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Iris Recognition in Postmortem Enucleated Eyes

Sashi K. Saripalle [1], Adam McLaughlin[2], Reza Derakhshani[3]

Abstract: This paper presents a comprehensive multispectral study of iris recognition on postmortem enucleated eyes over a period of three days. An off the shelf iris recognition methodology is employed to analyze the biometric capability of iris in the post mortem setting. We observed that iris patterns of enucleated eyes can provide biometric matches with no false accepts for up to 164 hours after death, albeit with high false rejection rates. We also present our observations on the effects of the environment and other confounding factors that may affect the performance of postmortem iris recognition, with recommendations for rehydration of specimen to regain postmortem biometric utility.

Keywords: Postmortem biometrics, iris recognition, biometrics, forensics.

1 Introduction

Human iris patterns are arguably among the best biometric modalities for personal identification due to their unique and stable textures. It has been observed that the matching probability of two different irides is about one in seven billion [JD01]. However, when it comes to postmortem settings, the functionality of iris as a biometric requires further investigations. Previous work from Warsaw University details several aspects of postmortem iris recognition, confirming that modern iris recognition systems can indeed match postmortem iris samples [MAP18, MAP16a, MAP16b]. However, many aspects of postmortem iris biometrics, especially with off the shelf iris recognition systems under different environmental and other external factors is not widely studied. In this work we revisit this challenging area of biometrics by collecting a new postmortem dataset to provide further information on the functionality of traditional iris biometric systems when applied to enucleated human eyes, and the effect of external environment factors on postmortem iris recognition.

To achieve these goals, we started our study by collecting a new dataset by capturing postmortem enucleated human eyes using a multispectral visible-IR camera and illuminator over a period of 96 hours. The choice of multispectral imaging was due to the reported postmortem iris color changes noted in pigs [EMD08]. Although not well-studied in humans, we noted the possibility of iris color changes in postmortem human iris. The second reason for multispectral imaging was to test the hypothesis that there could be faint blackbody afterglow signature pursuant to an infrared flash. This hypothesis was based on blood

[1] Computational Intelligence and Bio-Identification Technologies Lab, University of Missouri at Kansas City, ssqnf@mail.umkc.edu
[2] School of Medicine , University of Missouri – Kansas City, adammclaughlin81@gmail.com
[3] Computational Intelligence and Bio-Identification Technologies Lab, University of Missouri at Kansas City, derakhshanir@umkc.edu

spotting technique using lock-in amplifier for detection of black-body radiation of blood proteins similar to the method developed by Morgan [SM11]. However, we were not able to observe any changes immediately after infrared flash on iris tissue within the limitations of our experimental setup, and thus we won't be expanding upon it during this paper.

2 Data Collection

2.1 Hardware

The main study camera was a MS4100 multispectral unit (Optech Intl.) with multiple band-passed CCDs. The distance between the specimen and lens of the camera was 0.22 meters. We also built a custom multi-spectral ring light along its control unit to match our camera's centre multi-spectral frequencies. The light control unit also triggered camera's shutter based on a predefined sequence.

2.2 Capture Process

We obtained the study's enucleated human eyes from a local eye bank in temperature-controlled boxes stabilized at 2 degree Celsius. The eyes were then transported to a medical facility where they were stored under the supervision of an ophthalmologist. From twenty-seven acquired specimen, a total of eleven specimen were used for this study. Sixteen of the specimens were rejected due to either perforated iris tissue or punctured eyes balls at the start of study (figure 1). An ophthalmologist inspected the specimen to make sure the structure of eyeball and iris tissue were intact before the study was initiated on the specimen. The average time from death to procurement of eyes was around 7.5 hours, with the minimum of and maximum time lapses being 3.5 and 24 hours, respectively. The average time of procurement to study was six days. The average age of donor was 72 years. Analysis of our specimen was done in two parts: short-term and long-term. A total of 214 samples were used for short term analysis, and a total of 718 samples were used for long term analysis. The eye colors of the specimen were either light brown, blue, green, gray, or dark brown. Further experimental setup details can be found in section V.

We also captured data from fifty live control subjects over two sessions at UMKC under the auspices of an Institutional Review Board approved protocol. These sessions were at least one week apart, and multiple captures were acquired for each session with a time delay of at least 15 minutes between captures. The iris scores from control subjects were used to set the threshold for postmortem analysis.

3 Related Work

Postmortem iris recognition has been receiving less attention in literature in part due to a belief that iris possesses little biometric value after death. Other barriers to the study of

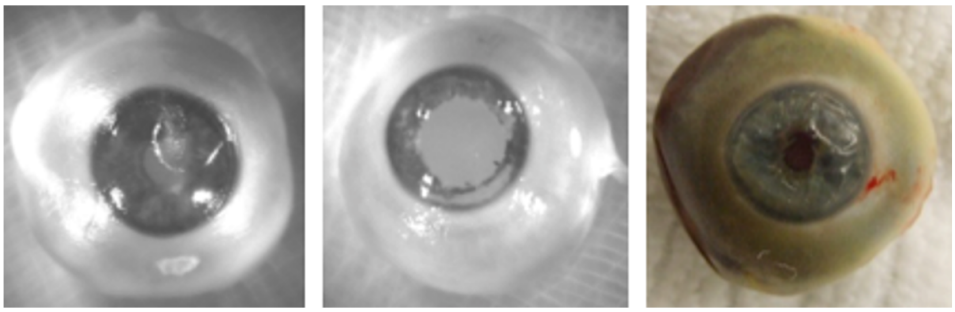

Fig. 1: (left to right): Deflation due to IOP, torn iris due to trauma, Tache Noire (in visible spectrum).

post-mortem human iris tissue include difficulties with obtaining and managing donated eyes for time-lapse postmortem studies.

With recent discoveries in postmortem iris biometrics, the role of iris as a forensic tool has gained the attention of researchers. Trokielewicz, Czajka and Maciejewicz pioneered postmortem iris recognition in humans in 2016 [MAP16a, MAP16b]. They have since published numerous articles providing an excellent account on postmortem iris biometrics.

Maciejewicz et. al. [MAP20] describe a method which employs a learning-based segmentation algorithm followed by a matching algorithm based on Gabor filters. They report equal error rates (EER) of less than 1% compared to 16.89% from off the shelf methods such as OSIRIS. These results are based on postmortem samples that are captured up to ten hours after death.

Maciejewicz et. al. [MAP19] analyzed the biometric capability of iris under different ocular pathologies. They showed the effects of different eye pathologies such as cataract on iris segmentation. They also show the biometric EER of irises with cataract are slightly greater than those of the normal irises.

In [MAP18], Maciejewicz et. al. discuss the effects of aging, disease and postmortem changes on the human iris. They show that differences in pupil dilation, combined with certain quality factors of the sample image and the progression of age as well as postmortem duration can significantly degrade the recognition accuracy.

Bolme et. al. in [Da16] discuss the effects of environment, including temperature, on natural decay of deceased bodies. The research collected a multi-modal postmortem biometric dataset and analyzed the feasibility of using fingerprint, face and iris under long term postmortem scenario. It was observed that postmortem fingerprints were easier to acquire and had lower false reject ratse compared to other postmortem biometric modalities.

Sansola et. al. [Al15] used IriShield M2120U iris recognition camera together with off the shelf IriCore matching software in their postmortem experiments involving 43 deceased subjects who had their irises photographed at different post-mortem time intervals. The study reported 19-30% false rejects and no false accepts. The study also reported on the

relationship between eye color and iris match scores, with blue-gray eyes yielding lower correct match rates than brown eyes.

4 Qualitative Analysis of Postmortem Iris

Researchers have studied qualitative changes related to ante to post mortem human ocular tissues including iris, retina, aqueous humor, and sclera [Da55]. Postmortem ocular changes, although not visible to the unaided eye, start early and on the onset of death. These processes are initially at molecular and cellular levels, and slowly progress into macroscopic level. Some of the affected tissues and the instigating factors related to postmortem iris recognition performance are described below.

Iris: The eye, when regarded as an extension of the body proper, can also be noted to exhibit the effects of trauma and systemic medical disease at the time of death. Several examples of trauma include injuries that could have led to the death of the subject, as well as post-surgical changes common in the elderly population (glaucoma surgery utilizing iridotomy or cataract surgery). These factors could impact the use of iris for biometrics. Complicating matters is the possibility of interval change in iris positioning and density caused by varying degrees of physiologic pupillary dilation.

Cornea: One of the most noticeable postmortem finding is corneal opacity. The cornea, although an extremely thin tissue, is particularly susceptible to changes in the environment. Corneal clarity is achieved by tightly organized collagen fibers with a specific percentage of hydration. If corneal hydration is altered by processes like surface epithelial drying or dysfunctional endothelial pump cells which could occur following death, corneal opacity can develop (Figure 2). In [JN94], the researchers observed that corneal opacity occurs approximately after two hours of death. Interestingly, the study also indicates that corneal opacity depends on season of death, i.e. postmortem opacity is increasingly seen in summer compared to winter season which is further corroborated by [Da16].

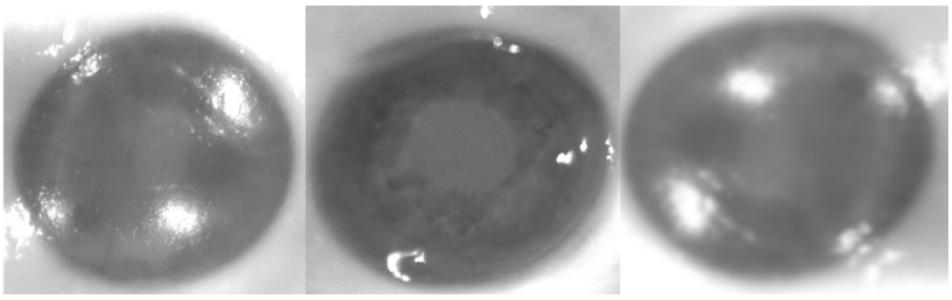

Fig. 2: (left to right): Pupil fadeout, limbic boundary diffusion, and corneal opacity.

Other Aspects *Tache Noire:* Tache Noire de la sclerotique is a phenomenon where conjunctivae darkens due to drying when the eyes remain open postmortem, creating darker

patches on the white of the eye [Pr03]. This process may make the eyeball rigid and and initiate deformation of the eyeball.

Limbic boundary fadeout: Limbic boundaries are circular and sharp. In the later stages of post-mortem analysis, these boundaries fade out due to opacification and natural degradation, making it difficult even for a human observer to determine the accurate limbic boundaries (Figure 2).

Intraocular Pressure (IOP): Loss of ocular tension in postmortem eyes causes the eye to flatten and lose its roundness, much like a deflated ball. This alters the shape and contour of the anterior segment of the eye, including the iris, and can negatively affect biometric utility [GDA15]. Change of intraocular pressure in postmortem studies is poorly understood due to a paucity of investigation.

5 Quantitative Study

Methods To analyze the postmortem utility of off the shelf iris recognition, we used a method similar to Open Source for IRIS (OSIRIS), which is an academic software developed within the BioSecure EU project [Su12]. It follows the original work of John Daugman, for iris image segmentation and subsequent normalization to a dimensionless polar coordinate system. A binary iris code is calculated using phase quantization of the Gabor filters. Hamming distance is used to compute dissimilarity score between two iris templates. Hamming distance between two irises 'a' and 'b', whose iris codes are codeA (Ca) and codeB (Cb), respectively, and whose valid segmentation masks are A and B, respectively, is given by:

$$d = \frac{\|(C_a \otimes C_b) \cap A \cap B\|}{\|A \cap B\|} \tag{1}$$

A match threshold of 0.42 was used in our study based earlier-mentioned control dataset. Since the goal of our experiment was to validate the effectiveness of iris recognition algorithms on postmortem enucleated iris, we manually corrected all limbic and pupil boundaries that were erroneous. We also removed iridial glare.

Experiment Setup We captured images in both visible and infrared spectra, and divided our quantitative experiments into three analyses:

1. Short Term Analysis (Unaided): For this analysis, data was captured during a six to seven hour observation period in one hour intervals. The enucleated eyes were left to naturally degrade at around 17 degrees Celsius. The aforesaid duration for short time analysis was experimentally determined based pilot observations on the first specimen, noting when it degraded to a point where iris tissue was completely deformed. This time is referred to as minimum decay time.
2. Long Term Analysis: After the minimum decay time, we continued imaging each specimen on a two-hour interval basis for two days, with two days being the longest possible duration after which the last specimen was entirely deformed.

3. Long Term Analysis with Hydration: While working on long term analysis, we observed that adding saline drops on specimen and storing the eyeballs in saline liquid helped the iris to retain its biometric value compared to when it was left out at room temperature. To further validate this observation, we stored a few specimens in saline under controlled temperature. These specimens were taken out only for iris captures. The iris was captured on an hourly basis for six hours per day for three days. In this setting, when the eyeball started to deform, we injected saline into the eyeball to retain its shape. This method was successful only until a certain iteration and stage, after which the eyeball could not retain its shape. This was especially evident on the onset of Tache Noire.

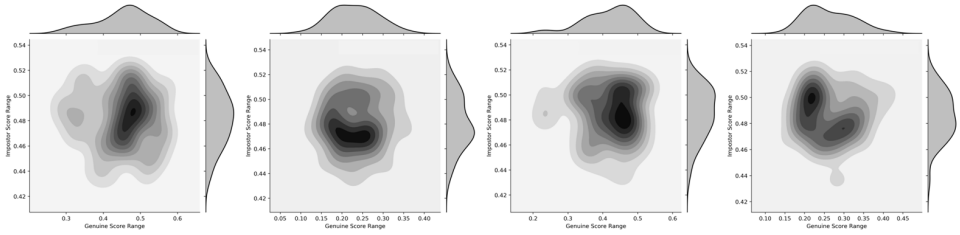

Fig. 3: (left to right) genuine (x-axis) and impostor (y-axis) score distributions for unaided long-term, unaided short term, aided long-term, and aided short-term analyses.

Quantitative Performance Analysis Figure 3 shows the distribution of genuine and impostor scores for different experiment settings. We report False Reject Rate (FRR) at 0% False Accept Rate (FAR) operating point, which was derived from the control subject data, as a measure of iris performance for the forthcoming analysis. The algorithm did reach the 0% FAR point for all the three postmortem experiment settings at such threshold, albeit with at varying FRRs.

1. Short term analysis: Short term analyses for both aided and unaided long-term study were similar. The enrollment template was computed from the first capture, and the remaining captures were used as verification samples. For the unaided study, the average FRR at 0% FAR was 3.25%. Similarly, for the aided study, the average FRR at 0% FAR was 0%. Figure 3 shows the distribution of match scores for this analysis. It was observed that the minimum and maximum FRRs for short term analysis were 0% and 12.5%, respectively. The specimen that caused higher FRRs had developed opacity at a faster rate than the other specimen. Also, it was noted that the iris colors of the specimen with larger FRR tended to be lighter.

2. Long term analysis (Unaided): Figure 5 shows the performance in terms of iris match scores with respect to postmortem duration for unaided long term analysis. The enrollment template was from corresponding short-term analysis experiment. Captures after the end of short term study were used as verification samples. The average FRR at 0% FAR was 78.47% for this experiment. Figure 3 shows the distribution of match scores for unaided short and long-term analysis. The minimum and

maximum FRRs for for this dataset was observed to be 62.5% and 91.6%, respectively. Six of the eleven specimen were used for this study.

3. Long term analysis with Hydration (Aided): Figure 4 shows the performance of long term analysis of eyes kept in saline solution (aided). The enrollment template was from corresponding short-term analysis experiment. Captures after the end of short term study were used as verification samples. The average FRR at 0% FAR was 55.8% for this long-term analysis. Figure 3 shows the distribution of match scores for this analysis. The minimum and maximum FRR for this dataset were 25.2% and 78%, respectively. Five of the eleven specimen were used for this study.

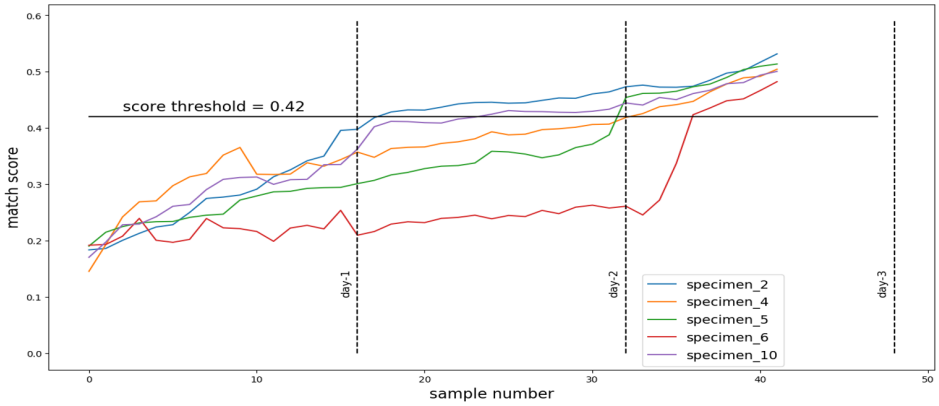

Fig. 4: iris match score progression with respect to aided short and long term postmortem period. .

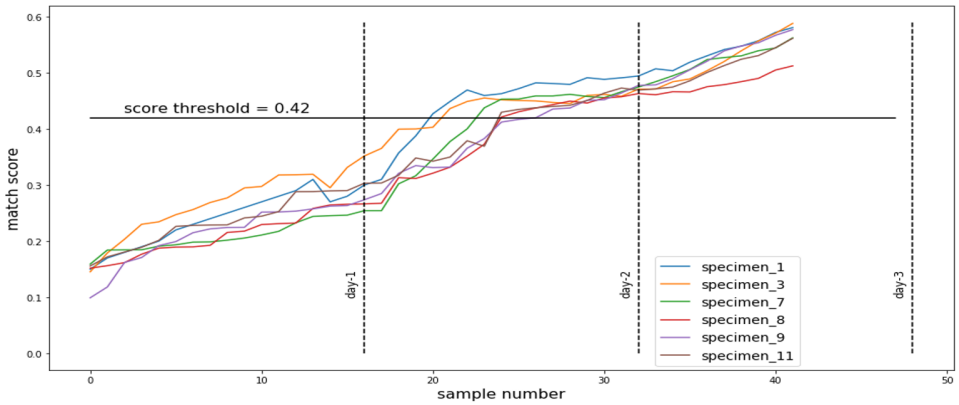

Fig. 5: iris match score progression with respect to unaided short and long term postmortem period.

6 Conclusion

This study answered many of our questions vexed at the start of our experiments, albeit with certain limitations.

First, we showed that off the shelf commercial iris recognition software can be used to identify enucleated cadaver eyes using normal (live population) thresholds. It was observed that the FRR of postmortem specimen can vary anywhere between 0% to 71% based on the postmortem period of the enucleated eyes, while FAR remains at 0. However, as shown by [SM11], the accuracy of traditional iris recognition methods can be further improved by using newer learning-based methods. Per the scope of this study, we did not evaluate postmortem iris recognition with such learning-based template extraction and matching algorithms.

We analyzed the effect of postmortem time lapse on enucleated eyes in terms of match score degradation under varying conditions. We observed the effect of environment and eye pressure (IOP) under different experimental setting on iris recognition performance. It was observed that retaining the shape of the eyeball by way of saline injections helped improving the genuine accept rates of the iris specimen, prolonging the biometric utility of postmortem iris tissue.

In [MAP18], the authors mention that a variant of OSIRIS with manual segmentation can reliably identify a postmortem iris in NIR spectrum up to 263 hours. In their study, iris was captured in-vivo; i.e. the eyeball was not enucleated. In our case, we could match enucleated iris up to 164.5 hours. However, in our study the time lapse is an average of (a) time of death to enucleation (b) enucleation of eye to date of first capture (c) time of first capture to loss of biometric value. It is interesting to note that only a few eyeballs started to deform under controlled storage mechanism. In our case, only two of sixteen rejected irises were due to deformed eyeball. However, while at room temperature, enucleated eyeballs deteriorated at varying rates, and in some cases they lost their iris textures in as little as eight hours.

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References

[Al15] Alora, S.K.H.: Postmortem iris recognition and its application in human identification. PhD thesis, Master's Thesis, Boston University, 2015.

[Da55] Davson, H.: The hydration of the cornea. Biochemical Journal, 59(1):24, 1955.

[Da16] David, B.S.; Ryan, T.A.; Chris, B.C.; Tiffany, S.B.; Kelly, S.A.; Wolfe, S. Dawnie: Impact of environmental factors on biometric matching during human decomposition. In: 2016 IEEE 8th International Conference on Biometrics Theory, Applications and Systems (BTAS). IEEE, pp. 1–8, 2016.

[EMD08] Elizabeth, A.; Margaret, C.; David, Q.: Pig-mentation: Postmortem Iris Color Change in the Eyes of Sus scrofa. Journal of forensic sciences, 53(3):626–631, 2008.

[GDA15] Gemma, P.; D, P. Maria; Aurelio, L.: Morphological and histological changes in eye lens: Possible application for estimating postmortem interval. Legal Medicine, 17(6):437–442, 2015.

[JD01] John, D.; D.Cathryn: Epigenetic randomness, complexity and singularity of human iris patterns. Proceedings of the Royal Society of London. Series B: Biological Sciences, 268(1477):1737–1740, 2001.

[JN94] Jaafar, S.; Nokes, L.D.M.: Examination of the eye as a means to determine the early postmortem period: a review of the literature. Forensic science international, 64(2-3):185–189, 1994.

[MAP16a] Mateusz, T.; Adam, C.; Piotr, M.: Human iris recognition in post-mortem subjects: Study and database. In: 2016 IEEE 8th International Conference on Biometrics Theory, Applications and Systems (BTAS). IEEE, pp. 1–6, 2016.

[MAP16b] Mateusz, T.; Adam, C.; Piotr, M.: Post-mortem human iris recognition. In: 2016 International Conference on Biometrics (ICB). IEEE, pp. 1–6, 2016.

[MAP18] Mateusz, T.; Adam, C.; Piotr, M.: Iris recognition under biologically troublesome conditions-effects of aging, diseases and post-mortem changes. arXiv preprint arXiv:1809.00182, 2018.

[MAP19] Mateusz, T.; Adam, C.; Piotr, M.: Iris recognition in cases of eye pathology. In: Biometrics under Biomedical Considerations, pp. 41–69. Springer, 2019.

[MAP20] Mateusz, T.; Adam, C.; Piotr, M.: Post-mortem iris recognition with deep-learning-based image segmentation. Image and Vision Computing, 94:103866, 2020.

[Pr03] Prasad, B.K.: Post-mortem ocular changes: a study on autopsy cases in Bharatpur Hospital. Kathmandu University medical journal (KUMJ), 1(4):276–277, 2003.

[SM11] Stephen, M.L.; Michael, M.L.: Document Title: Rapid Visualization of Biological Fluids at Crime Scenes using Optical Spectroscopy. 2011.

[Su12] Sutraand, G.; Dorizzi, B.; Garcia-Salicetti, S.; Othman, N.: A biometric reference system for iris. OSIRIS version 4.1. Telecom Sud Paris, France, Tech. Rep, 2012.