wise indoor and outdoor visible images. We observe that second session images which are captured indoors are classified with 82.98% PAD accuracy as compared to 65.53% and 73.73% for first session outdoor and second session outdoor images respectively. The higher classification accuracy of second session indoor images can be associated with the fact that the DESIST algorithm is trained with images captured in indoor environment. Also, it is seen that first session outdoor images are classified with lower accuracy as compared to second session outdoor images. One reason for this can be that the data acquired in first session outdoor has three times more images collected in sunny weather as compared to the second session. Capturing visible spectrum images in sunny weather can lead to more ambient light and reflection, thus, making it difficult to discern real iris images.

5. Conclusion

Researchers are actively exploring the area of iris recognition in visible spectrum due to its advantages in unconstrained iris recognition, particularly in outdoor environment where NIR may be of limited use. However, very few databases exist for iris recognition in visible spectrum which are acquired in an unconstrained manner. At the same time, similar to NIR spectrum, iris recognition in visible spectrum is also vulnerable to different types of presentation attacks. Our experimental results demonstrate that there is a need to actively investigate and mitigate the effect of presentation attacks in iris recognition for visible spectrum.

To promote the research in the area of presentation attack detection of textured contact lenses, we introduce the first contact lens database in visible spectrum, named as UVCLI database. The database contains over 3,800 real and textured contact lens images belonging to 70 iris classes. This database is acquired with varying unconstrained environmental scenarios and is multi-session in nature. Moreover, this database can also be utilized for research in iris recognition in unconstrained visible spectrum. We also observe that the images in the proposed UVCLI database are very challenging to segment, particularly the images which are captured outdoors. This highlights the need for developing robust visible spectrum iris segmentation algorithms. In the future, we aim to incorporate additional variations in the database by including visible spectrum images captured by mobile phones with more number of subjects.

The effect of textured contact lenses on the performance of iris recognition in visible spectrum is further evaluated and it is seen that the presence of contact lenses drastically degrades the performance by over 25%. To analyze the efficacy of current PAD algorithms on the proposed database, three iris PAD algorithms are utilized. The state-of-the-art PAD algorithm for detecting multiple types of iris attack in NIR spectrum yields PAD accuracy of 82.85%. This highlights the need to develop efficient algorithms for detecting contact lenses in visible spectrum. The proposed unconstrained visible contact lens iris (UVCLI) database will be valuable in further developing and improving the performance of iris recognition and PAD algorithms.

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