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Existing and Emerging Covariates of Iris Recognition

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Abstract— Iris as a biometric trait has established itself in last two decades. Iris being unique and reliable is used for recognition and authentication purpose instead of using Passwords and PINs. Security is a major concern in any recognition system so is the case with iris recognition system. Further, recognition performance depends upon many factors among which distance, lighting conditions, subject cooperation, and pupil dynamics to name some important ones. The above mentioned covariates have been studies vastly in reference to iris recognition. In this paper, we have considered various novel factors that affect the performance of iris recognition system. Pupil dilation, contact lenses, periocular recognition, template aging, use of drugs and alcohol and sensor interoperability have been under investigation as emerging covariates of iris recognition; in recent times. The focus of this paper is to present a review of various covariates (existing as well as emerging) and their effects on recognition performance. This work shows that these covariates have considerable effect on iris recognition performance and need to be considered while implementing any commercial iris recognition systems.

Keywords—Covariates, Iris Recognition, Pupil dilation, Contact Lenses, Synthetic Iris, Template Aging, Interoperability.

I. Introduction

The human iris is unique, stable, non-invasive and externally visible; making it ideally suited as a biometric modality to be used for human identification. The iris is a muscle in the eye that regulates pupil size. Ophthalmologists have confirmed that iris is a highly distinguishable pattern that is considered as a biometric trait. Since 2001, the government of the United Arab Emirates has been using iris recognition to prevent people who have been deported and placed on a do-not-enter list from re-entering the country. UAE is all set to launch the world's first "biometric path" which will offer visitors a flawless airport journey at Dubai International airport. India's UIDAI [2] program has enrolled more than 1.25 billion people so far representing almost 90% of India's population. UID popularly known as AADHAR consists of face, fingerprint, and iris of a person to be used as a biometric authentication card. Fig. 1 shows the UID enrolment process in India. NEXUS is a biometric program developed to fasten the border crossings for low-risk and pre-approved travellers into Canadian and US borders. It is a joint venture of CBSA (Canada Border Services Agency) and U.S. Customs and Border Protection. The Office of Biometric Identity Management (formerly known as US-VISIT Program) supports the US Department of Homeland Security to identify the people by using iris recognition. Other major and internationally known iris recognition deployments include e-KTP run by Government of Indonesia, ICA by Government of Singapore, and Mexico's RENAPO. Thus, for Security, Defence and Forensic sectors, Iris is significant as a means of recognition and identification of subjects. Latest applications of iris consists of Conduct of Elections, Attendance record management, Entitlements and benefit authorization, credit card authentication, biometric key cryptography and Anti-Terrorism. In November, 2017, Somaliland's Presidential Elections were the first ever elections to use iris as an ID with 80% voter turnout.

Fig. 1: UID Enrolment Process in India [2]

While biometrics research has made much progress in recent years and is nearing perfect recognition rates under ideal circumstances, further research is still necessary to improve accuracy in non-ideal circumstances. There are numerous factors that affect the performance of the recognition system. These factors which affect the recognition performance of a biometric system are called covariates. Here, our focus is to study such covariates (both existing and emerging) especially in context to iris recognition. To our belief, this kind of study is not available in the literature up to date. In this work, we presented a review of covariates of iris recognition.

Rest of the paper is organized as follows, Section II contain the related work of Iris Recognition, Section III contain the review of existing covariates of iris recognition and Section IV reviews emerging covariates of iris recognition, followed by conclusion presented in section V.

II. IRIS RECOGNITION

Iris recognition is an automated process of biometric identification that uses mathematical pattern recognition techniques on digital images of the iris of a subject, whose complex and textural structures are distinct, stable, and externally visible. Fig. 2 shows an iris (shown in visible spectrum; though usually NIR spectrum images of irises i.e. grayscale images are used for recognition purpose.) showing pupil and iris structure differently. The pupil is the inner circle which is black in colour as most of the light entering in the eye is absorbed by pupil and iris is the annular part between inner circle and outer circle circumferences. The human iris pigmentation consists of two molecules namely Eumelanin (over 90%) and Pheomelanin [1]. Iris colour mainly depends upon the combination of these two molecules. Pupil boundary (inner one) is known as pupillary boundary and iris boundary (outer one) is known as limbic boundary. The textural part of iris is unique in all human beings which enables iris to be used as a means of recognition of a subject against a dataset of iris templates of many.

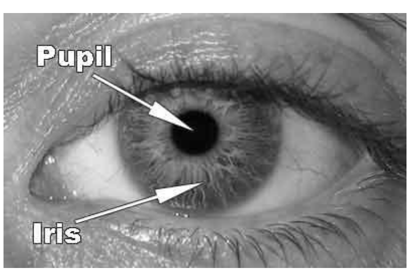

Fig. 2: The Iris

The idea behind using iris is its inherent isolation and protection from outside environment. The key function of the iris is to limit the amount of light entering to the eye. All the distinguishing features of iris come from textural details such as freckles, coronas, crypts and grooves [3]. The iris formation starts during prenatal period and can be considered as developed in fourth month of pregnancy. Its pattern depends on the atmosphere in which embryo is formed, yet most of its details do not inherit genetically. Every iris is unique in terms of textural features; even identical twins do not have same irises. Irises of left eye and right eye of a human being also do not match. The iris changes biometrically during initial few years of childhood and become stable afterwards. Thus, the stability is the most important physiological property of an iris which makes it appropriate for being used as a biometric trait for recognition purpose. According to Flom and Safir [4], the probability of an iris of being same as another iris all around the world is approximately 1 in 10^{72}. All these unique facts about iris make it distinctive, precise, stable and reliable. Moreover, non-invasiveness of iris is another reason which makes it apt for authentication and recognition purpose. Iris Recognition is primarily a five stage process composed of Iris image Acquisition, Image Enhancement & Segmentation, Image Normalization, Feature Extraction and Matching & Decision Making. Every stage is equally significant in the sense that using right procedures, techniques and algorithms only will fetch the best results. Fig. 3 shows the iris recognition process. Segmentation is a critical stage in recognition process as the real success of recognition depends upon the accuracy in this step. Normalization and Feature Extraction follow the segmentation step as shown in Fig. 3. During Normalization, textural part of segmented iris is taken for feature extraction and these features are transformed into a binary template to be stored into databases so that it can be used for matching later-on, in order to reach to a decision of acceptance or rejection of the input as compared to gallery image templates (entries pre-saved into database). Hamming distance is the most general criteria to be used for matching which uses XOR operation between two templates to be matched against each other. The above stated Daugman's method [7] is used as the fundamental implementation by many companies and organizations for iris recognition. Accurate calculation of pupil and iris boundaries, exact features extraction and correct matching are its salient features. An open source implementation [12] of the same is available. Segmentation and Normalization of an input iris image are shown in Fig.4. Several other implementations of iris recognition system such as [6], [21], [23], [25] and [26] exist in literature.

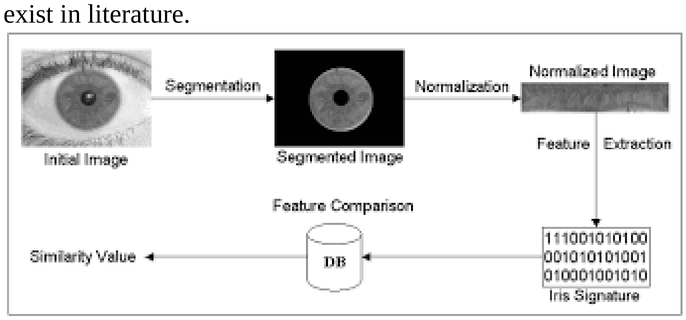

Fig. 3: Iris Recognition Process [5]

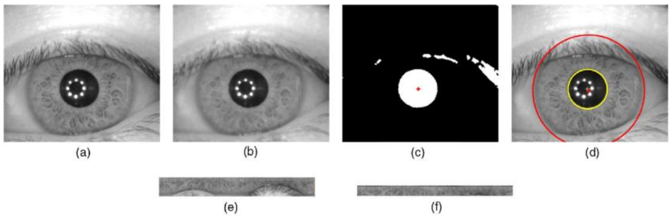

Fig. 4: Segmentation and Normalization of an iris [14]

One of the problems related to iris recognition which makes it difficult in noisy conditions (unconstrained scenario) is *true image acquisition*. If we acquire and present noisy images to the biometric system, the recognition accuracy decreases. Low availability of distinctive features in images, degraded images, images acquired in different perspectives, poor lighting conditions, occlusion rate, distance are some reasons, to name a few. With an aim of making iris recognition an all-around acceptable way of recognition, it is necessary to work upon iris recognition especially in the presence of such factors. In last few years; there have been several separate attempts to study one, two or more such factors but there haven't been any such attempt studying all these collectively till date; to our best belief.

Various factors having an impact on the overall performance of iris recognition are considered covariates of iris recognition. There are several covariates of iris recognition which have been studied vastly in the literature and have been discussed in brief in next few sections; categorizing them broadly into two categories; namely *Existing and Emerging Covariates*. Moreover, their impact on the iris recognition performance is another area of consideration in order to decrease FRR and FAR for better accuracy. Some Existing and Emerging Covariates are given in Fig. 5.

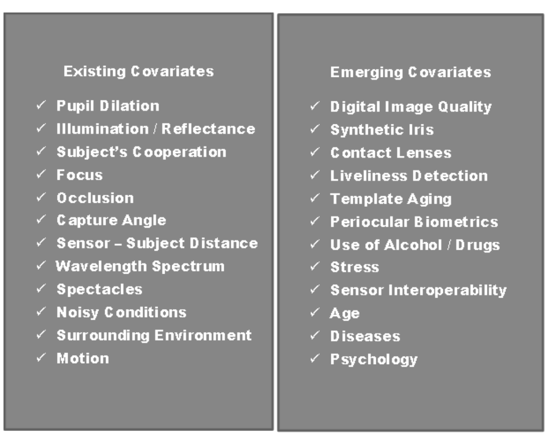

Fig. 5: Existing and Emerging Covariates of Iris Recognition

III. EXISTING COVARIATES OF IRIS RECOGNITION

Iris recognition is now a young field as the use of iris for recognition and authentication dates back to early 90s. Early studies on iris recognition were concentrated on one or more of the following: illumination or lighting conditions, reflection, eyelashes, eyelids, focus, subject-sensor distance, surrounding conditions, wavelength spectrum (NIR, visible). Later on, the momentum of research shifted to more recent challenges like digital image quality, contact lenses, periocular recognition, presentation attack detection, and sensor interoperability, template aging and template security. Does iris change over time? Do iris templates get aged? Does aging affects iris stages? Can we use contact lenses to befool iris systems? How can periocular biometrics affect iris recognition? How does image quality affects recognition rates? What is a presentation attack? How it affects the FAR and FRR with respect to a biometric system? Does use of alcohol and drugs effect iris recognition performance? Recently various attempts have been made to answer these questions separately but these attempts have not proved sufficient and lot more scope of improvement exists. In the following subsections, we have also attempted to deal with such queries.

A. Pupil Dilation

Pupil dilation is a natural process of change in pupil's size when light enters into eye. The pupil dilates during dim light whereas it constricts in bright light. Generally, normal pupil size ranges in 2 to 4 mm in bright light and 4 to 8 mm in the dark. Pupil dilation is abnormal in case of a brain injury or consumption of certain drugs or excessive amount of alcohol. Pupil dilation especially after cataract surgery does not affect iris recognition rates much. Different researchers have studied pupil dilation as a factor affecting iris recognition performance under two categories which are light induced and drug induced dilation [36]. *Mydriasis* is the medical term used for normal pupil dilation [45]. When pupil is subjected to different stimuli, non-elastic deformation of the iris tissue occurs as a response and the visible features of the iris change accordingly. Apart from variations in incident light, pupil dilation can also occur due to alcohol [29], drugs [27, 30, 31], diseases [51], stress [53], cataract surgery [57] or psychology [28]. Further, pupil size gets smaller with age [32, 52]. All these factors affect recognition rates under pupil dilation covariate.

B. Illumination / Reflectance

Image quality in case of an iris is greatly impacted by illumination [43, 44] being a function of many factors including lighting, focus, occlusion, and other sensor imposed artifacts. NIR illumination is preferred over visible illumination because of its obvious advantages as it produces better images with more distinctive textural features which aids in the control of pupil dilation [13]. Obviously, better quality images will fetch better results in terms of recognition rates so there must be some mechanism in the IRS to avoid illumination occlusion while acquiring the images from the subjects. Ordinal Measures (intrinsic features of iris which are invariant to illumination) have been studied by Z. Sun et al. [54] where they developed a model using differential filters to overcome scale, distance, location and orientation issues.

C. Subject Cooperation

Subject Cooperation is required in almost all iris recognition implementations and deployments done so far. Iris recognition in non-ideal circumstances requires less or no subject cooperation. Proenca [8] has done excellent work for non-cooperative iris recognition. He designed and developed a system that can work in unconstrained circumstances. Although lack of subject cooperation adds computational complexity to the system and generates new challenges, yet it is a desirable practice in all practical system implementations.

D. Distance from Camera

Due to dissimilarities in the image acquiring distances and variations in the lighting settings that impacts the pupil dilation, the region of interest corresponding to the iris will also vary highly. To compensate these differences, publically available iris recognition applications translate the segmented iris into a double dimensionless pseudo-polar coordinate system during iris normalization using *rubber-sheet model*. [11] As the distance between subject and sensor increases, the expected variation in resulting iris images also increases which results in other covariates like focus, angle, resolution and illumination to come into picture.

E. Eyelashes, Eyelids and Other Occlusions

Eyelids, eyelashes, spectacles, and hair etc. occlude generally while capturing the subject's eye for verification purpose. Various works have considered the effect of eyelashes, eyelids and spectacles occlusion on recognition. Noisy images under UBIRIS [8] database cover all such cases. Many researches with a target of improving the ultimate performance of an iris recognition system have been out; successfully handling occlusions.

F. Wavelength Spectrum

Iris recognition uses digital camera or sensor technology with subtle NIR illumination to acquire images of the texture-rich and complex iris patterns which are externally visible. Mathematical and statistical algorithms are used to encode digital templates from these patterns to allow the identification of an individual.

Most of the publically deployed implementations of iris recognition systems (both commercial as well as experimental) have used Near-Infra-Red wavelength band (electromagnetic spectrum range: 700–900 nm) generated images for recognition purpose. The dominant phenotype of most of the people all around the world is dark brown which reveals less visible texture in Visible wavelength band (electromagnetic spectrum range: 380–760 nm) yet some attempts for iris recognition in visible band exists in literature [20, 26, 47, 48, 49].

G. Surrounding Conditions and other factors

Indoor or Outdoor Environment also plays a role in iris recognition efficiency as lightning conditions differ. Moreover, various other reasons to impact iris recognition performance are capture angles, poor focus, low contrast, and heavy occlusion. Subject's eye may not be fully opened when captured by the sensor which can lead to poor segmentation results affecting recognition accuracy in turn. Also, extra wide open eye affects the ideal scenario for iris and pupil which may be due to stress, anxiety or pressure. Acquisition or Enrolment setup is also another major factor in this category.

IV. EMERGING COVARIATES OF IRIS RECOGNITION

Before we can be able to study the impact of new covariates of iris recognition, it is better to review them briefly. Few of them are given below:

A. Digital Image Quality

Digital Image quality is a significant covariate with respect to all digital systems' performance. Kalka et al. [35] have worked on image quality assessment of iris biometric. Proenca et al. [20] assessed quality of degraded images acquired in visible wavelength. Galbally et al. [24] have worked on image quality assessment for fake biometric detection with application to face, finger and iris. They have developed a system to detect spoofing attack in iris recognition systems. S. Kumar et al. [56] have analyzed image quality of segmented iris using different image processing filters in order to study the effect of image quality on iris recognition performance.

B. Fake or Synthetic Irises

Synthetic irises have been discovered by researchers that can compromise the security of iris recognition system. Synthetic iris can be made with the help of contact lenses using reverse engineering. Zuo et al. [15] have conducted widespread functional studies and experiments to generate synthetic irises in their works. Makthal et al. [16] have worked on the generation of synthetic iris by characterizing iris texture using Markov Random Fields. They guided synthesis of iris from a random noised image using key textural points and patterns. Shareef et al. [17] have engineered a light-attenuating artificial iris using a photochromic material called Photopia; having self-adaptive light transmission properties. This artificial iris is capable of reversely regulating the incident light intensity. Due to this rapid reversible change in opacity, these artificial irises are able to mimic the functionality of natural iris and thus possibly providing a better treatment alternative for patients who have damaged their iris due to accident or some optical diseases. Cui et al. [19] have developed synthetic iris based on PCA and super resolution method. S. Shah et al. [22] have also developed synthetic iris using feature agglomeration. S. Kumar et al. [50] have studied synthetic iris as a vulnerability of iris recognition.

C. Contact Lenses

Cosmetic as well as Non-Cosmetic lenses having iris texture printed; are available in market. Baker et al. [55] indicated that wearing prescribed transparent contact lenses can actually degrade recognition performance. Kohli et al. [34] have revisited iris recognition with color cosmetic lenses. They suggested that FRR significantly increases at a constant FAR in presence of color cosmetic lenses. They also proved that incorporating lens detection algorithm in IRS maintains performance. At the same time, they also hinted that classic lens detection algorithms are not adequate and needs further research for improvement. Iris patterns embedded on contact lenses make synthetic irises capable of defeating iris recognition systems [33, 37]. Recently, synthetic iris made up of contact lenses were invented which can fool the iris recognition system or at least reduce the accuracy.

D. Periocular Biometrics

Periocular biometric is the soft biometric trait that can enhance the accuracy of iris recognition [46]. Periocular Biometrics plays an important role in increasing the efficiency of recognition. Several Researchers have contributed in establishing periocular recognition as a vital part of an iris recognition system in recent times; Woodard et al. [38] have worked on the fusion of periocular and iris biometrics in non-ideal imagery. Hollingsworth et al. [39] have compared machine and human performance on periocular biometrics under NIR and visible light. Santos et al. [40] have demonstrated the application of an iris dataset combined with periocular features. They evaluated iris segmentation and recognition algorithms along with periocular recognition techniques. They also proposed the application of iris and periocular recognition methods based on state-of-the-art encoding and matching strategies, side by side demonstrating the ways to overcome the issues concerned with periocular biometrics and mobile environments. A. Sharma et al. [41] have experimented pericocular iris recognition with sensor interoperability. U. Park et al. [42] have checked the feasibility of periocular recognition in visible wavelength band.

E. Alcohol or other Drugs Intake

Alcohol and other drugs intake can have significant impact on iris recognition performance. Alcohol consumption and intake of various drugs can cause pupil dilatation/constriction which further leads to deformation of iris structure, possibly affecting recognition rates [27]. Multiple drugs of abuse affect pupil size and reaction [30]. Intake of cocaine, LSD and methamphetamine (MPM) cause pupillary mydriasis [30, 31].

F. Template Aging

Temporal template aging or time gaps in recording and using templates of iris images can have a drastic effect on iris recognition performance. Template aging means an increase in recognition error rate as time difference between enrollment and recognition increases. Earlier it was believed that templates do not age i.e. time gaps between enrollment and recognition do not affect recognition rates but experiments from Fenker et al. [9] and Baker et al.[10] have turned the belief. Analyzing results from a dataset having 3-year time-lapse, Fenker et al. [9] found approximately 150% increase in the FnMR at a decision threshold representing one in two million FMR. They also studied age related effects on eyes of a human being with respect to iris recognition specially pupil dilation. With a time lapse of approx. 4 years between the initial and the most recent iris images taken for a subject, Baker et al. [10] investigated "template aging" for iris. Tome-Gonzalez et al. [18] also compared matching results between images acquired with no significant time lapse with matching results between images acquired with 1-4 weeks of time lapse. To observe template aging effect, one must take care of sensor (version & technology), matcher (again, version & technology), time interval, quality of images in the dataset and dataset itself. Compromising any one of these can make it difficult to analyze the effect of template aging [35]. The template aging effects can be handled by setting up a suitable schedule for re-enrollment [11].

G. Sensor Interoperability

Sensor Interoperability is another issue. Interoperability between systems ultimately affects the recognition rate as geometric relation between the iris and the illuminator differs among different sensors [9]. It happens in case of technology (both hardware and software) upgrade. The main factors generating differences in sensors technology are field of view, relative location of NIR illumination and the camera technology. The experiments done by Bowyer et al. [11] shown that the cross-sensor performance degraded mainly due to a match distribution shift rather than the non-matches. One possible way to deal with the sensor interoperability is to take both the sensors (from which the iris code is generated and from which the verification match is being done) into account; but that again adds to the complexity of the system.

V. CONCLUSION AND FUTURE SCOPE

Different Covariates of Iris recognition have been reviewed in this work under the broad classification of Existing and Emerging covariates. Apart from light intensity, several other factors such as alcohol, drugs, age, disease and psychology, are known to affect the size of the pupil, therefore iris recognition rates. All the covariates stated above have some line of research currently but researchers need to develop more sophisticated models to tackle each of these in context to iris recognition. A detailed analytical study devoted to emerging covariates of iris recognition need to be done in future.

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