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Real-world Non-NIR Illumination and Wavelength-specific Acquisition Variants in Iris Recognition

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***Abstract*—Experiments with real-world non-NIR illumination as well as wavelength-specific acquisition settings are conducted with respect to impact on iris recognition performance, in particular considering variations in genuine score distribution. Illumination includes daylight, light bulbs, fluorescent tubes, halogen lamps, and mixed modes, while acquisition is done in visible wavelength, near infrared wavelength, and a combination of both. Results indicate very different results for blue and brown eyes respectively, with halogen illumination and visible and mixed-mode acquisition being an interesting option for a compromise setting.**

***Keywords*-iris recognition, visible wavelength, NIR, illumination, light bulbs, fluorescent tubes, halogen lamps**

I. Introduction

Iris recognition is said to be the most accurate biometric modality [1], [2], at least when conducted in somewhat constrained conditions using near-infrared (NIR) illumination and NIR acquisition. When being operated in non-cooperative and less constrained settings (e.g. surveillance-type video footage), several issues need to be resolved to maintain high recognition accuracy [3]. The "Iris-on-the-move"-system established significant improvements in terms of acquisition distance as compared to the highly constrained and static acquisition conditions of the earlier systems. However, one of the most limiting factors is the non-availability of pure NIR illumination in unconstrained setting, giving as well rise to the question which imaging technique should be employed under less controlled illumination. Thus, a wide variety of iris-imaging techniques (wrt. illumination and acquisition) have been developed and investigated [4].

One of the considered questions in this context is which (multi)spectral wavelengths are most appropriate for iris recognition – in this context wavelength band clustering and specific bands have been investigated [5], [1], [6]. Due to the availability of NIR image datasets (acquired during enrollment) but potentially non-NIR sample acquisition, the question of cross-spectral recognition has gained interest and promising techniques have been developed [7], [8], [9], [10]. The importance of this topic is underpinned by the recent 2nd Cross-Spectrum Iris/Periocular Recognition Competition (at IJCB 2017). Of course, specific attention has been paid towards the visible wavelengths (VWL) [11], representing the most important "natural" illumination source. Due to the widespread use of mobile devices (which are mostly restricted to VWL acquisition), also in the context of (biometric) authentication applications, mobile iris recognition using VWL illumination and acquisition has been discussed to some extent [12], [13], [14]. However, recognition accuracy is clearly reduced as compared to constrained NIR iris recognition in this setting.

In this (experimental) work we focus on typical illumination settings as present in real-world scenarios, i.e. daylight, light bulbs, fluorescent tubes, and halogen lamps. For these illumination variants, we consider three acquisition types (i.e. NIR, VWL, NIR+VWL = mixed acquisition) in order to determine the most appropriate one for each illumination type. The work most closely related to this present study is [15], where the authors investigate VWL acquisition under LED lighting conditions.

In Section 2 we present a motivating experimental example, where the known dis-function of VWL-imaging in case of brown irides is drastically exhibited (thus demonstrating that VWL illumination and acquisition cannot be a viable option for iris recognition). Section 3 describes in detailed manner our experimental setup in terms of illumination, data acquisition, and recognition experiments, while experimental results are presented and discussed in Section 4. In Section 5, we present the conclusions of this work.

II. A Motivating Example: VWL Iris Recognition on Dark Irides (UTIRIS)

It is a well known fact (and one of the reasons for using NIR imaging for high accuracy iris recognition) that it is difficult to conduct iris recognition on dark irides. Reports on reasonable performance of VWL iris recognition, often conducted on datasets containing a small number of dark irides only [12], [13], [14], [11], somewhat conceal this phenomenon.

In order to provide a clear motivation to look into the performance of differently coloured irides in great detail, we conduct experiments on the University of Tehran IRIS

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(UTIRIS[1]) image repository. UTIRIS is a hybrid dataset containing iris data taken from 79 subjects, taken in both the NIR and VWL domain, respectively. For each subject, there exist four images for each eye for NIR as well as for VWL. Figure 1 shows examples for both illumination / acquisition settings.

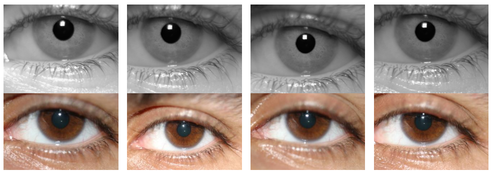


Figure 1: Example images of subject 011, left eye (first row NIR, second row VWL).

Since this database was created in Iran, most images contained within UTIRIS naturally exhibit dark brown iris patterns. This fact makes UTIRIS an interesting and challenging dataset especially for VWL iris recognition (and comparison to the NIR domain).

To perform the experiments we use USITv2[2] (University of Salzburg Iris Toolkit v2.0.x [2], [16]), a publicly available iris recognition software package which comprises different algorithms for iris pre-processing, feature extraction, and comparison. *Segmentation* is performed using a method based on contrast-adjusted Hough transform (`caht`) proposed by [2]. *Normalisation* is performed using the rubber sheet model [17]. *Feature extraction* is based on 1D log-Gabor filters (`lg`), as proposed by Masek [18], resulting in binary iris codes.

For matching, we compute the Hamming distance (HD) between sample and template iris codes, compensating for head tilt by shifting the codes against each other in each direction by $\pm$ 7 bits, taking the minimum HD as distance between them. In Figs. 2 and 3 we display the resulting genuine score (HD resulting from matching iris codes of the same subject only, displayed in blue, termed "Same eyes") as well as imposter score (HD resulting from matching iris codes of different subjects only, displayed in red, termed "Different eyes") distributions, respectively.

For the NIR case (Fig. 2), we do not get non-overlapping distributions as desired, however, the sensible extent of separation for most of the scores will at least allow for a medium recognition performance. The situation is very different for the VWL case (Fig. 3): Genuine and imposter score distributions overlap almost completely in a range between 0.4 and 0.5 (which is the expected HD for imposter matches), exhibiting only a small amount of genuine scores ("Same eyes") with HD $<$ 0.4. Thus, with these data, sensible iris recognition is not possible. Therefore, it is quite obvious that there is need for looking into illumination and acquisition alternatives, in case NIR imaging is not possible, as VWL does not work at all on dark irides.

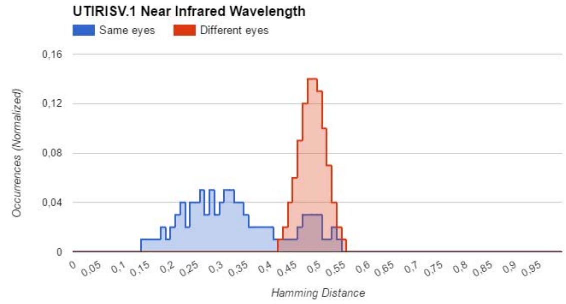


Figure 2: Genuine and imposter distributions for NIR data.

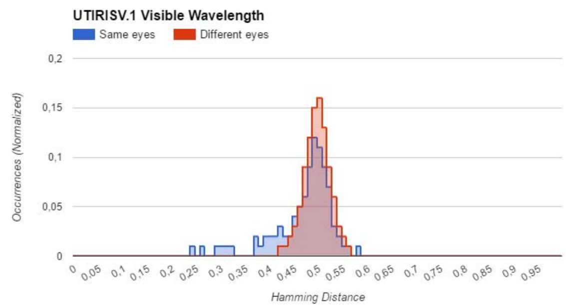
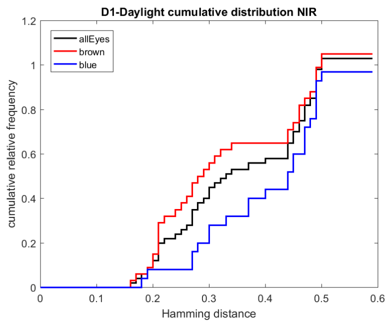


Figure 3: Genuine and imposter distributions for VWL data.

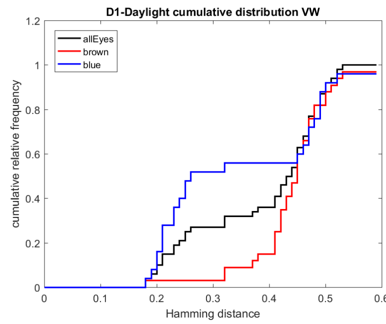
III. Experimental Setup

We focus on real-world illumination conditions which may occur or might be available in environments not dedicated to NIR iris recognition. With the knowledge that daylight is hardly a viable solution for dark brown irides we want to investigate alternative solutions, specifically for indoor illumination and acquisition. Potential example application scenarios include airports or general land- and sea-borders where the aim is to have less constrained acquisition conditions and subjects to be identified could be on the move in an surveillance-related acquisition setting. Thus, in such settings, NIR illumination as done for classical iris recognition systems is not an option.

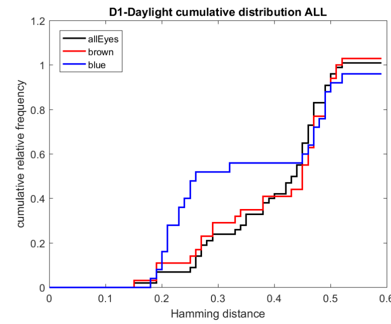
With respect to illumination, we use daylight as a baseline, and additionally consider illumination by a light bulb, by a fluorescent tube, and by a halogen lamp. The latter illumination is also considered in a combination with daylight. One of the biggest problems in non-NIR iris imaging are reflections in the eye caused by the illumination. To limit these artifacts to the minimum and not to mix recognition problems caused by reflections and inability to visualise iris texture patterns, iris images are taken from subjects lying on the back, pictures taken from above, with the illumination also done from above. Acquisition is done with a Canon



(a) Acquisition: NIR



(b) Acquisition: VWL

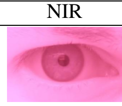
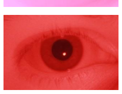
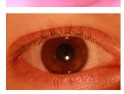
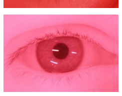
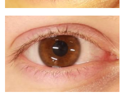
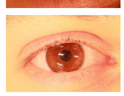
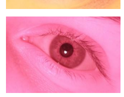
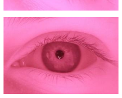
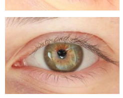
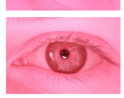


(c) Acquisition: NIR+VWL

Figure 4: Illumination: Daylight.

DSLR, EOS 5D MarkII, which has been modified to enable NIR acquisition (the NIR blocking filter has been removed from the sensor). The applied RGB filter blocks all light below 830 nm. Thus, we are using three acquisition variants: Pure NIR (by applying the RBG filter), pure VWL (by applying the NIR filter), and the mixed mode in which we use the camera without blocking filter. Table I visualises an example of each acquisition variant (three columns) applied to each illumination variant (five lines) of a single eye.

TABLE I. Exemplary Images

	NIR	VWL	Mixed
Daylight			
Light bulb			
Fluorescent tube			
Halogen lamp			
Halogen + day			

The example imagery in the table clearly exhibit reflections of significant size for VWL and mixed (NIR+VWL) acquisition when daylight and halogen + daylight illumination is applied. Bulb and halogen lamp have the best reflection properties, as the reflections are situated in the pupil area only for all three acquisition variants. Fluorescent tube reflections are clearly visible also no matter which acquisition is used, however, the artifacts are rather small and stationary (in our acquisition settings).

We have acquired 4 images per eye and both eyes of each subject, the number of subjects was different in the various acquisition conditions. For assessing the suitedness of the acquired imagery for iris recognition, we have computed all genuine score matches to analyse the differences in genuine score distributions. Having acquired 4 images of both eyes of each subject, this results in 6 genuine matches per eye and 12 genuine matches per subject (using the identical feature extraction and matching technique as used in the previous section on the UTIRIS dataset). Table II shows the resulting number of genuine matches used in our assessment. Note that the number of overall matches exceeds the sum of blue and brown eye matches (except for “bulb”) as subjects with green irides were also involved.

TABLE II. Number of matches in each eye class.

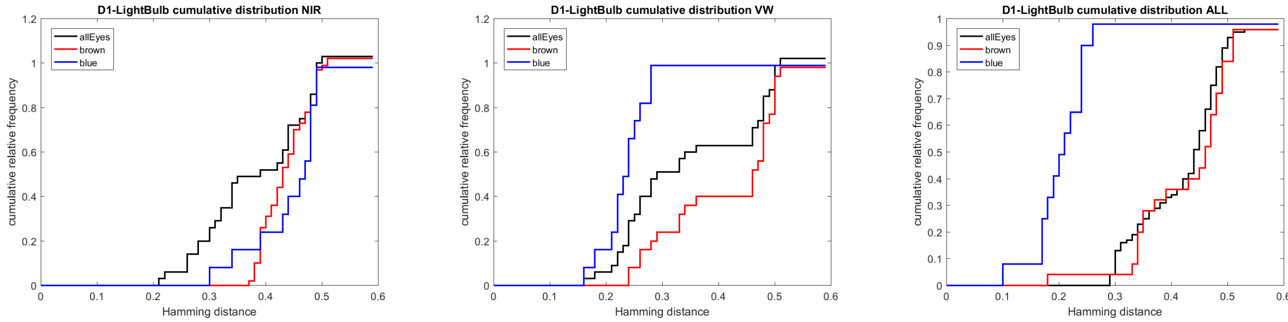
	day	bulb	tube	halogen	halogen + day
overall	60	36	60	48	48
blue	24	12	24	24	24
brown	24	24	24	12	12

Given the different number of considered matches in the five illumination settings, corresponding genuine score histograms are difficult to compare (visually and computationally). Normalisation wrt. an identical number of matches helps, but visually different histograms are still difficult to compare. Therefore, we use cumulative distribution functions (i.e their discrete versions) of normalised histograms to compare the genuine score distributions of different illumination and acquisition settings. In the ideal case of a genuine score distribution (i.e. many low HD values), the cumulative distribution has a steep onset for low values of HD, reaches 1 early and stays constant at 1 for larger HD values.

IV. Experimental Results

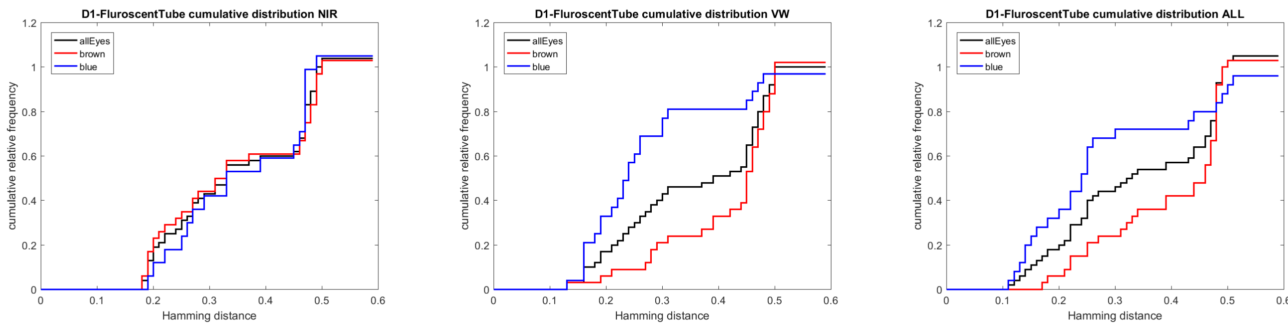
As the reference case, we look at the results of daylight illumination. Figs. 4a - 4c display the results of the corresponding acquisition variants.

The overall impression of the UTIRIS results, i.e. VWL is not suited for dark brown irides, is confirmed. We observe that for VWL acquisition (Fig. 4b), blue eye matching scores



(a) Acquisition: NIR (b) Acquisition: VWL (c) Acquisition: NIR+VWL

Figure 5: Illumination: Lightbulb.



(a) Acquisition: NIR (b) Acquisition: VWL (c) Acquisition: NIR+VWL

Figure 6: Illumination: Fluorescent tube.

are very well while those of brown eyes are very poor. On the other hand, for NIR acquisition (Fig. 4a), brown eye matching scores are clearly better than those of blue eyes, which is the first surprising result.

For mixed acquisition (Fig. 4c), the extremely poor performance of brown eyes is mitigated, while the blue eye performance is not harmed. However, the overall performance (allEyes) is slightly reduced as compared to the NIR only case.

As the next illumination variant, we consider light bulb in Figs. 5a - 5c. It is interesting to observe that for NIR only acquisition (Fig. 5a), results are worse as compared to daylight illumination. In particular, brown eyes matching score are drastically worsened, indicating a negligible NIR share in the light emitted by the bulb.

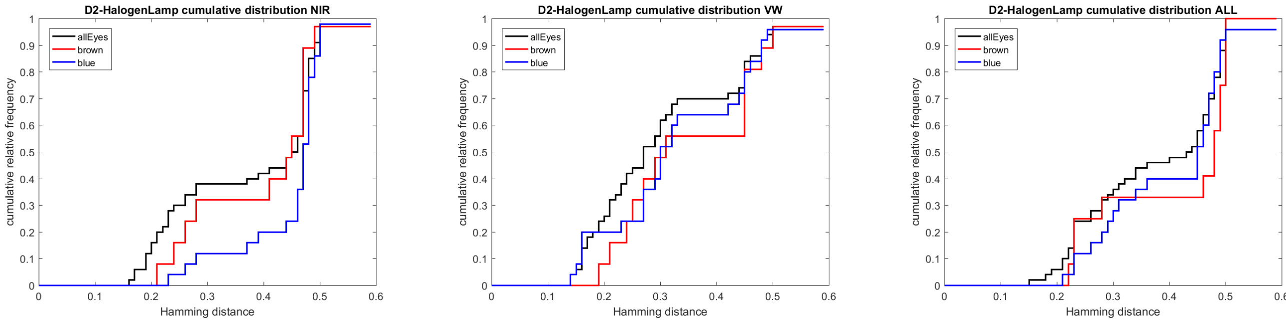
Results differ dramatically when acquisition involves VWL as seen in Figs. 5b and 5c. In particular VWL only acquisition shows clearly better genuine scores for blue eyes under daylight illumination and VWL and mixed acquisition. The behaviour for allEyes is on par with that for allEyes under daylight illumination and NIR acquisition. Overall, this setting is an interesting variant if there is a large share of non-brown irides, while still having not too bad scores for brown eyes. For mixed acquisition, brown eyes and overall matching scores are significantly deteriorated while still maintaining excellent results for blue eyes.

Figs. 6a - 6c show the results for fluorescent tube illumination. The NIR only acquisition (Fig. 6a) exhibits almost equal score distribution for all eye types considered, not favouring any eye type, with overall mediocre results.

When involving daylight, we face a significant discrimination of the genuine score distributions wrt. to different eye colours. Blue eyes exhibit clearly better behaviour as compared to brown eyes under these conditions. Mixed acquisition (Fig. 6c) represents a compromise behaviour – while the advantages of blue eyes are somewhat reduced, results of brown eyes and average results get slightly better.

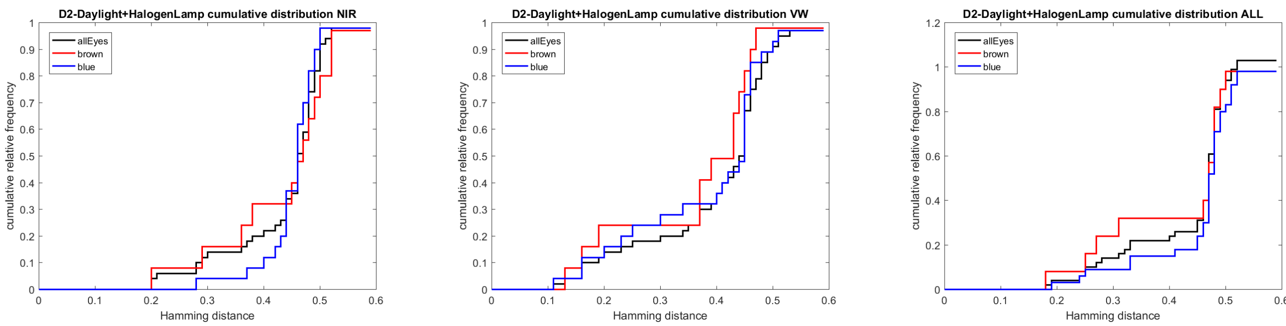
Figs. 7a – 7c show the results of halogen (only) illumination. For NIR acquisition, matching scores are quite poor, e.g. clearly poorer compared to fluorescent tube illumination. This is especially true for blue eyes.

VWL acquisition (Fig. 7b) exhibits very different behaviour. We see rather equal behaviour for all eye types and overall, this illumination and acquisition setting combination is the best of all being considered. Only for blue eyes, there are better options (i.e. light bulb illumination with VWL and



(a) Acquisition: NIR (b) Acquisition: VWL (c) Acquisition: NIR+VWL

Figure 7: Illumination: Halogen lamp.



(a) Acquisition: NIR (b) Acquisition: VWL (c) Acquisition: NIR+VWL

Figure 8: Illumination: Daylight + halogen lamp.

mixed acquisition). For mixed acquisition as displayed in Fig. 7c, we notice clearly worsened behaviour as compared to VWL only acquisition.

Finally, Figs. 8a – 8c display the results of mixing daylight with halogen illumination.

It can clearly be observed that this illumination variant is the worst, not providing useful genuine scores for any of the involved eye types. We suspect that on of the reasons might be the presence of strong reflections caused by the daylight illumination. However, it is not clear why the additional usage of halogen illumination significantly worsens the results when compared to daylight illumination only.

V. Conclusion

Our experimental results confirm known defects of VWL acquisition under daylight illumination when it comes to recognising brown irides. Interestingly, we also find particularly worsened genuine score values for blue eyes under NIR acquisition. Based on our results, we give the following *recommendations*. If an equal share of dark brown and lighter (i.e. blue and green) irides are present in the population, the best overall imaging variant has turned out to be halogen lamp illumination when using VWL acquisition. In case of populations with dominating blue eyes, light bulb illumination with VWL acquisition is the best option. Contrary, in populations with dominating brown eyes, we do not recommend to use daylight illumination with NIR acquisition, as the genuine scores for brown eyes are only negligibly better as compared to those under halogen lamp illumination with VWL acquisition, while under NIR acquisition, overall results as well as blue eyes behaviour is clearly deteriorated. Thus, even in populations with dominating brown eyes, we still recommend halogen lamp illumination with VWL acquisition (as long as a significant share of non-brown eyes is present).

Acknowledgments

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