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Implications of ocular pathologies for iris recognition reliability☆

Mateusz Trokielewicz[a,b], Adam Czajka[a,b,*], Piotr Maciejewicz[c]

[a]Biometrics Laboratory, Research and Academic Computer Network (NASK), Kolska 12, Warsaw 01-045, Poland
[b]Institute of Control and Computation Engineering, Warsaw University of Technology, Nowowiejska 15/19, Warsaw 00-665, Poland
[c]Department of Ophthalmology, Medical University of Warsaw, Lindleya 4, Warsaw 02-005, Poland

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ABSTRACT

This paper presents an analysis of how iris recognition is influenced by eye disease and an appropriate dataset comprising 2996 images of irises taken from 230 distinct eyes (including 184 affected by more than 20 different eye conditions). The images were collected in near infrared and visible light during routine ophthalmological examination. The experimental study carried out utilizing four independent iris recognition algorithms (MIRLIN, VeriEye, OSIRIS and IriCore) renders four valuable results. First, the enrollment process is highly sensitive to those eye conditions that obstruct the iris or cause geometrical distortions. Second, even those conditions that do not produce visible changes to the structure of the iris may increase the dissimilarity between samples of the same eyes. Third, eye conditions affecting the geometry or the tissue structure of the iris or otherwise producing obstructions significantly decrease same-eye similarity and have a lower, yet still statistically significant, influence on impostor comparison scores. Fourth, for unhealthy eyes, the most prominent effect of disease on iris recognition is to cause segmentation errors. To our knowledge this paper describes the largest database of iris images for disease-affected eyes made publicly available to researchers and offers the most comprehensive study of what we can expect when iris recognition is employed for diseased eyes.

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1. Introduction

1.1. Iris recognition in the presence of ocular pathologies

The iris is a colored, annular structure surrounding the pupil of the eye. It displays intrinsically complex patterns that are unique due to random epigenetic factors. The distinctive patterns, developed in the fetal stage, provide features that can be used with high confidence for biometric identification. Uniqueness, combined with the feasibility of fast template creation and matching, allows for the building of large-scale applications of iris recognition. Examples are India's AADHAAR Unique Identification Authority of India [1] with more than 1.2 billion people enrolled, and CANPASS system [2] maintained by the Canadian Border Services Agency (CBSA) which provides efficient entry into Canada for frequent travelers.

Iris recognition is also being considered by the International Civil Aviation Organization (ICAO) as a candidate for inclusion in the next generation of biometric passports along with fingerprint and face biometrics [3]. The temporal stability of iris patterns is strongly supported by Safir and Flom in a 1987 patent describing theoretical principles of iris recognition. The authors assert that the '*significant features of the iris remain extremely stable and do not change over a period of many years*' [4]. Further support comes from John Daugman whose 1994 patent states: '*the iris of the eye is used as an optical fingerprint, having a highly detailed pattern that is unique for each individual and stable over many years*' and '*the iris of every human eye has a unique texture of high complexity, which proves to be essentially immutable over a person's life*' [5]. The NIST IREX VI report presents an experimental study showing lack of aging in the iris [6]. (However, one should be aware of other studies presenting evidence of aging in the iris, published by University of Notre Dame, USA [7–9], and Warsaw University of Technology, Poland [10,11].)

Those statements and the excellent performance of iris recognition are related to the immutability of the iris pattern in a healthy eye. When an injury, disease or other ocular pathology is present, it is not a given that such a condition will not affect the visibility or appearance of the features of the iris. Such occurrences may degrade the performance of the iris recognition system either by altering the iris or obstructing its view. In certain circumstances, it may even render the eye unsuitable for use in authentication at all. This can be the case in occurrences of aniridia, a medical disorder, often bilateral, in

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* Corresponding author at: Biometrics Laboratory, Research and Academic Computer Network (NASK), Kolska 12, Warsaw 01-045, Poland.
E-mail address: aczajka@elka.pw.edu.pl (A. Czajka).

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which only a small, ring-shaped portion of tissue is present where the iris would normally be located. This often leaves a large and possibly irregularly shaped pupil [12].

Eye trauma and injuries are also contributing factors to degradation of iris recognition accuracy. Although Daugman states that '*as an internal organ of the eye the iris is well protected from the external environment*' [5], in some cases this kind of protection (*i.e.*, by the cornea and the aqueous humor in the anterior chamber of the eye) may not be sufficient. Safir and Flom, being ophthalmologists and thus aware of this issue, acknowledged it in their patent claim: '*A sudden or rapid change in such a feature [of iris pattern] may result in a failure to identify an individual, but this may alert the individual to the possibility of pathology of the eye*' [4].

1.2. Scope of this study

Various medical conditions affecting the structures of the eye, the iris in particular, may cause a deterioration of the reliability of iris recognition. Investigation into previous research (*cf.* Section 2) shows that we are still far from fully understanding how various eye conditions impact iris recognition. This can be attributed to the lack of large, heterogeneous, and publicly available databases appropriate for this subject. This paper aims to answer **four questions** related to ocular disorders and their impact on iris recognition while providing an appropriate database of images of unhealthy eyes to researchers. **The questions are**:

1. Do ocular pathologies impact the enrollment process? If so, which structural impairments translate into an increase in the failure-to-enroll rate (FTE), *i.e.*, the proportion of samples that could not be enrolled to the overall number of samples?
2. Does iris recognition perform worse in unhealthy eyes without visible impairments in comparison with healthy irises when photographed in near-infrared (NIR) light? In other words, can we assume that there are some properties of the iris image, not revealed in NIR light, that prevent iris recognition from achieving optimal performance?
3. What kind of visible impairments in unhealthy irises have the greatest impact on iris recognition?
4. What are the main reasons for bad performance when iris recognition is applied to unhealthy eyes?

To answer these questions, a dataset of iris images representing more than twenty different eye diseases was built with the use of a professional iris recognition camera operating in NIR light, along with an ophthalmological commentary (*cf.* Section 3). Most of the NIR samples are accompanied by color images to make possible independent ophthalmological interpretations. Experimental study done for four different and independent iris recognition algorithms is presented (*cf.* Sections 4 and 5).

To our knowledge, this paper describes the largest published dataset of NIR and color images for unhealthy eyes with a professional, ophthalmological commentary and offers the most extensive study to date of ways in which different types of diseases of the eye impact iris recognition.

2. Related work

Previous studies related to the topic of the influence of ocular disease on iris recognition show that the need for large, heterogeneous, publicly available databases has yet to be fully appreciated. With few exceptions, most heretofore available studies utilize small datasets and focus on only one disease.

Probably the first experiment devoted to this field of research was conducted by Roizenblatt et al. [13] and involved 55 patients suffering from cataract. Each person was enrolled in the LG IrisAccess 2000 biometric system before cataract removal surgery, 30 days after cataract removal, and 7 days after stopping the administration of pupil-dilating drugs (when pupils had reverted to normal size and reaction to light). After the 30-day period, differences in the size of pupils were no larger than 1.5 mm when compared with images obtained prior to the treatment. Each eye that underwent a surgery was also given a score between 0 and 4 based on visual inspection performed by an ophthalmologist. One point was given for each of the following ocular pathologies: depigmentation, pupil ovalization, and focal atrophy with and without trans-illumination. A correlation was revealed between the visual inspection score and change in Hamming distances (HD) between templates created using pre- and post-surgery samples. 6 out of 55 eyes were no longer recognized, thus yielding FNMR of about 11%. For remaining irises there were significant shifts towards worse HD (11.3% increase in average HD when scores between gallery samples and post-surgery samples are compared against scores between gallery samples and pre-surgery samples) and worse visual scores (11.13% increase in average visual score for images collected post-surgery, as compared to average visual score for those obtained pre-surgery), however, those eyes were classified correctly. Authors suggest that the energy released inside the eyeball during the cataract surgery may be a cause of atrophic changes to the iris tissue. Re-enrollment is suggested as a countermeasure in cases with significant, visual alteration to the iris visible during a slit-lamp examination.

A similar scenario regarding the impact of cataract surgery was explored by Seyeddain et al. [14] who performed an experiment to establish the effects of phacoemulsification and pharmacologically induced mydriasis on the iris (Phacoemulsification refers to the extraction of the lens through aspiration. The procedure involves the insertion of a small probe through an incision in the side of the cornea. The probe emits ultrasound waves that break up the opacified lens which is later removed using suction [15].). The experiment aimed to determine whether the irises, following phacoemulsification or drug induced mydriasis (preventing the dilated pupil from reacting to light stimulation) perform more poorly when compared to the same irises before the procedure or before the drug-induced pupil dilation. They revealed that 5.2% of the eyes that were subject to cataract surgery could no longer be recognized after the procedure. In the pupil dilation group, this portion reached as high as 11.9%. In both cases the authors suggest re-enrollment for patients whose eyes were not successfully identified after the surgery or instillation of mydriatics. No false acceptances were observed in either case.

Trokielewicz et al. [15] aimed at quantifying the impact of cataracts on iris recognition performance. An experiment involving three different iris recognition methods revealed differences in system performance when comparison scores calculated before surgery from cataract-affected eyes are used instead of those obtained from healthy eyes. For all three methods there was a perceivable degradation in average genuine comparison scores with differences reaching from 12% of genuine score increase for an academic matcher, up to 175% of genuine score increase for one of the commercial matchers. For two out of three matchers, these changes also affected the final false non-match rate.

Dhir et al. [16] studied the influence of the effects of mydriatics accompanying cataract surgery. A group of 15 patients had their eyes enrolled before surgery. A verification was performed at 5, 10, and 15 minute intervals after application of the drug and again two weeks following the procedure itself. None of the eyes was falsely rejected after this two-week period. One must, however, keep in mind that the authors excluded from the dataset eyes with pre-existent corneal and iris pathologies, or those with iris tissue damaged during the surgery. The study suggests that recognition deterioration may originate from a slight shift of the iris towards the center of the eyeball resulting from implantating an artificial lens that is thinner than

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