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Eye Based Authentication: Iris and Retina Recognition

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Abstract

Biometric authentication comes in play to release the users from the difficulties of remembering and protecting passwords as required by traditional authentication systems. Among all the biometrics in use today, eye biometrics (iris and retina) offers the highest level of uniqueness, universality, permanence, and accuracy. Despite these convincing properties of iris and retina biometrics, they have not been in widespread use. Moreover, humans have more or less a natural ability to recognize individuals staring at the person's eye. So, it is interesting to investigate to what extent the eye based biometrics (iris and retina recognition) are capable of distinguishing individuals, and what factors are there, which hinder the adoption of these technologies.

This report presents a comparative study on iris and retina biometrics based on literature review. The study aims to investigate the two biometrics, conduct a comparative analysis in a fair level of technical detail, and identify the challenges and future possibilities towards their ubiquitous use. In presenting the findings, the study contributes in three ways: (1) This report may serve as a tutorial of eye biometric for those who are new in the area, (2) The comparison between iris and retina biometrics will be helpful for individuals and organizations in choosing the appropriate eye biometric for use in their context. (3) The technical, security, and usability issues identified by the study reveal avenue for further research in order to improve eye biometrics.

Contents

List of Tables

List of Figures

Men are born with two eyes, but only one tongue, in order that they should see twice as much as they say.

Charles C. Colton (1780 - 1832)

1 Introduction

Today we are living in digital kingdoms having computer slaves, who make our life much easier, but not necessarily more secure. With the advancement of science and technology our daily activities have become faster and easier at the cost of having complex tools and technologies. Think about the Stone Age when valuable data were probably engraved on gigantic stone, where to steal such data or corrupt it would have taken a tremendous effort. In today's modern world information storage and transfer have been much easier with the help of technologies like database, networks, etc. It has been possible to access remote information without being physically present on site. This necessitates efficient mechanisms for access control and user authentication.

Traditional authentication systems requires the user perform the cumbersome task of memorizing numerous passwords, personal identification numbers (PIN), pass-phrase, and/or answers to secret questions like "what is your mother's maiden name?", etc. in order to access various databases and systems. More often, it becomes almost impossible to the different formats due to case sensitivity, requirement of alphanumeric text, and the necessity to change passwords or pass-phrases periodically to prevent from accidental compromise or theft. Many users choose passwords to be part of their names, phone numbers, or something which can be guessed. Moreover, to handle the hard task of remembering so many passwords, people tend to write them in files, and conspicuous places such as desk calendars, which exposes chances of security violation [6].

Biometric authentication comes in play to deal with these difficulties with traditional password systems. Potentially, biometric systems can be employed in all applications that need authentication mechanism, and so in all applications that today use passwords, PINs, ID cards, or the like [24]. To date different biometrics have been researched and used, such as fingerprint, hand geometry, face, odor, voice, ear, gait and so on. Table 1.1 and 1.2 presents comparison on aspects of different biometrics.

1.1 Motivation

Essentially, the use of biometrics saves people from the trouble of remembering passwords, and functionally, the people themselves become their passwords. However, the use of biometric also raises issues related to privacy, security, and

Biometrics	Universality	Uniqueness	Permanence	Collectibility
Face	high	low	medium	high
Fingerprint	medium	high	high	medium
Hand Geometry	medium	medium	medium	high
Iris	high	high	high	medium
Retina	high	high	medium	low
Signature	low	low	low	high
Voice	medium	low	low	medium
F. Thermogram	high	high	low	high

Table 1.1: Comparison of different biometrics [17]

Biometrics	Performance	Acceptability	Circumvention
Face	low	high	low
Fingerprint	high	medium	high
Hand Geometry	medium	medium	medium
Iris	high	low	high
Retina	high	low	high
Signature	low	high	low
Voice	low	high	low
F. Thermogram	medium	high	high

Table 1.2: Comparison of different biometrics [17]

user acceptance. Unlike fingerprint and hand geometry, where the user needs to touch the sensor device, biometrics which don't require user's physical contact with the sensor device tend to get more acceptance from the user. Moreover, a non-contact approach is relatively non-intrusive [5]. As we see in Table 1.1 and 1.2, uniqueness, universality, performance, and circumvention of both iris and retina being high make them quite promising for biometric recognition. Interestingly, acceptability of both these biometrics appears low. So, further research on iris and retina as biometrics is needed to make them more acceptable to the users.

Another reason of motivation to investigate eye biometric is the fact that people in general more or less have the ability to recognize individuals by looking at their eyes only, even if the remaining portion of the face is covered in a mask, or very commonly when muslim women cover their entire face except the eyes only with scarf or veil. Hence, it is really interesting to investigate the current state in eye biometrics for recognition. Such an investigation aims to provide a good understanding about to what extent human's natural ability to recognize persons is implemented in computing systems, what the challenges are, and what more can be done to improve eye biometrics.

1.2 Background

Figure 1.1 shows the major components of human eye, and the location of of iris and retina. According to Webster's New World Dictionary, the *iris* is "the round pigmented membrane surrounding the pupil of the eye, having muscles

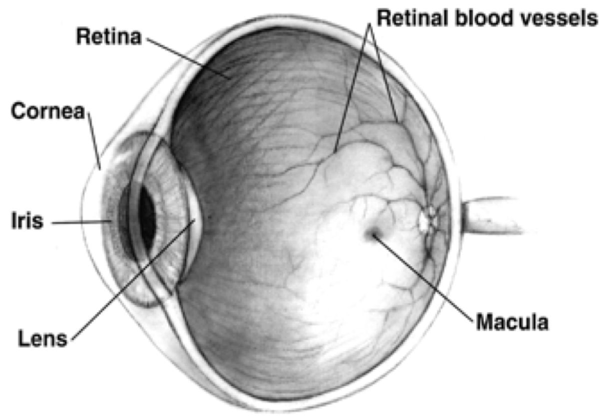

Figure 1.1: Principal components of human eye [39]

that adjust the amount of light entering the eye." The iris is layered beneath the cornea and has patterns that are intricate, richly textured, and composed of many furrows and ridges. The basis of iris recognition is the fact that the texture of iris is unique for each person.

The retina is a thin layer of cells at the back of the eyeball of vertebrates. The principle behind retinal scanning is that the blood vessels of a person's retina provide a unique pattern, which may be used as a tamper-proof personal identifier.

1.3 Outline

This report presents a detail study on eye biometric, and comparison between iris and retina recognition in terms of accuracy, security, and user acceptance. The report is organized as follows. Chapter 2 discusses iris as a biometric.

Chapter 3 includes detail of retina recognition. Chapter 4 compares the two biometric technologies. Finally, chapter 5 summarizes the report, puts remark on the present state of the art, and reveals future possibilities in the area of eye biometrics, namely iris and retinal pattern recognition.

What a blessing it would be if we could open and shut our ears as easily as we open and shut our eyes!

George Christopher Lichtenberg
(1742 - 1799)

2 Authentication by Iris Recognition

This chapter discusses iris texture recognition in detail. Section 2.1 describes in short what an iris is. Section 2.2 presents the historical advancement towards iris as a biometric technology. Section 2.3 includes technical detail of the process and algorithms for iris pattern recognition. And finally section 2.4 concludes the chapter with a summery on iris recognition technology.

2.1 The Iris

Iris is the plainly visible ring on the front side of the eye that surrounds the pupil of one's eye. Figure 2.1 presents the anatomy of iris visible in an optical image. Figure 2.2 displays anatomy of the human iris. The upper panel illustrates the

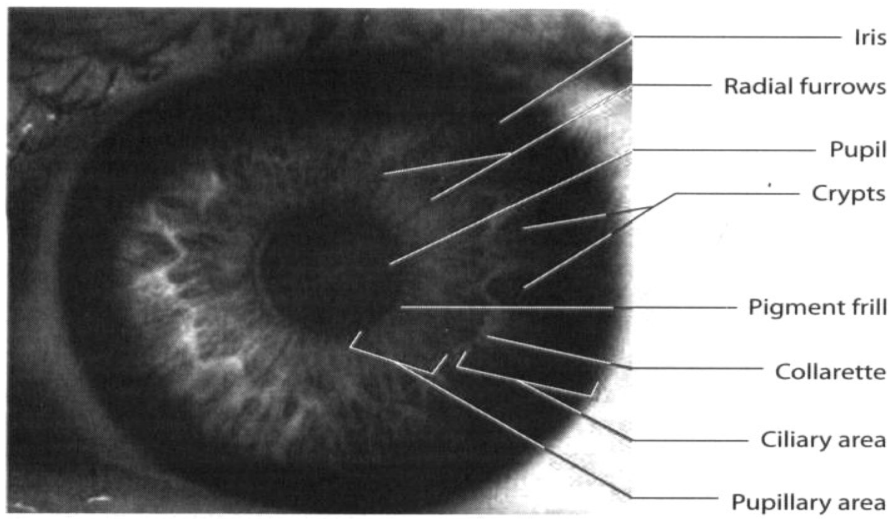

Figure 2.1: Anatomy of iris visible in an optical image [13]

structure of the iris seen in a transverse section, and the lower panel illustrates the structure of the iris seen in a frontal sector. The iris is composed of several layers. The posterior surface is composed of heavily pigmented epithelial cells that make it impenetrable to light. Anterior to this layer there are two muscles: the *dilator* and the *sphicter*, that allow it to adjust its size and control the amount of light entering the eye through the pupil. When iris is fully constricted, its tissue mass becomes thicker, and the size of the pupil and the amount of light entering the eye is increased. When the iris is expanded, the reverse occurs and less light is allowed to enter the eye.

In addition to direct adjustments in response to changes of light in the environment, the two muscles of the iris are also linked to the automatic nervous system and thus affected by internal physiological responses. Sympathetic re-

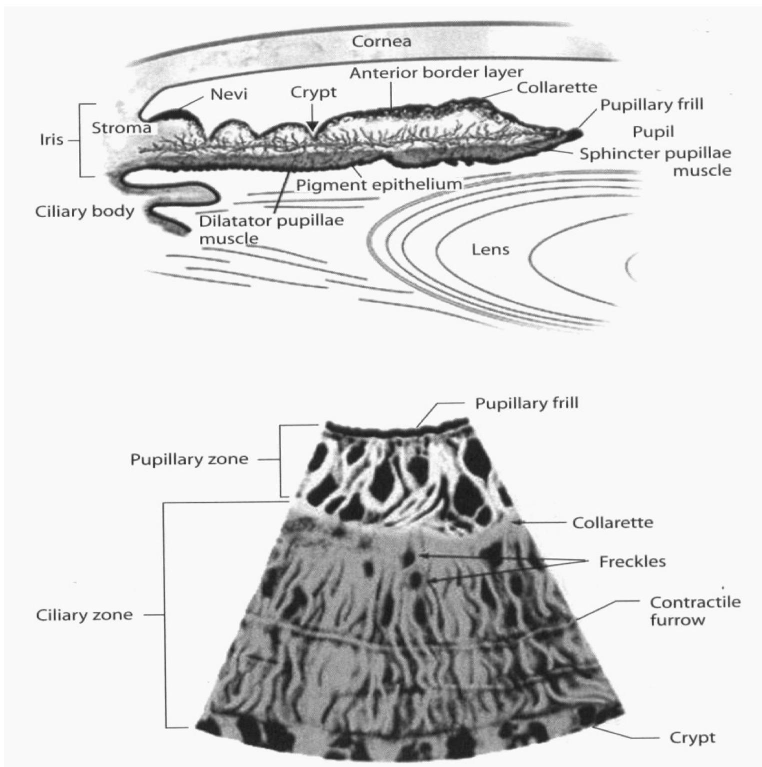

Figure 2.2: Anatomy of human iris [37]

sponses, also known as "flight and fright" conditions, stimulate the dilator, causing the iris to constrict and the pupil to dilate. Parasympathetic responses, also known as "rest and relaxation" conditions, stimulate the sphincter, enlarging the iris and reducing the size of the pupil. The visual appearance of the iris is a direct result of its multilayered structure. Iris color results from the differential absorption of light impinging on the pigmented cells in the anterior border layer.

The texture of iris is made up of a complex fibrous and elastic structure, sometimes referred to as the "trabecular meshwork", the fine detail of which is randomly established prior to birth and under normal health condition remains unchanged from early childhood to death of the individual [5, 18]. Not only the iris patterns are unique for each individual, but also irises of left and right eyes of the same individual are also unique [5]. This uniqueness holds in family siblings, and even identical twins, where other genetic details such as facial appearance are so similar [5, 18]. This stable uniqueness of iris texture becomes the basis of iris based biometric recognition.

2.2 History of Iris Recognition

Ophthalmologists first noted the distinctive features of iris and observed the patterns to be different between left and right eyes of the same individual. Ophthalmologists Leonard Flom and Arin Safir were awarded a patent in 1987 for describing methods and apparatus for iris recognition on visible iris featuers. Dr. John Daugman of Cambridge University later developed the algorithms, math-

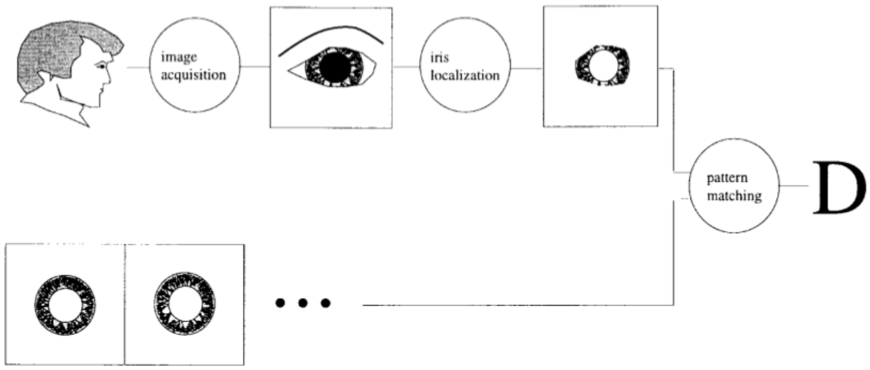

Figure 2.3: Schematic diagram of the major steps in iris recognition [37]

ematical methods, and techniques to encode iris patterns and compare them in an efficient manner. All commercial applications currently implement Daugman's patented techniques, and currently licensed and marketed through Iridian Technologies, Inc. of Moorestown, New Jersey, and Geneva, Switzerland [18].

2.3 Iris Recognition Technique

There are three basic steps to iris recognition: image acquisition, image localization (and iriscode generation), and matching [35, 37]. All these three steps are described below. Figure 2.3 shows a schematic diagram of the major steps in the process of iris recognition.

2.3.1 Iris Image Acquisition

The image capturing method is based on video camera technology similar to that found in ordinary camcorders. Like these cameras, the image capturing process does not require bright illumination or close-up imaging [35]. With a device activated by proximity sensor, a subject positioned 3" to 10" from the Enrollment Optional Unit is guided by a mirrored, audio assisted interactive interface to allow an autofocus camera to take a digital video of the iris. Individual images from the live video are captured using a frame grabber. Figure 2.4 shows an active sensing approach for iris image capture. Figure 2.5 shows passive sensing approaches to iris image acquisition. The upper diagram in the figure 2.5 shows a schematic diagram of the Daugman image acquisition rig, and the lower diagram shows a schematic diagram of the Wildes et al. [37] image acquisition setup. In order to cope with the inherent variability of ambient illumination, extant approaches to iris image sensing provide a controlled source of illumination as a part of the method [13].

For image capture, a subject merely needs to stand still and face forward with their head in an acquisition volume of 600 vertical by 450 horizontal and a distance of approximately 0.38 to 0.76 m, all measured from the front-center of the acquisition rig. Capture of an image that has been proven suitable to drive iris recognition algorithm can then be achieved totally automatically, typically within 2-10 seconds [13].

2.3.2 Image Localization and Feature Extraction

Having the iris image captured, the next step is to identify and locate the presence of an iris within the video image, and to convert it to 'Iriscode' [35]. This can be thought of in terms of the application of a circular edge detector

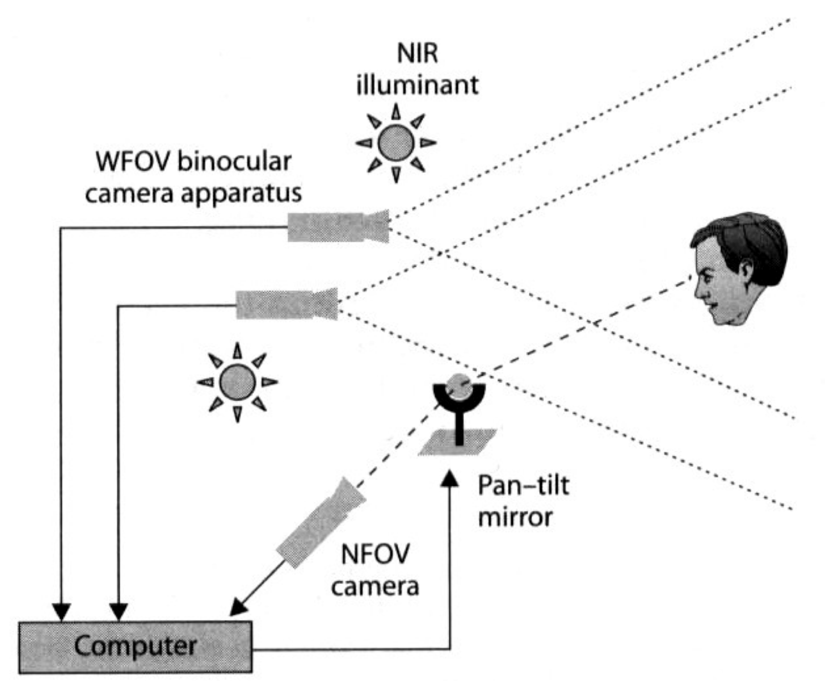

Figure 2.4: Active sensing approach to iris image capture [13]

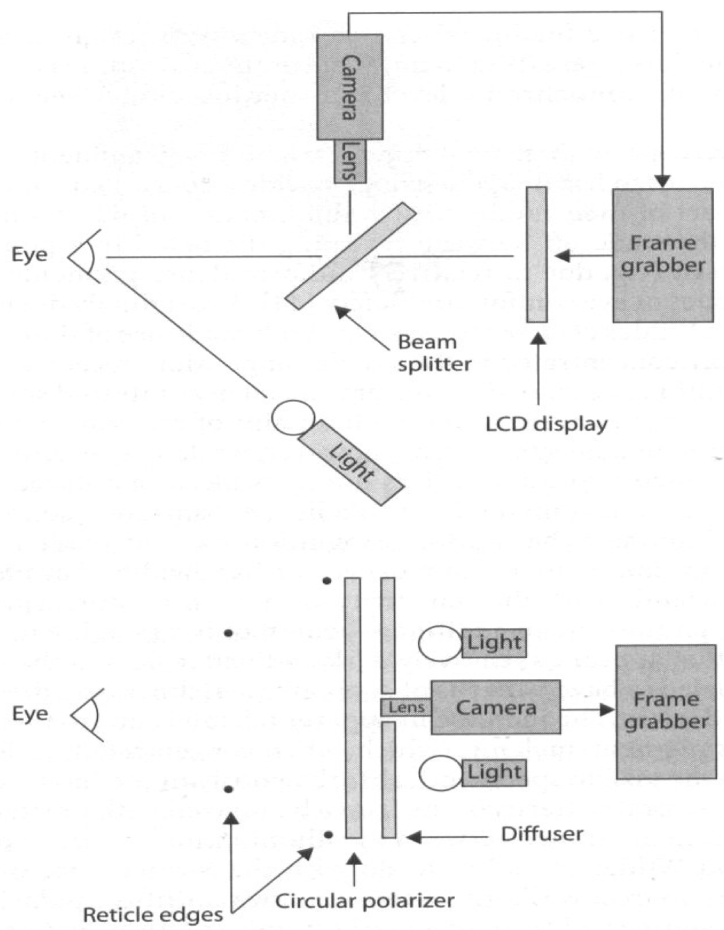

Figure 2.5: Passive sensing approaches to iris image acquisition [37]

to define the distinct boundary between the iris and sclera (white tissue of the eye) followed by further refinement to distinguish the boundary between the iris and pupil.

Iris Localization

Approaches of both Daugman and Wildes et al. make use of first derivatives of image intensity to signal the location of edges that correspond to the borders of the iris. Here, the notion is that the magnitude of the derivative across an imaged border will show a local maximum due to the local change of image intensity. Both systems model the various boundaries that delimit the iris with simple geometric models. For example, they both model the limbus and pupil with circular contours. The Wildes et al. system also explicitly models the upper and lower eyelids with parabolic arcs. In initial implementation, the Daugman system simply excluded the upper and lower most portions of the image where eyelid occlusion was most likely to occur; subsequent refinements include explicit eyelid localization [13].

Daugman's and Waldes et al. approaches differ mostly in the way that they search their parameter spaces to t the contour models to the image information. Let $I(x, y)$ represents the image intensity value at location (x, y), and and let circular contours (for the limbic and pupillary boundaries) be parameterized by center location (x_c, y_c) and radius r. The Daugman system ts the circular contours via gradient ascent on the parameters (x_c, y_c, r) so as to maximize

$$\left| \frac{\partial}{\partial r} G(r) * \oint_{x_c, y_c, r} \frac{I(x,y)}{2\pi r} ds \right|$$

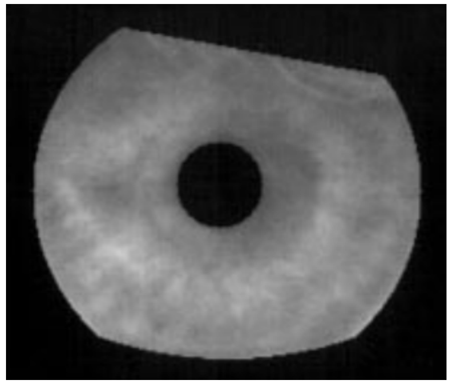

Figure 2.6: illustrative result of iris localization [37]

where $G(r) = (1/2\pi\sigma)e^{-((r-r_0)^2/2\sigma^2)}$ is a radial Gaussian with center r_0 and standard deviation σ that smoothens the image to select the spatial scale of edges under consideration, * symbolizes convolution, ds is an element of circular arc, and division by $2\pi r$ serves to normalize the integral.

The Wildes et al. approach performs its contour fitting in two steps. First, the image intensity information is converted into a binary edge-map. Second, the edge points vote to instantiate particular contour parameter values. The histogram-based approach to model fitting should avoid problems with local minima that the active contour model's gradient descent procedure might experience. However, by operating more directly with the image derivatives, the active contour approach avoids the inevitable thresholding involved in generating a binary Edge map. Figure 2.6 shows an illustrative result of iris localization.

Feature Extraction and Template Creation

Having produced the zones of analysis we need to examine the texture of the iris for distinguishing features within these zones. This is achieved by the application of 2-D Gabor filters which provide information about orientation and spatial frequency of minutiae within the image sectors. From this information a 256 byte iris code is generated as a representation of the features of the individual iris.

The distinctive spatial characteristics of the human iris are displayed at a variety of scales. The Daugman approach makes use of a decomposition derived from application of a two-dimensional version of Gabor filters to the image data. Since the Daugman system converts to polar coordinates, (r, θ), during matching, it is convenient to give the filters in a corresponding form as

$$H(r, \theta) = e^{-i\omega(\theta-\theta_0)} e^{-(r-r_0)^2/\alpha^2} e^{-i(\theta-\theta_0)^2/\beta^2},$$

where α and β covary in inverse proportion to to generate a set of quadrature pair frequency-selective lters with center locations specied by (r_0, θ_0). These filters are particularly notable for their ability to achieve good joint localization in the spatial and frequency domains [37].

The Wildes et al. approach makes use of an isotropic bandpass decomposition derived from application of Laplacian of Gaussian (LoG) filters to the image data. The LoG filters can be specified as

$$-\frac{1}{\pi\sigma^4}(1 - \frac{\rho^2}{2\sigma^2})e^{-\rho^2/2\sigma^2},$$

where σ the standard deviation of the Gaussian and ρ the radial distance of

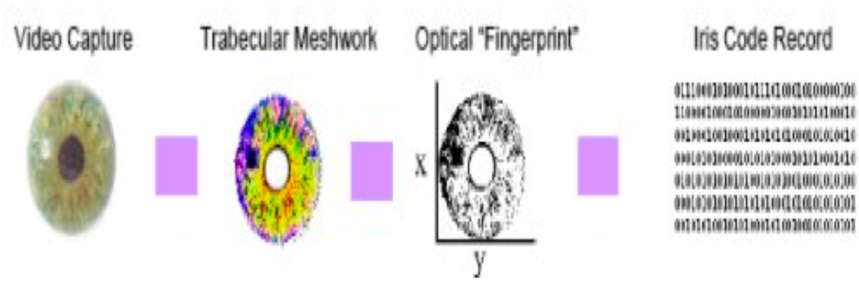

Figure 2.7: Artifacts in the process of Iriscode generation [39]

a point from the filters center. In practice, the filtered image is realized as a Laplacian pyramid [37]. Figure 2.7 displays the major artifacts generated in the process of Iriscode generation.

2.3.3 Matching

Iris matching can be understood as a three-stage process as follows [13].

1. The first stage is concerned with establishing a spatial correspondence between two iris signatures that are to be compared.

2. Given correspondence, the second stage is concerned with quantifying the goodness of match between two iris signatures.

3. The third stage is concerned with making a decision about whether or not two signatures derive from the same physical iris, based on the goodness of match.

Given the combination of required subject participation and the capabilities of sensor platforms currently in use, the key geometric degrees of freedom that has to be compensated for inthe underlying iris data are shift, scaling and rotation. Shift accounts for offsets of the eye in the plane parallel to the camera's sensor array. Scale accounts for offsets along the camera's optical axis. Rotation accounts for deviation in angular position about the optical axis. Another degree of freedom of potential interest is that of pupil dilation [13]

Daugmans approach uses radial scaling to compensate for overall size as well as a simple model of pupil variation based on linear stretching. The scaling serves to map Cartesian image coordinates (x, y) to polar image coordinates (r, θ) according to

$$x(r, \theta) = (1 - r)x_p(\theta) + rx_1(\theta)$$

$$y(r, \theta) = (1 - r)y_p(\theta) + ry_1(\theta)$$

where r lies on [0, 1] and θ is cyclic over [0, 2π], while $(x_p(\theta), y_p(\theta))$ and $(x_1(\theta), y_1(\theta))$ are the coordinates of the pupillary and limbic boundaries in the direction θ. Rotation is compensated for by brute force search: explicitly shifting an iris signature in θ by various amounts during matching.

The Wildes et al. approach uses an image registration technique to compensate for both scaling and rotation. This approach geometrically projects an image, $I_a(x, y)$, into alignment with a comparison image, $I_c(x, y)$, according to a mapping function $(u(x, y), v(x, y))$ such that, for all (x, y), the image intensity value at $(x, y)(u(x, y), v(x, y))$ in I_a is close to that at (x, y) in I_c. More precisely, the mapping function (u, v) is taken to minimize

$$\int_x \int_y (l_c(x, y) - l_a(x - u, y - v))^2 dxdy$$

while being constrained to capture a similarity transformation of image coordinates (x, y) to (x, y), i.e.,

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} x \\ y \end{pmatrix} - sR(\phi) \begin{pmatrix} x \\ y \end{pmatrix}$$

with s a scaling factor and $R(\phi)$ a matrix representing rotation by ϕ. An appropriate match metric can be based on direct point wise Comparisons between primitives in the corresponding signature representations. The Daugman approach quantifies this matter by computing the percentage of mismatched bits between a pair of iris representations, i.e. the normalized Hamming distance. Letting A and B be two iris signatures to be compared, this quantity can be calculated as

$$\frac{1}{2048} \sum_{j=1}^{j=2048} A_j \otimes B_j$$

With subscript j indexing bit position and $\otimes$ denoting the exclusive-OR operator. The Wildes et al. system employs a somewhat more elaborate procedure to quantify the goodness of match. The approach is based on normalized correlation between two signatures (i.e. pyramid representations) of interest.

The final subtask of matching is to evaluate the goodness of match values to make a final judgement as to whether two signatures under consideration do (authentic) or do not (impostor) derive from the same physical iris. In the Daugman approach, this amounts to choosing a separation point in the space of (normalized) Hamming distances between the iris signatures. Distances smaller than the separation point will be taken as indicative of authentics; those larger will be taken as indicative of impostors. In the Wildes et al. approach, the

Operation	**Time in msec**
Assess image focus	15
Scrub specular reflections	56
Localize eye and iris	90
Fit pupilary boundary	12
Detect and fit both eyelids	93
Remove lashes and contact lens edges	93
Demodulation and IrisCode generation	102
XOR comparison of two IrisCodes	10

Table 2.1: Speeds of various stages in iris recognition process [18]

decision making process must combine the four goodness of match measurements that are calculated by the previous stage of processing (i.e. one for each pass band in the Laplacian pyramid representation that comprises a signature) into a single accept/reject judgement. Table 2.1 shows the time needed at different phases of iris recognition using Daugman approach executed on a 300 MHz Sun workstation.

2.4 Summery

Iris is circular fragmented ring around the pupil of the eye. The iris has quite a rich texture, which is unique for every eye. Iris biometric involves the recognition of iris texture pattern. Iris as a biometric originated from ophthalmology, which is an area of medical science. The major phases in the process of iris pattern recognition include iris scan for image acquisition, iris localization for distinguishing the iris from rest of the eye, feature extraction and template creation followed by matching. At present Daugman's approach dominates in the process, which uses 256-byte IrisCode as template, and performs matching applying XOR operations on the IrisCodes. A very high level of accuracy is attained in iris recognition today, which suggests it to be a very promising biometric for authentication purposes.

Nothing is impossible. Not if you can imagine it. That's what being a scientist is all about.

Professor Hubert Farnsworth

3

Authentication by Retina Recognition

This chapter includes detail about retina biometric. The chapter begins with a brief introduction of the retina in section 3.1. Then section 3.2 tells the historical development of retinal pattern recognition as a biometric technology. Section 3.3 describes the technical detail of the process and algorithms used for retinal pattern recognition. Finally, section 3.4 summarizes the chapter.

3.1 The Retina

The retina can be described as a layer of complex blood vessels and nerve cells on the back of the eye. Figure 3.1 shows a front view of the blood vessel pattern within the retina. The retina is to the eye as film is to a camera. The retina

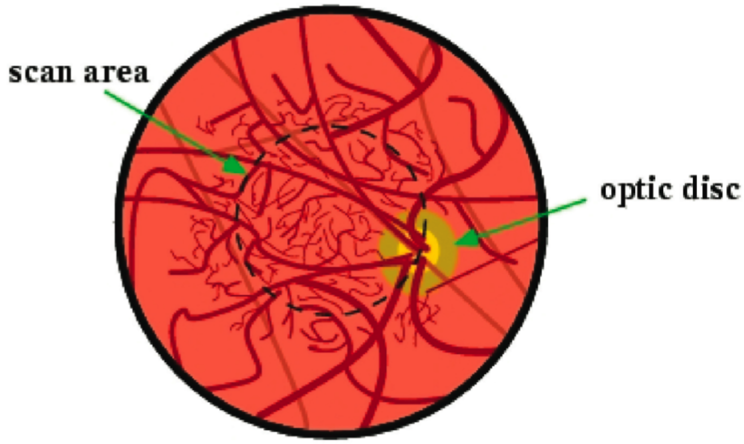

Figure 3.1: Front view of the blood vessel pattern within the retina [11]

is essentially sensory tissue consisting of multiple layers. The retina consists of millions of photoreceptors whose function is to gather the light rays that are sent to them, and transform that light into electrical pulses that travel through the optic nerve into the brain, which then converts these pulses into images.

The two distinct types of photoreceptors that exist within the retina are called *rods* and *cones*. There are about 125 million rods in an eye, which help to see in low intensity lights and contribute in peripheral vision. There are about six million cones that help to see different colors. Figure 3.2 shows these two types of photoreceptors existing in an eye.

3.2 History of Retina Recognition

Retinal scanning devices were available commercially before iris scanning was developed and have been utilized in various military and other high security

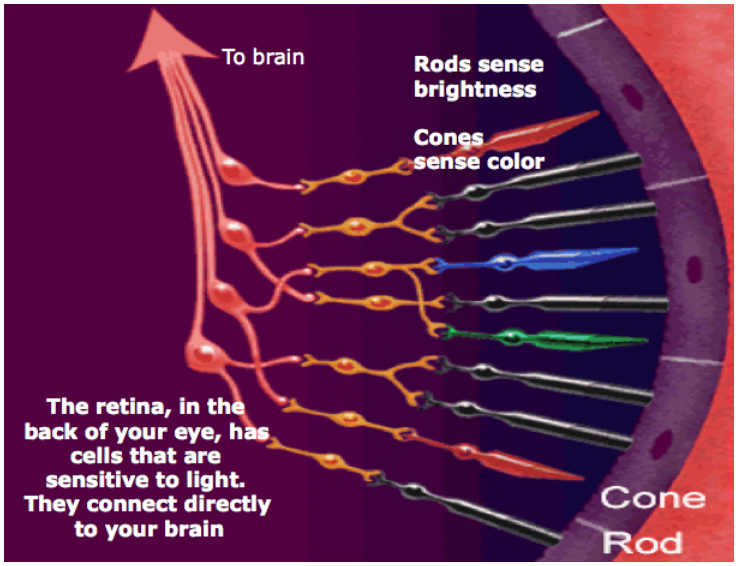

Figure 3.2: Rods and cones in the retina [39]

applications for some time [5]. Two famous studies confirmed the uniqueness of the blood vessel pattern of retina. In 1935, a paper was published by Dr. Carleton Simon and Dr. Isodore Goldstein, in which they laid out their discovery that every retina possesses a unique blood vessel pattern. They later published a paper suggesting the use of photographs of these blood vessel patterns of retina as a means of identifying people. The second study conducted by Dr. Paul Tower in the 1950s. He discovered that even among identical twins, the blood vessel patterns of the retina are unique.

The first major vendor for the research/development and production of retinal scanning devices was a company called EyeDentify, Inc., created in 1976. The first type of devices used to obtain images of the retina were called *fun-*

dus cameras. These were instruments created for ophthalmologists, adapted to obtain images of the retina. The first true prototype of a retinal scanning device was developed in 1981, which used infrared light to illuminate blood vessel pattern of the retina [35].

3.3 Retina Recognition Technology

The process of enrollment and verification/identification in a retinal scanning system is same as the process for other biometric technologies:

1. Acquisition and processing of images
2. Unique feature extraction and template creation
3. Matching

3.3.1 Image Acquisition

Retinal image acquisition is done using retinal a scanning device. There are three major components of a retinal scanning devices [35]:

Imaging/Signal Acquisition/ Signal processing: This involves a camera capturing the retinal scan, and converting that scan into a digital format.

Matching: A computer system for verification and identification of the user (as is the case with the other biometric technologies).

Representation: The unique features of the retina are represented as templates.

In the *image acquisition* process the user must first place his eye near a lens located in the retinal scanning device at extremely close range. It is very important that the user remains still at this point, in order to ensure that a robust image will be captured. Also the user must remove any eyeglasses that he might be wearing, because any light reflection from the lens of the eyeglasses could cause interference with the signal of the retinal scanning device. Once the user is situated comfortably, he then will notice a green light embedded against a white background through the lens of the scanning device. Once the retinal scanning device is activated, this green light moves in a complete circle (360 degrees) and captures images of the blood vessel pattern of the retina through the pupil. At this phase, normally 3 to 5 circular images are captured.

After the image acquisition, the vascular pattern of the retina needs to be identified. Research on retinal vascular pattern recognition was primarily for the applications related to medical realm, and here on image registration and subsequent detection of vascular pattern. The registration process can be feature-based or area-based [7]. In the later case, pixel intensities of retinal image are used in objective functions based on statistical properties such as cross-correlation, phase correlation, or error values [10, 25, 27, 32]. For feature based registration, the process is similar to that used in manual registration by matching characteristic high-contrast or point entities using a similarity measure, and may also use geometric features such as bifurcations and angles in vascular patterns to achieve matchings [8, 22, 33]. Moreover, hybrid approaches are also proposed for use in both diagnostic and registration applications. An adaptive thresholding method followed by binary thinning was also used to detect major vessels [34]. A line finding algorithms along with a probabilistic relaxation was introduced by K. Akita and H. Kuga [4] to extract and subsequently describe the patterns of blood vessels in retinal images. Concept of signal detection using matched filters was also used to detect piecewise linear segments of blood vessels [9]. Methods based on the analysis of gradient orientation [19] are not directly affected by image intensity.

Based on the hypotheses posited by Simon and Goldstein [30, 31], the applications for the biometric identification and verification were examined by Hill, initially using fundus cameras [2, 15, 16]. The required apparatus and algorithms are patented to him. Halvor Borgen and et al. [7] presented a visible spectrum based retina recognition algorithm, which is based on Hill's algorithm. Moreover, Majid Shahnazi and et al. [29] described a wavelet based retinal recognition approach which applies gradient orientation analysis. Both this approaches are described below in short. Table 3.1 presents comparative results of applying different retinal pattern recognition approaches.

3.3.2 Visible-Spectrum Approach

The visible-spectrum approach requires the pixel values of the acquired retinal image to be presented in an array which is subsequently smoothed to reduce the effect of noise. The high resolution retinal image allows several possible extraction mechanisms for values on a scan circle, including sampling of all values along the scan circle or using averaging over surrounding pixels. The

Method	Jafariani [14] method (using Fourier-Mellin function)	XU [38] (using blood vessel curvature function)	Majid [29] method (using wavelet energy feature)
Average recognition rate with different orientation without noise	100%	100%	100%
Average recognition rateof noisy images	96%	97%	100%
Recognition rate of whole database	98%	98.5%	100%
Average recognition time	5.86 second	4.63 minute	3.34 second

Table 3.1: Comparison of different retinal pattern recognition methods [29]

extent of average block size in pixels depends on the image resolution and is then simply calculated as a $n \times n$ matrix around the pixel of interest where the matrix is computed by using the radius value, $\frac{n}{2}$ to determine the diameter coordinates in the x and y direction, respectively, for each point on the scan circle. The array of extracted grey-scale values can in turn be plotted in a coordinate system to visualize the actual waveform as a function of position on the scan circle. To obtain a grey-scale image from RGB images, only the green channel is extracted since this channel yields the best contrast between the blood vessels and other features, and the retina itself. Contrast enhancement is required to compensate for the relatively low contrast portions, which is obtained after RMS (root mean square) adjusting the acquired waveforms to the template through histogram equalization, using a grey-scale transformation T to minimize $|c_1(T(k)) - c_0(k)|$, where c_0 is the cumulative histogram, c_1 is the cumulative sum of all histograms for all intensities k.

Matching can be done by calculating the correlation coefficient between arrays A and B for the images according to equation 3.1.

$$\rho = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{(\sum_m \sum_n (A_{mn} - \bar{A})^2)(\sum_m \sum_n (B_{mn} - \bar{B})^2)}} \tag{3.1}$$

The RMS-adjusted waveforms are transformed from the time-domain to the frequency-domain through a Fourier transformation, where it can be seen that the signal is symmetrical over $\frac{F_s}{2}$. The FFT transformations for vectors of length N are by equation 3.2 and 3.3.

$$X(k) = \sum_{j=1}^{K} x(j)\omega_K^{(j-1)(k-1)} \tag{3.2}$$

$$x(j) = \frac{1}{K}\sum_{k=1}^{K} X(k)\omega_K^{-(j-1)(k-1)} \tag{3.3}$$

where, $\omega_K = e^{(-2\pi i)/K}$ is a Kth root of unity. Frequencies on the outer edges of $\frac{F_s}{2}$ was eliminated. This signal is then transformed back to the time domain, and real values are used for matching. Sample arrays are considered a match if the correlation coefficient is found to be greater than or equal to certain threshold.

3.3.3 Wavelet Based Approach

In the wavelet based approach the gradient vectors of the image are obtained and normalized into the unit gradient vectors, as only gradient orientation is required for gradient orientation analysis (GOA). Features in retinal images are detected by finding discontinuities in gradient orientation. Let $g(x, y)$, $g_x(x, y)$

and $g_y(x,y)$ denote a retinal image, partial derivatives of $g(x,y)$ in x (horizontal) and y (vertical) directions respectively. The unit gradient vectors are then obtained by equation 3.4 and 3.5.

$$n_x(x,y) = \frac{g_x(x,y)}{\sqrt{g_x^2(x,y) + g_y^2(x,y)}} \tag{3.4}$$

$$n_y(x,y) = \frac{g_y(x,y)}{\sqrt{g_x^2(x,y) + g_y^2(x,y)}} \tag{3.5}$$

To find discontinuities in gradient orientation, we compute the first derivatives of the unit vectors according to the following equations.

$$d_{xx}(x,y) = n_x * k_x$$

$$d_{yx}(x,y) = n_y * k_x$$

$$d_{xy}(x,y) = n_x * k_y$$

$$d_{yy}(x,y) = n_y * k_y$$

The discontinuity magnitude of gradient orientation $D(x,y)$ may be expressed as

$$D^2(x,y) = d_{xx}^2(x,y) + d_{yx}^2(x,y) + d_{xy}^2(x,y) + d_{yy}^2(x,y)$$

With the aim of detecting various sizes of features, the GOA is applied at three different scales. The Sobel operator is first used as k_x and k_y to detect very fine features. To detect larger features, the Sobel operator is modified as

$$k_x = \begin{pmatrix} 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & -2 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -1 \end{pmatrix}, k_y = \begin{pmatrix} 1 & 0 & 2 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & -2 & 0 & -1 \end{pmatrix}$$

and is used to the original image, and also the half sized sub-image of it. Denoting the discontinuity magnitude of gradient orientation at each scale $D_1(x, y)$, $D_2(x, y)$, and $D_1(x, y)$ respectively, a response of GOA $D_{GOA}(x, y)$ is defined as

$$D^2_{GOA}(x, y) = D^2_1(x, y) + D^2_2(x, y) + D^2_3(x, y),$$

where $D_3(x, y)$ is resized to the original image size by upsampling. In the case of extracting blood vessels (i.e., valleys), high GOA responses owing to ridges need to be excluded, which can be achieved by the sign of $\nabla^2 g(x, y)$ according to equation 3.6,

$$D^2_{valley}(x, y) = \begin{cases} D^2_{GOA}(x, y), & \text{if } sign(\nabla^2 g(x, y)) \geq 0 \\ 0, & \text{otherwise} \end{cases} \quad (3.6)$$

where ∇^2 denotes the Laplacian operator. Figure 3.3 shows the result of retinal blood vessel detection using gradient orientation analysis.

After detection of blood vessels in the retinal image is done, *feature extraction* is carried out by analyzing the retina using multi-resolution analysis through the wavelet based approach. Two dimensional wavelet transformation can decompose the image in several directions as different resolutions (scales).

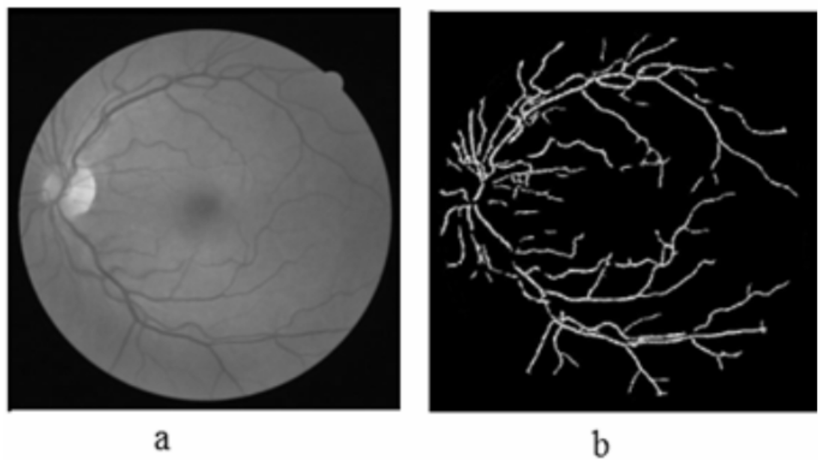

Figure 3.3: (a) Retinal image, (b) Blood vessel extraction using GOA [29]

Two wavelets are defines that are, respectively, the partial derivatives along x and y of a two dimensional smoothing function $\theta(x, y)$:

$$\psi^1(x, y) = \frac{\partial\theta(x, y)}{\partial x}$$
$$\psi^2(x, y) = \frac{\partial\theta(x, y)}{\partial y} \tag{3.7}$$

and for function $f(x, y) \in L^2(R^2)$, the wavelet transformation defined with respect to $\psi_s^1(x, y)$ and $\psi_s^2(x, y)$ has two components:

$$W^1 f(s, x, y) = f * \psi_s^1(x, y)$$

$$W^2 f(s, x, y) = f * \psi_s^2(x, y)$$

Discrete wavelet transformation (DWT) is implemented using filters. The Kth level wavelet decomposition is shown in figure 3.4, where A_{k-1} is the approximation coefficient of the $(K-1)^{th}$ level decomposition, $A_k, H_k, V-K$, and D_k

are the approximation, horizontal, vertical, and diagonal detail coefficients of the K^{th} level decomposition respectively. A_0 is the original image I. So, after decomposition on the J^{th} level, the original image I is represented by $3J + 1$ sub-images: A_j, H_i, V_i, D_i for $i \in \{1, 2, ..., J\}$. The wavelet energy in horizontal, vertical, and diagonal direction at i^{th} level can be defined respectively as

$$E_i^h = \sum_{x=1}^{M} \sum_{y=1}^{N} (H_i(x, y))^2$$
$$E_i^v = \sum_{x=1}^{M} \sum_{y=1}^{N} (V_i(x, y))^2$$
$$E_i^d = \sum_{x=1}^{M} \sum_{y=1}^{N} (D_i(x, y))^2$$

The feature vector is defined as

$$(E_i^h, E_i^v, E_i^d) \text{ for } i \in \{1, 2, ..., M\}$$

where M is the total wavelet decomposition level. This feature vector computes the global features of the blood vessels, and so to determine the features in special locations of different detail the detail images are equally divided into $S \times S$ non-overlap blocks, and the energy of each block is computed. Moreover, the energies of all blocks are used to construct a vector, which is then normalized by total energy to produce the wavelet energy feature (WEF). This WEF is used to distinguish blood vessels in the retinal image.

Retina recognition includes two stages: training stage and recognition stage. In the training stage, WEFs of all training samples are captured, and the template of a retina is obtained by averaging the WEFs of all training samples captured from the same retina. In the recognition stages, WEF of the input

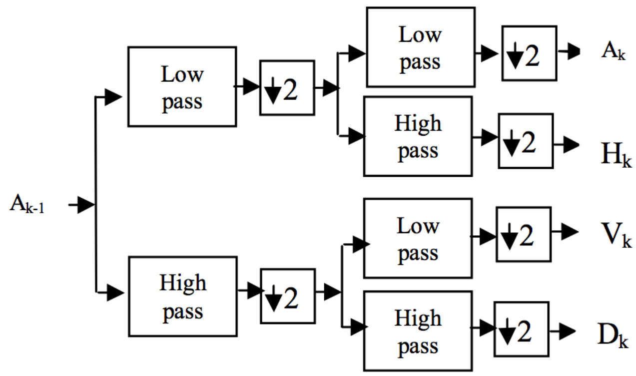

Figure 3.4: One level DWT decomposition [29]

retina is computed firstly; and then compared with all the registerd templates; finally the most similar template is found, which is taken as the recognition result.

3.4 Summery

The retina is a layer of complex blood vessels and nerve cells on the back of the eye. Retina biometric based on recognition of the complex pattern in the retinal blood vessels. Retina recognition as a biometric technology initially originated from the medical science. For retinal pattern recognition, first, a circular image of the retina is obtained using special scanning device, which applies low intensity infrared light to illuminate the retina. Once the retinal image is obtained, the blood vessels are identified through further processing. Then from the complex network of blood vessels distinguishing features are extracted and stored in templates, which are later used in the matching process.

There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact.

Mark Twain (1835 - 1910)

4

Iris versus Retina Recognition: Comparison

This chapter includes a comparative discussion on iris and retina biometrics. The technical similarities and differences, advantages, drawbacks, as well as security and usability issues of both this biometrics are presented. Section 4.1 presents the similarities between these two biometric technologies. The properties and principles that distinguish them from each other are presented in section 4.2. Finally, section 4.3 summarizes and concludes the chapter.

4.1 Similarities

Origin: Both iris and retinal pattern recognition are eye based biometrics, initially originated in the area of ophthalmology.

Users' Cooperation: For both iris and retinal image acquisition the user has to put his or her open eye in front of a digital camera.

Illumination: In acquisition of digital images of the iris or retina, typically some form of illumination is applied. Both techniques use *near infrared light* to illuminate the object (iris or retina) of interest [28].

Pupil Size: In response to the intensity of light on the eye the iris expands or squeezes causing variation in the size of the pupil. This constriction or expansion of the iris may affect the iris recognition process. Moreover, the variation in the size of the pupil affects the amount of light entering onto the retina, which in turn may affect the retinal recognition process [35].

Uniqueness and Stability: The iris pattern is randomly established prior to the birth of an individual and remains intact through out life under normal health condition. Iris patterns are unique not only for each individual, but also irises of the left and right eye of the same individual are distinct. Even identical twins possess different iris patterns. Similar to the iris, each retina retina has a unique blood vessel pattern. This uniqueness hold in identical twins as well. Like the iris pattern the retinal blood vessel patterns under normal health condition also remains unchanged from childhood to death. This two properties, *uniqueness* and *stability* made both iris and retina recognition promising candidates for biometric authentication. Moreover, both retina and iris are universally available in people, with few exceptions in blind people or people suffering from eye diseases that affect the iris or retina.

Vulnerability: Both iris and retina recognition being non-contact biometrics are less vulnerable to identity theft compared to there biometrics such as fingerprint, voice, etc. The users may use them only where they want to. Moreover, it is not trivially possible to re-engineer or reconstitute the template to reproduce any sort of visual image [35].

Universality: There are relatively few people who don't have at least one eye, so there are only a few people who can't use eye biometrics (iris or retina recognition). While blind people may be difficult to enroll, there are instances, where blind people have used iris recognition successfully. The technology is pattern-dependent, not sight-dependent [35]. However, some eye diseases may affect the applicability of iris or retinal recognition. For example, iris melanoma is a degenerative disease that affects (and alters) the iris. Eye injuries such as detached retina or severe impact to the eye could result in hemorrhaging, blotching, occlusion, or otherwise disrupting or damaging the vascular network. Drainage problems and excess fluid pressure in the eye and on the retina are characteristics of glaucoma that can cause deformations, constricting blood vessels on and around the optic nerve. Diabetic retinopathy causes abnormal blood flow and leakage in the retina that can degrade vision or lead to blindness. Although no studies have conclusively established that these diseases degrade recognition performance, they affect the iris or retina, and therefore, may over time have a degenerative affect on both iris and retina recognition, particularly if templates are never updated [18].

4.2 Differences

Iris and retina recognition both being eye based biometrics are sometimes mixed up [35]. But they have differences in the principle, methodology, users' acceptance and other characteristics. These differences are discussed below.

4.2.1 Required Apparatus

Iris image capturing method is based on video camera technology similar to that found in ordinary camcorders. Retinal scanning devices require specialized cameras generally used in ophthalmology. Consequently retinal scanning devices are very expensive compared to iris scanning devices.

4.2.2 Image Acquisition

Image acquisition or iris recognition obtains image of the external eye. Such an image initially includes the iris surrounding the pupil, the white portion of the eye, the eye lids, and possibly the eye lash as well. Before feature extraction, such an image needs preprocessing for iris localization as described in chapter 2.

On the contrary, for retinal pattern recognition, the image of the retina is obtained, which is an internal part of the eye. The acquired image is typically a circular image of the vascular pattern of the retina (see figure 3.1 in chapter 3). However, before feature extraction, preprocessing is also required to detect the blood vessels in the image.

4.2.3 Feature Extraction

From the iris's 11 mm diameter, algorithms provide 3.4 bits of data per square mm. This density of information is such that each iris is said to have 266 degrees of freedom instead of 13 - 16 for most other biometric technologies [35]. The complex iris patterns carry an astonishing amount of information and so, over 200 unique spots can be extracted from an iris scan image [39]. The Daugman approach extracts the distinguishing features and converts them to a hexadecimal representation stored in an IrisCode (see chapter 2) into a 256 byte template [18, 23, 28]. However, perhaps additional header information or changes have since been added to the process as Iridian Inc. now describes the iris as being processed into a 512 byte IrisCode [18, 35]. The odds of two different irises generating a sufficiently similar code to produce a false match is theoretically 1 in 1.2 millions [18].

On the other hand, the unique features gathered from the blood vessel pattern of the retina forms the basis of the template of only 96 bytes [11, 18, 35]. This is considered to be one of the smallest biometric template [11, 35]. As genetic factors do not dictate the blood vessel pattern of the retina, retinal blood vessel pattern possesses very rich, uniques features. As a result, it is possible that up to 400 unique data points can be obtained from the retina, as opposed to around 200 unique data points available in the iris [11, 35].

4.2.4 Matching

It has been calculated that the chance of finding two randomly formed identical irises is on an almost astronomical order of 1 in 1078 [35]. Iris recognition boasts an extremely low false recognition rate (FRR) of 1:12,00,000 [18, 35]. A retinal pattern recognition has even lower error rate of 1 in 10,000,000 [26].

Small template size allows the template database to be small as well, and allows quit fast matching speed. On a 300 MHz CPU exhaustive searches possible at a rate about 100,000 irises per second, and on a 2.2 GHz server one million IrisCodes can be compared in 1.7 seconds [35]. Based on initial performance observations with optimized, integer-base IrisCode, Dr. Daugman concluded [18]:

> "The mathematics of iris recognition algorithms make it clear that databases the size of entire nations could be searched in parallel to make a confident identification decision, in about 1 second using parallel banks of inexpensive CPUs, if such large national iris database ever came to exist."

One the other hand, the relatively smaller template size, and intuition on feature density suggest the information space of retina encoding is less than an iris encoding [35], and hence, if appropriate algorithms applied, retinal pattern matching process is expected to be faster than iris pattern matching.

4.2.5 Users' Acceptance

Biometric authentication by iris pattern recognition tends to be more acceptable to the users compared to retinal pattern recognition, though currently both mechanism require cooperation from the users in the authentication process.

During image acquisition process for iris pattern recognition is non-invasive. The subject can stand as far as 10 inch away from the scanning unit, and even wear glasses, or contact lenses without compromising system accuracy. The process may take 2 to 4 seconds, and the majority of that time is spent by the subject aligning his or eye [18, 35]. Recent tests observed that the average transaction time for iris verification to be about 10 seconds, where that time also included entry of a four-digit PIN [18].

Image acquisition for retinal pattern recognition is intrusive, and requires comparatively more cooperation and patience from the users. Before the process starts the user must remove any eyeglases or contact lenses that he or she might be wearing, because any light reflection from the eyeglass or contact lens may cause interference with the signal of the retinal scanning device. Moreover, during the scanning process the user must position himself about 2 to 3 inches from the scanner, align eye into the lens, and remain perfectly still for the 1 to 2 seconds it takes the scanner to illuminate, focus, and capture retinal image [18]. At these phase, normally 3 to 5 images are captured, which may take over a minute to complete [35]. This often appears to be inconvenient and lengthy process to the users depending on how cooperative the user is.

For retinal image acquisition, the retinal blood vessels need to be illuminated using low intensity near infrared light. As such infrared has insufficient energy insufficient energy to cause photochemical effects, the principal potential damage modality is thermal. When infrared is produced using light emitting diodes (LED), the resulting light is incoherent. Any risk for eye safety is remote with a single LED source using today's technology. Multiple LED illuminators can, however, may cause eye damage if not carefully designed and used [28]. But, iris image acquisition may, or may not use such illumination. Therefore, users' concern about their eye's protection may be more severe in case of retinal scanning compared to iris scanning. The "ability-to-verify rate" standard describes the probability of the overall user group that can be verified by the retinal scanning system on a daily basis. For retinal pattern recognition, this percentage has been as low as 85%. This can be attributed mostly to users' concerns about using retinal scanning device and having their eye scanned at a very close range [35].

4.2.6 Vulnerability to Spoofing

The retina is an internal protected organ to the body and so specialized ophthalmologic cameras are used for retinal image acquisition. These have kept it impossible to spoof the retina till date. But iris spoof attacks have been reported by the journalists [20]. A straightforward method that has been used to spoof an iris sensor is based on a high-quality photograph of the eye [21]. Another method used to successfully spoof some iris sensors is to use a contact lens on which an iris pattern is printed [36]. Even more sophisticated, multilayered and three-dimensional articial irises may also be produced to spoof a sensor [3].

Involuntary oscillation (at a rate of approximately 0.5 Hz) of the pupil at rest (hippus) or in reaction to changing ambient light conditions may be checked to determine if a live eye is in the sensors field of view [12, 13, 18]. In addition, challenge-response transactions may be implemented wherein the person under test is asked to blink or move their eyes in a certain direction to ensure that the random instructions are carried out properly [1].

4.3 Summary

Both iris and retina biometrics are very promising to use for authentication purposes as both of them have very high level of uniqueness, universality, permanence, and accuracy. The retina being an internal organ offers tamper free biometric authentication, whereas a number of ways for mounting spoofing attacks on the iris recognition system have been reported. Moreover, the template size for retina recognition is much smaller than that of iris pattern recognition. Even though retinal scanning devices have been available before iris scanning techniques, retinal pattern recognition has not been adopted in the community due to its cost and usability issues. Comparatively, iris recognition as biometric authentication has been used in a number of government and commercial organizations.

Perfect as the wing of a bird may be, it will never enable the bird to fly if unsupported by the air. Facts are the air of science. Without them a man of science can never rise.

Ivan Pavlov (1849 - 1936)

5 Conclusion

Both Iris and retina biometrics have very high level of uniqueness, universality, permanence, accuracy, and protection against threats to vulnerability. Templates generated for both these biometrics are pretty small in size, and therefore very suitable to incorporate into identification cards. Retinal scanning technology came into being before iris scanning, and the template size for retinal pattern recognition is less than half the template size of the iris pattern recognition. As iris is exposed to the environment, there are possibilities of spoofing attack, but the retina being an internal organ is quite protected from such attacks or accidental damage due to injury. These in principle suggest retinal pattern recognition to be comparatively more promising biometric compared to iris pattern recognition. But, retina scan procedure is invasive necessitating special scanning device to acquire image of the retina inside the eye. Retina biometric is often regarded as the "ultimate biometric", but its high cost and usability issues have prevented it from making a commercial impact [11].

5.1 A Few Misconceptions

Because the retina is an internal organ, or perhaps in part of heightened sensitivities from recent "big brother" privacy debates, there is a misconception that retina scans for identification purposes also reveal personal medical information. This had led some to believe that retinal scanning biometrics are inherently more prone to privacy abuse than to other biometrics, which is not actually the case [18]. The confusion might have been raised from biometric retinal scanning being incorrectly associated with a different process of retinal image scanning used for medical diagnostic purposes, called *angiography*. Angiography uses an orange or green dye that is physically injected into the subject's eye and captures hundreds of dye-enhanced images over time and is concerned with investigating the detail of blood circulation over the entire retinal surface. On the contrary, scanning for recognition captures only a few images (one good one is all that is needed) and is interested in only a relatively small band of pattern information around the optic nerve.

A therapeutic health science known as *iridology* branched off from early medical studies and perhaps culminated in the late 1800s with the publication of an iris chart. This iris chart was a detailed mapping of various regions of the iris to internal human organs and health conditions, and others expanded on this concept to include personality traits and characteristics such as athletic performance. Iridology's assumption that changing health conditions can actually be diagnosed from iris patterns suggests the iris, too, must be dynamic and subject to change. This belief contradicts the premise for iris recognition biometric that iris is in fact stable, constant, and highly distinguishable structure. Dr. Daugman gathered references from medical journals from experts who evaluated and rejected iridology. He qoutes Berggren as follows [18].

> "Good care of patients is inconsistent with deceptive methods, and iridology should be regarded as a medical fraud."

5.2 Present State of the Art and Future Possibilities

The growing use of iris biometric in large sector of the economy, such as transportation, health-care, and national identification programs. Some of the organization that are currently using iris recognition technology for access control or authentication are US House of Representatives, US Department of Treasury, Bank United (Texas), AK Bank (Turkey), British Telecommunication, Venerable Bede School in the United Kingdom, Brussels Bank, KPN Telecom (The Netherlands), Hewlett Packard, Lake Country Sheriff's Office, Olympic Memorial Hospital, and many others [23]. In the largest national deployment of iris recognition to date the United Arab Emirates (UAE) Ministry of Interior requires iris recognition tests on all passengers entering the UAE from all 17 air, land and sea ports [35]. Although security is the prime concern, iris recognition is being adopted for productivity enhancing applications like time and attendance tracking systems [35].

Currently, a few companies that have been working on iris scanners are XVista, Jiristech, and Panasonic. XVista is working on a portable iris scanner. XVistas scanner is reported to have a false match odds at 1 in 7 billion and can hold up to 250,000 identifications on a 256MB card. The Jiristech Iris Scanner is built more for personal security, and can pick up your eye signature in less than a second. Panasonic is building a walkthrough iris scanner that can pick up ones eye signature in two seconds.

Due to high cost and usability issues, retinal pattern recognition systems have not been that much deployed as iris recognition systems have been. A digital security corporation called eEye is the most recent manufacturer of retina scanner. The occurrence of false negatives is even lower than that of John Daugmans IrisCode. The primary application for retinal pattern recognition till date have been for physical access entry for high-security facilities such as military installations, nuclear facilities, and sophisticated laboratories. One of the best-documented application of the use of retinal pattern recognition was conducted by the state of Illinois in an effort to reduce welfare fraud.

One of the recent research activities in the area of eye biometric is aiming iris and retinal biometric fusion. There is only one announced and manufactured scanner (prototype) that fuses the iris and retinal recognitions together. Retica Inc. developed the Cyclops in 2006, which is a retinal scanner that also uses some of the iris patterns to create its own set of code. It is the first scanner that can both identify a person with their retinas and irises, and would be the

Biometric	**Crossover**	**Expected FAs and FRs (Per 1,000,000 Subjects)**
Iris/Retina Scanner (Full Integration)	1:1,300,000,000,000	Approx. 0.00003% chance of 1
Retina Scanner	1:10,000,000	Approx. 20% chance of 1
Iris Scanner	1:131,000	18
Cyclops	1:25,000,000	Approx. 7% chance of 1
Face Recognition	1:500	4,000
Signature	1:20	100,000

Table 5.1: Crossover comparison for different biometrics

best candidate at the moment that would be able to find a correlation between the two. The fusion of the iris and retinal identifications has created the best false match and false non-match odds of any other biometric security identifier in the industry. It can capture the biometric patterns of both the iris and the retina at distances up to one meter. With the small amount of information that is stored in an iris and retina scanner, combining the two would amount to a small 344 bytes of information per code that is stored. The crossover comparison of a true combined iris/retina scanner using these input parameters for the matching is over 1:1,300,000,000,000. Table 5.1 shows the approximate crossover comparisons of different biometrics.

Like the movie "Minority Report", iris scanning from quit a distance without the subjects cooperation may be possible in reality in the future, as research is going on towards such goal. This, when possible, will make iris biometric ready for pervasive use. On the other hand, retina biometric tends to remain suitable for mainly the high-scurity facilities. However, the usability issues with retinal scanning procedure needs to be addressed in order to increase its user acceptance.

Both iris and retina recognition technologies are essentially single-vendor, proprietary implementations that are known to function well for access control applications. So, which is better? No biometric by itself is ever a magic solution to identification applications. The advantages of scanning the eye's internal surface as opposed to the external, visible surface are a matter of application, purpose, and user preference. Running cost, initial cost, as well as installation and integration may also weigh in as determining factor.

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