

THE IRIS RECOGNITION USING GRAY LEVEL CO-OCCURRENCE MATRIX
FOR GABOR WAVELET TRANSFORM AND PRINCIPAL COMPONENT
ANALYSIS THROUGH PATH ANALYSIS TEST CASE

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ABSTRACT

Iris biometric is considered as one of the most efficient and trusted biometric methods for authenticating users. This thesis proposed an effective iris recognition system based on two different hybrid algorithms. Firstly, both Gray Level Co-occurrence Matrix (GLCM) and (2D) Gabor filters were hybridized to extract iris features. Secondly, the hybrid of Principal Component Analysis (PCA) and GLCM were used to obtain a secure iris recognition system. The features extracted by the hybrids methods were normalized and Euclidean distance was used to classify the features. Furthermore, the proposed designed system was tested in many cases and their performances were measured and compared in both algorithms. The processes of Path Analysis Test Case of the two algorithms were performed through the use of three classes of the image to evaluate the performance of the designed system and their reliability was measured. The results show that the overall system accuracy obtained by the Gabor and GLCM was 99.17% success rate with 0.82% false accepted rate and 0.83% false rejected rate while, the overall success rate obtained by the PCA algorithm was 99.15% with 0.82% false accepted rate and 0.85% false rejected rate. The reliability of Gabor filter was given as 95% and for PCA, 94%. The Gabor method overcame the PCA in all the tested cases.

ABSTRAK

Iris biometrik merupakan salah satu kaedah yang paling berkesan dan paling dipercayai dalam pengesahan pengguna. Tesis ini mencadangkan satu sistem yang berkesan dalam pengesahan iris berdasarkan dua algoritma hibrid yang berbeza. Pertama, kedua-dua penapis Gray Level Co-occurrence Matrix (GLCM) dan (2D) Gabor filter dihibridkan untuk mengekstrak ciri iris. Kedua, Principal Component Analysis (PCA) dan GLCM dihibridkan untuk mendapatkan sistem pengiktirafan iris yang selamat digunakan. Ciri-ciri yang diekstrak dengan kaedah kacukan dibiasakan dan jarak Euclidean digunakan dalam mengklasifikasikan ciri-cirinya. Walau bagaimanapun, sistem yang dicadangkan telah diuji dalam banyak kes dan prestasi mereka diukur dan dibandingkan berdasarkan kedua-dua algoritma. Proses Path Analysis Test Cases bagi kedua-dua algoritma telah dilakukan melalui penggunaan tiga kelas imej untuk menilai prestasi sistem yang direka dan kebolehpercayaan mereka diukur. Keputusan menunjukkan bahawa keseluruhan ketepatan sistem yang diperolehi oleh Gabor dan GLCM adalah 99.17% kadar kejayaan dengan 0.82% kadar diterima palsu dan 0.83% kadar ditolak palsu, manakala kadar kejayaan keseluruhan yang diperolehi oleh algoritma PCA adalah 99.15% dengan 0.82% kadar diterima palsu dan 0.85% kadar ditolak palsu. Kebolehpercayaan penapis Gabor adalah 95% dan untuk PCA, 94%. Justeru itu, kaedah Gabor telah mengatasi PCA dalam semua kes-kes yang telah diuji.

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LIST OF SYMBOLS AND ABBREVIATIONS

n_k	–	The Number of Pixels at Intensity Level
n	–	The Total Number of Pixels
∇f	–	The Magnitude of Gradient Vector
S_t	–	Covariance Matrix
θ	–	Theta
R	–	Training Set of Image
U	–	Basis Vectors Matrix
$V_{i\theta}$	–	Standard Deviation
VAR	–	Variance of Gray Level
σ	–	Sigma
μ_i	–	The Mean of Image
Rel	–	Reliability
$GLCM$	–	Gray-Level Co-occurrence Matrix
NaN	–	Not-a- Number
$K-NN$	–	k -Nearest Neighbor
$CASIA$	–	Institute of Automation, Chinese Academy of Sciences
SVM	–	Support Vector Machine
FFT	–	Fast Fourier Transform
$2D$	–	Two Dimensional
DWT	–	Discrete Wavelet Transform
FAR	–	False Accepted Rate
FRR	–	False Rejected Rate
TSR	–	Total Success Rate
GUI	–	Graphical User Interface
RGB	–	Red, Green, and Blue
ROI	–	Region of Interest

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CHAPTER 1

INTRODUCTION

1.1 General Overview

In an increasingly digitized world, the reliable personal authentication has become an important human computer interface activity. National security, e-commerce, and access to computer networks are now very common where establishing a person's identity has become vital. Traditional methods for personal identification include the token-based methods that use specific things such as identification cards or keys for authentication and knowledge-based methods that use something to know such as password for identification. However, these methods are usually not reliable (Cui *et al.*, 2004). Therefore, deoxyribonucleic acid (DNA), facial features, voice patterns, hand geometry, retinal patterns, vein patterns, signature dynamics, voice verification, facial thermograph, nail bed identification, gait recognition, ear shape recognition, and finger prints have all been explored as biometric identifiers with varying levels of success. However, the iris, being unique and stable for a lifetime period is the most reliable biometric (Lenina & Kokare, 2009). A very important characteristic of an iris is that it is a naturally protected organ and stable without any variations along with the ageing of an individual. Thus, the aim of feature extraction is to find a transformation from an n-dimensional observation space to a smaller m-dimensional feature space.

The features of iris were extracted in this project using two algorithms, which are Gabor Wavelet and Principal Component Analysis (PCA). The main reason for performing feature extraction is to reduce the computational complexity for iris recognition. Previous existing features extraction methods for iris recognition are

based on the local properties such as phase, and shape. Besides, PCA can produce spatially global features (Bae *et al.*, 2003). Gabor filtering is vastly used in iris recognition literature for feature extraction. Conventionally, Gabor parameters values are supplied by pre-knowledgeable values so that the filter bank size is increased to prevent loss of information (Bae *et al.*, 2003). However, this research extracted more features for iris pattern from the Gabor filter and PCA using proposed methods such as Correlation, Contrast, Energy, Homogeneity, and Entropy.

1.2 Motivation

Biometrics is the science of verifying the identity of an individual through physiological measurements or behavioural traits. Fingerprint verification is one of the most reliable personal identification methods and it plays a very important role in forensic applications like criminal investigations, terrorist identification, and National security issues. Since biometric identifiers are associated permanently with the users, they are more reliable than token or knowledge based authentication methods (Zhu *et al.*, 2002).

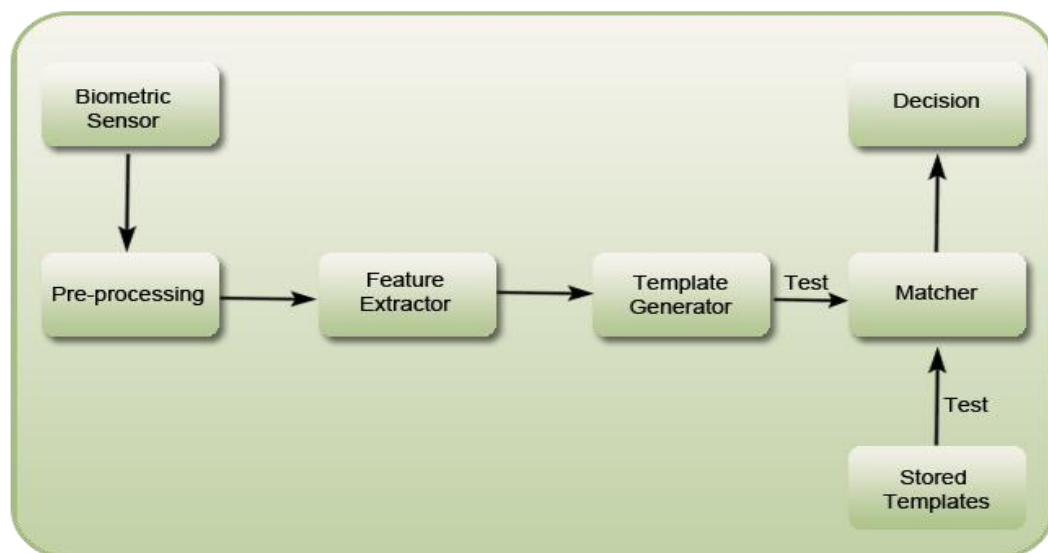


Figure 1.1: Biometrics Security Process (Zhu *et al.*, 2002)

Besides, biometrics offers several advantages over traditional security measures. Biometrics based security systems are far most secured and accurate than traditional password or token based security systems. For example, a password based

security system has always the threat of being stolen and accessed by unauthorized user.

Furthermore, the traditional security systems are always prone to accuracy, as compared to biometrics, which is more accurate. For example, in a case of one individual with multiple identification cards: The traditional security systems were unable to solve the problem of individuals having multiple Identification cards and multiple passports to enter a foreign country. Biometrics gives us a system in which an individual cannot possess multiple Identification cards or change his Identification throughout his life time. Each individual is identified through a unique biometric identity throughout the world.

1.3 Problem Statement

Iris verification is the most reliable personal identification method and it plays a very important role in forensic applications such as in criminal investigations, terrorist identification, and National security issues. Therefore, increasing the success rate and reducing the false accepted rate of iris recognition is needed. However, complexity of some Iris recognition systems may require so much computation as to be impractical (Wan *et al.*, 2004).

1.4 Research Objectives

Based on the research background and the related issue, the objectives of this research have been formulated as follow:

- (i) Design a new feature extraction for iris based on Gabor wavelet and Principal Component Analysis using Gray Level Co-occurrence Matrix.
- (ii) Analyze the iris recognition system based on Accuracy and Complexity.
- (iii) To compare the performance of the proposed system with the existing one based on Total Success Rate, False Rejected Rate, and False Accepted Rate.

1.5 Research Scope

The research started by collecting online database (Dobe & Machala, 2003) for iris patterns, then the fundamentals of image processing were applied to denoise the

database and enhance the quality, image segmentation, and normalization as the image features extraction was based on Gabor wavelet transform and PCA. Classification process was done based on the nearest neighbour, and finally, on obtaining recognition of iris, the final score of accuracy and complexity such as computation time was measured.

1.6 Significance of the Research

Iris recognition is a particular type of biometrics system that can be used to reliably identify a person by analyzing the patterns found in the iris. The iris is so reliable as a form of identification because of the uniqueness of its pattern (Amrita *et al.*, 2013). Although there is a genetic influence, particularly on the iris colour, the iris develops through folding of the tissue membrane and then degeneration (to create the pupil opening) which results in random and unique iris traits, thus, the iris recognition system has been found useful in both forensic investigations and civilian applications.

1.7 Contribution of Thesis

This thesis contributes in the increase of the overall accuracy of iris recognition system by increasing the success rate and decreasing the false accepted rate. Furthermore, this work contributes in reducing the complexity of the system by reducing the processing time.

1.8 Outline of Thesis

This thesis provides description and report on the effort that was carried out throughout the duration of the project in order to achieve the project scope and objectives. This thesis is divided into five chapters that cover the whole project. General description to the contents of the chapters is summarized below.

Chapter 1 provides a brief introduction to biometrics and its application to security issues using iris pattern. It explains the iris recognition prototype system in detail. Furthermore, this chapter explains the problem statement and states the motivation, scope, and objectives of this project.

Chapter 2 introduces the history of iris recognition system and the theories involved in the process of designing iris recognition system. In this chapter, previous methods and algorithms are discussed and summarized. Besides, related topics and works relevant to the study based on various journals and publications are reviewed and used as reference to this project.

Chapter 3 proposed for designing iris recognition algorithm which depended on the Gabor wavelet and PCA. This chapter introduces several image pre-processing techniques for the purpose of enhancing the iris images. Comparative study of iris recognition system is built based on the Total Success Rate, False Accepted Rate, and False Rejected Rate.

Chapter 4 discusses the obtained results from the proposed methods and evaluated the parameters such as, False Accepted Rate, False Rejected Rate, and Total Success Rate. This chapter also introduces comparatives of the obtained accuracies by the two proposed algorithms through path analysis test case.

Lastly, Chapter 5 summarizes and concludes the full project and proposes future work for the system in order to increase the accuracy, reliability, and reduce the complexity of the algorithm used in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter introduces the general concept of biometrics that is used for verification and identification. It also explains the applications of biometrics and introduces its characteristics. Biometric is an automated method of identifying a person or verifying the claimed identity of a person based on physiological or behavioural characteristics. Physiological characteristics are fingerprint, hand geometry, iris, and facial characteristics, whereas behavioural characteristics are traits that can be learned or acquired such as keystroke dynamics, speaker verification, and dynamic signature verification. In this project, iris recognition system is explained in detail and previous work is discussed in this chapter.

Based on the researches done from diverse resources, the iris verification and recognition system was found in abundance. Different methods and concepts were reviewed and discussed on how it can be used, worked, and implemented.

According to numerous other researches, there are many monitoring and security systems that are based on biometrics, such as eye tracking system, fingerprint, voice recognition systems, and face detection systems which share the same goal. However, identification and verification can be differentiated through various methods implemented, algorithms used, the environments, and the security level.

2.2 Biometrics

Biometrics is technological science which has been used to identify people in one form or many others over decades, as long as it belongs to an individual's unique physical characteristics and which can never be lost or duplicated and is widely considered as rapid, accurate, and a dependable approach of verifying a person. Biometrics system can be classified according to physical and behavioral traits, as shown in Figure 2.1. Any biometrics system can be functional in the three following approaches (Zhu *et al.*, 2002).

- (i) **Detection:** In this mode, the system should perform matching comparison from the captured biometric based on certain biometrics to determine if it is a physical characteristic that the system uses to detect.
- (ii) **Verification:** In this mode, the system performs a one-to-one comparison from the captured biometric with a defined mold from a biometrics database to verify an individual.
- (iii) **Identification:** In this mode, the system performs a one-to-many comparison across a biometrics database to establish the identity of an unknown individual.

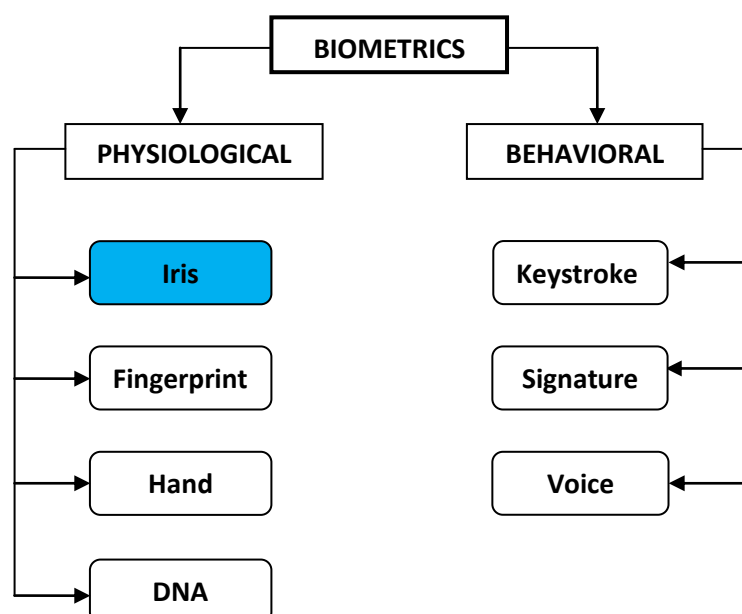


Figure 2.1: Biometrics Classification

The biometrics systems nowadays are quite acceptable for most applications in the recognition performance, but much work is still needed to provide convenient, privacy-friendly, and secured systems. One of the negative involvements of increased technology is the ease of spoofing into a biometrics identification systems. Hence, by increasing these kinds of attacks, it reduces the reliability and the security of biometrics systems. Furthermore, since most biometrics algorithms do not have the ability to differentiate live biometric from ones that are not live, it cannot differentiate between online and offline systems.

2.2.1 Fingerprint

Fingerprints are one of the oldest forms of biometric identifiers and also the most frequently deployed biometrics system due to their proven track record document. Fingerprints are unique to each person and each finger, where there are two fingers that share the same thumb. The basis for identification is primarily based on minutiae that mark ends or bifurcation of ridges as in the white lines, as shown in Figure 2.2 below. The orientation and location of these minutiae were recorded and compared to each. About 10-11 minutiae are sufficient in uniquely identifying a person (Sonkamble *et al.*, 2010). An indexing system, known as the Henry system, is also used widely and is adopted by computer based identification schemes for classification purpose. The minutiae form a triplet (x, y, θ) , where x and y are their locations (of the point of ridge ending or bifurcation) and θ is the point of orientation of the minutiae (as if the ridge continued in the ridge ending case).

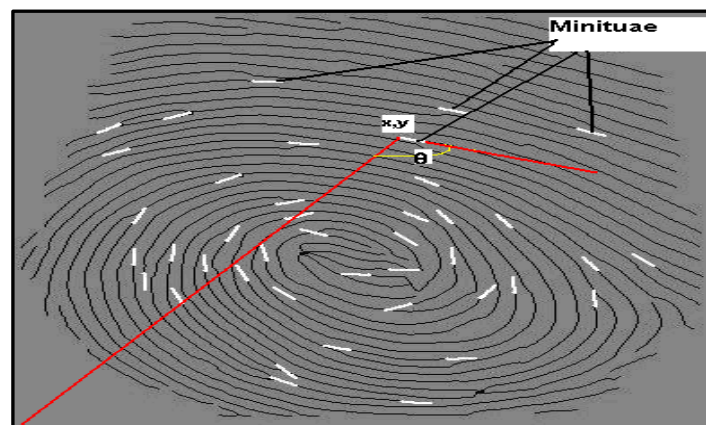


Figure 2.2: Fingerprint Elaboration (Raghavan, 2012)

2.2.2 Palm Print

Palm print is of human hand's inner surface skin impression that extends from the wrist to tip of the fingers. It is rich in lines, valleys, ridges, textures, and points that would give sufficient information for the distinction between individuals. The distinction result that is expected from palm print is better than fingerprint because its area is larger than that of fingerprint, but the capture device will be larger and costly (Michael *et al.*, 2011) as well. Figure 2.3 below illustrates the main patterns for palm print.

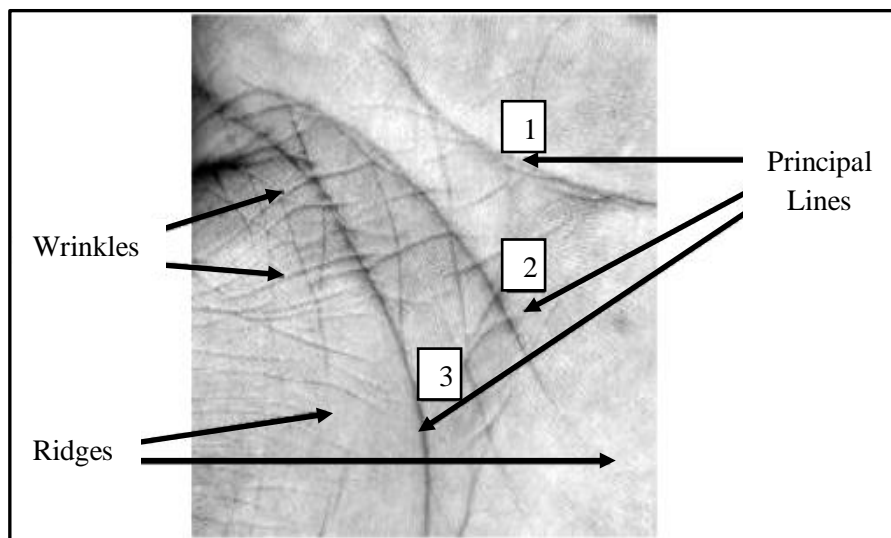


Figure 2.3: The main Patterns for Palm Print (Michael *et al.*, 2011)

2.3 Iris Biometric for Authentication

Biometrics has advantages of being:

- (i) Unique for a person with no chance of unintentional duplication.
- (ii) Much longer and random compared to a password that is within the ability of a human to remember and most importantly, it is always conveniently there with the person.

The iris makes its use suitability as an exceptionally accurate biometric because of the high random appearance on the iris. Hence, the characteristics of iris are:

- (i) Extremely data-rich physical structure.

- (ii) Genetic independence as no two eyes is the same.
- (iii) Stability over time.
- (iv) Physical protection by a transparent window (the cornea) that does not inhibit external view ability.

2.4 Historical Approach to Iris Recognition

In 1936, ophthalmologist Frank Burch proposed the concept of using iris patterns as a method to recognize human beings. In 1985, Drs. Leonard Flom and Aran Safir, ophthalmologists, proposed the concept that no two irises are alike and were awarded a patent for the iris identification concept in 1987. In 1993, the Defence Nuclear Agency in the United States began work to test and deliver a prototype unit which was successfully completed by 1995 due to the combined efforts of Drs. Flom, Safir, and Daugman. In addition, in 1994, Dr. Daugman was awarded a patent for his automated iris recognition algorithms (Daugman, 1992). Furthermore, in 1995 the first commercial products became accessible. In 2005, the broad patent covering the basic concept of iris recognition expired, providing marketing opportunities for other companies that have developed their own algorithms for iris recognition (Daugman, 1993). Finally, the patent on the iris codes implementation of iris recognition that was developed by Daugman expired in 2011.

2.4.1 Iris Recognition System

Iris is flat and sections the front of the eye (anterior chamber) from the back of the eye (posterior chamber) (Boles & Boashash, 1998). In the centre of the iris, there is a round opening that is called the pupil and the operation of the opening and closing of pupil is controlled by the iris muscle, as shown in Figure 2.4.

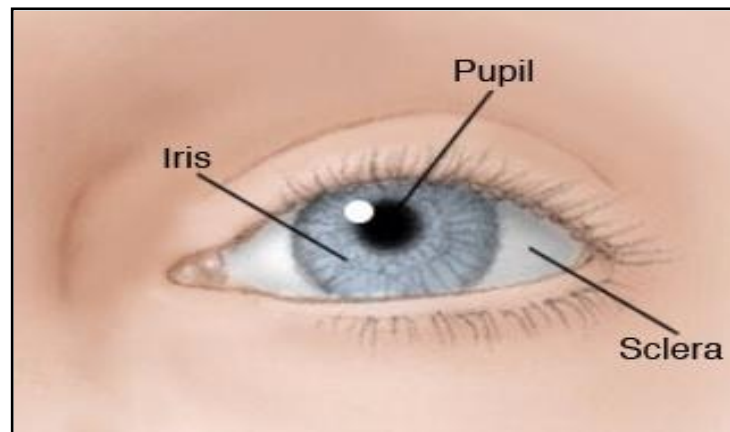


Figure 2.4: Illustration of the Areas of Pupil, Iris and Sclera (Riverside, 2013)

Iris recognition emerges from the need to recognize an individual's identity from the texture of his/her iris pattern. There are four stages carried out for iris recognition: acquiring image of iris, segmentation iris, extracting of useful features, and matching of pattern.

Iris recognition is known to be the most accurate biometric due to some reasons like its colour is fixed from birth, it is stable for a lifetime where the iris visual texture stabilizes during the first two years of life, template size is small, image encoding and matching processes are simple and fast, and its high rate of recognition (Ziauddin & Dailey, 2010). All other biometrics modalities do not give enough good performance or high level of security. Thus, recognition based on iris pattern is proposed as an alternative way of high accurate biometrics recognition (Ziauddin & Dailey, 2010). Limitations of iris recognition can be enclosed in the area of the eye where one of these; watery eyes, long eyelashes, hard contact lens, and eye diseases, could occur. Figure 2.5 shows how the Iris Identification system works.

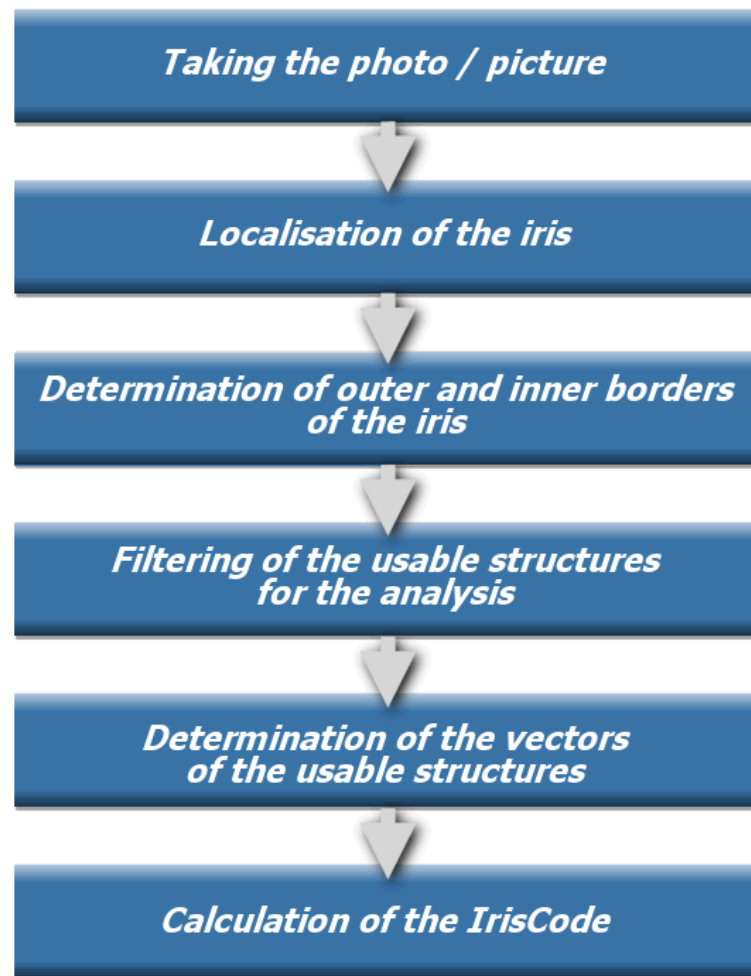


Figure 2.5: The Iris Identification System

2.4.2 Iris Recognition Technology

Iris recognition technology relies on the unique patterns of the human iris to automatically identify or verify the identity of human beings. Iris is the colour part of the eye that forms a ring surrounding the pupil. Even though it may appear to be on the surface level of the eye, it is actually covered and protected by the clear cornea, as shown in Figure 2.6.

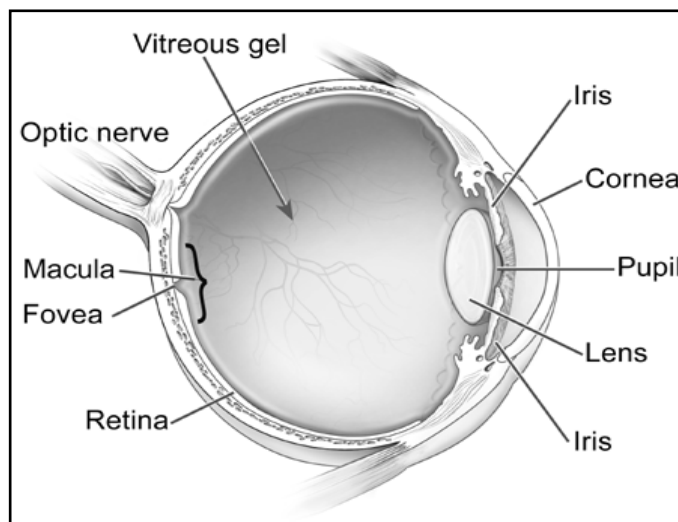


Figure 2.6: A Side-View Cross-Sectional Diagram of the Eye (Michael, 2002)

Every iris is distinct, including the two irises belonging to the same individual and the irises of twins as well. Iris patterns are formed before birth and do not naturally change over the course of a lifetime. Iris is highly stable as a recognizable characteristic because of the natural protection of the eyes in the face and the protection of the iris beneath the cornea (Daugman, 1993). Furthermore, the medical procedures such as refractive and cataract surgeries or cornea transplants do not affect its recognizable characteristics.

2.4.3 Applications of Iris Recognition

Major applications of the iris recognition technology so far have been: substituting for passports, aviation security and controlling access to restricted areas at airports (Boles & Boashash, 1998), database access and computer login, access to buildings, homes and hospital settings, including mother-infant pairing in maternity wards, database searching at border crossings and other Government programs.

2.4.4 Advantages of using Iris Recognition

The following are the important advantages of using the iris recognition system:

- (i) It performs 1: N identification with no limitation on numbers.
- (ii) The most robust biometrics technology available in the market today.

- (iii) Biometrics templates once captured need not to be enrolled again as the iris is stable throughout a user's life.

2.5 Image Enhancement Technique

Image enhancement is a technique used to improve the information in images for iris and provide better input for other automated image processing techniques. The principal objective of image enhancement is to modify the attributes of an image to make it more suitable for a given task and a specific observer. Through this process, one or more attributes of the image are modified. The choice of attributes and the way they are modified are specific to a given task. Besides, observer-specific factors, such as the human visual system and the observer's experience will introduce a great deal of subjectivity into the choice of image enhancement methods (Raman & Himanshu, 2010). There are many techniques that can enhance a digital image without spoiling it, such as gray scale and histogram enhancement.

Histogram equalization is a common technique for enhancing the appearance of images. Suppose there is an image that is mostly dark, its histogram would be skewed towards the lower end of the gray scale and all the image details are compressed into the dark end of the histogram. If the gray levels stretch out at the dark end, it would produce a more uniformly distributed histogram and the image would become clearer (Raman & Himanshu, 2010). The probability density function of a pixel intensity level, r_k is given in the following equation:

$$p_r(r_k) = \frac{n_k}{n} \quad (2.1)$$

where

$0 \leq r_k \leq 1$, $k = 0, 1, \dots, 255$, n_k is the number of pixels at intensity level, r_k , $p_r(r_k)$ is the probability density of a pixel and n is the total number of pixels. The histogram is derived by plotting $p_r(r_k)$ against r_k . A new intensity S_k of level k is defined as:

$$S_k = \sum_{j=0}^k \frac{n_j}{n} = \sum_{j=0}^k p_r(r_j) \quad (2.2)$$

Applying the histogram equalization locally using local windows of $N \times N$ pixels will result in expanding the contrast locally and changing the intensity of each pixel according to its local neighbourhood (Aravinth & Valarmathy, 2012).

Gray level is the spatial domain equivalent to band-pass filtering. A gray level slicing function can either emphasize a group of intensities and diminish all others or it can emphasize a group of gray levels and leave the rest alone (Raman & Himanshu, 2010).

2.6 Iris Localization

Iris scans analyze the features that exist in the colour tissue surrounding the pupil which has more than 200 points that can be used for comparison, which includes rings furrows and freckles. However, the scans use a regular video camera style and can be done from further away than a retinal scan (Ziauddin & Dailey, 2010). Furthermore, the uniqueness of eyes, even between the left and right eye of the same person, makes iris scanning very powerful for recognition. The likelihood of a false acceptance is extremely low and its relative speed and ease of usage make it a great potential biometric. Besides, Sobel operator techniques can be used to detect the edges of the iris images. Figure 2.7 illustrates Iris Localization.

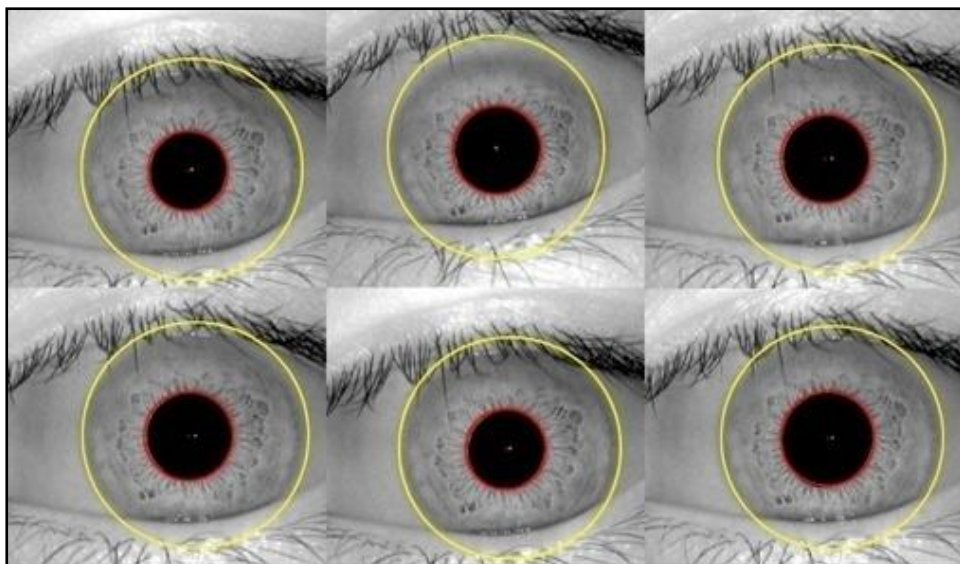


Figure 2.7: Iris Localization (Daugman, 1994)

2.6.1 Region of interest using Sobel operator

An important quantity in edge detection is the magnitude of this vector, denoted ∇f .

where

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} \quad (2.3)$$

The magnitude gives the maximum rate of increase of $f(x, y)$ per unit distance in the direction of ∇ .

where

$\nabla f = |\nabla \mathbf{f}| = \sqrt{G_x^2 + G_y^2}$. Another important quantity is the direction of the gradient vector. That is the angle of $\nabla \mathbf{f} = \tan^{-1} \left(\frac{G_y}{G_x} \right)$

where

The angle is measured with respect to the x -axis. The direction of an edge at (x, y) is perpendicular to the direction of the gradient vector at that point. Computation of the gradient of an image is based on obtaining the partial derivatives of $\partial f / \partial x$ and $\partial f / \partial y$ at every pixel location (Che-Ming, 2011).

2.6.2 Sobel Edge Detection

The aim of Sobel edge detector is to compute the gradient magnitude and the angle of the gradient. Figure 2.8 and Figure 2.9 below illustrate the areas of an image and the Sobel operators.

P1	P2	P3
P4	P5	P6
P7	P8	P9

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Figure 2.8: A 3×3 Area of an Image

Figure 2.9: The Sobel operators

$$|G| = |G_x| + |G_y|$$

$$|(P_1 + 2P_2 + P_3) - (P_7 + 2P_8 + P_9)| + |(P_3 + 2P_5 + P_9) - (P_1 + 2P_4 + P_7)| \quad (2.4)$$

where

G_x and G_y convolve the image and produce the gradient.

2.7 Principal Component Analysis (PCA)

The aim of feature extraction is to find a transformation from an n -dimensional observation space to a smaller m -dimensional feature space, as given by literature. The main reason for performing feature extraction is to reduce the computational complexity for iris recognition. However, most existing iris recognition methods are based on the local properties such as phase and shape, and these do not give enough information about the image. Furthermore, iris image recognition based on local properties is difficult to implement (Cui *et al.*, 2004). The PCA searches for k n -dimensional orthogonal vectors that can best be used to represent the data, where $k \leq n$. Hence, the original data are projected onto smaller space which results in data reduction (Pravin *et al.*, 2012).

2.7.1 Summary of Feature Reduction Using PCA

The PCA is a statistical method for reducing data dimensions. In PCA, the training data is used to obtain the Eigen basis vectors. Then, the training sets R and T are projected into those vectors. The PCA can be summarized by the following steps:

- (a) The mean M of the training set is calculated and subtracted from the training set:

$$M = \frac{1}{n} \sum_{i=1}^n R_i \quad (2.5)$$

where

M : Mean of Training Set.

R_i : Trained Image.

For all training set perform

$$R_i = R_i - M \quad (2.6)$$

- (b) The Eigenvectors and values of the training set covariance matrix S_t are calculated.

$$S_t = R.R^T \quad (2.7)$$

where

S_t : Covariance Matrix.

R : Training set of image.

R^T : Transpose Training set of image.

The Eigen vectors corresponding to the N largest Eigen values of S_t are picked. These construct the N principal components matrix (V).

- (c) The Basis vectors matrix (U) is constructed as:

$$U = V.R^T \quad (2.8)$$

where

U : Basis vectors matrix.

V : Eigen Value.

R^T : Transpose Training set of image.

- (d) The reduced feature vector is calculated for training and testing data as:

$$W_R = R.U \quad (2.9)$$

where

U : Basis vectors matrix.

R : Trained Image.

$$W_T = T \cdot U \quad (2.10)$$

where

U : Basis vectors matrix.

T : Tested Image.

The mean M must be subtracted from the testing data T . Many experiments were conducted using different numbers of Eigenvectors (N) between (10-60), depending on the size of image database. The final features are projected to reconstruct the reduced dimension images and are used for other features extraction.

2.8 Gabor Wavelet Transform

Iris reputed for its potential to identify the people with high accuracy in large scale. However, this is not achieved unless the iris patterns are well represented. Gabor filtering is vastly used in iris recognition literature for feature extraction. Conventionally, Gabor parameters values are supplied by pre-knowledgeable values so that the filter bank size is increased to prevent loss of information (Manikandan & Sundararajan, 2010).

The basic idea is to extract features at multiple scales and orientations using Gabor wavelet decomposition. Two dimensional (2D) wavelet transform is performed and a 3-level decomposition, for better evaluation. These features will be compared favourably with other features extracted via PCA. The filter has a real and an imaginary component representing orthogonal directions. The two components may be formed into a complex number or used individually. Gabor filters are directly related to Gabor wavelets since they can be designed for a number of dilations and rotations. However, in general, expansion is not applied for Gabor wavelets since this requires computation of bi-orthogonal wavelets, which may be very time-consuming. Therefore, usually, a filter bank consisting of Gabor filters with various scales and rotations is created (Bhattacharya *et al.*, 2013). The filters are convolved with the signal, resulting in a so-called Gabor space. This process is closely related to processes in the primary visual cortex. Jones and Palmer showed that the real part of the complex Gabor function is a good fit to the receptive field weight functions found in simple cells in a cat's striate cortex. The Gabor space is very useful in image processing applications such as optical character recognition, iris recognition, and

fingerprint recognition. Relations between activations for a specific spatial location are very distinctive between objects in an image. Furthermore, important activations can be extracted from the Gabor space in order to create a sparse object representation. The local regions of an iris are projected onto quadrature (2D) Gabor filter using the following equations (Bhattacharya *et al.*, 2013).

$$G(x, y, f, \theta) = \exp\left[-\frac{1}{2}\left\{\frac{x'^2}{\delta_x^2} + \frac{y'^2}{\delta_y^2}\right\}\right] \cos(2\pi f x') \quad (2.11)$$

$$x' = x \cos \theta + y \sin \theta \quad (2.12)$$

$$y' = x \sin \theta - y \cos \theta \quad (2.13)$$

where

f is the frequency of the sinusoidal plane wave along the direction θ from the x-axis, and δ_x and δ_y specify the Gaussian envelope along x and y axes, respectively.

Before filtering the iris image, the gray level intensities are normalized in each cell separately to a constant mean and variance (Bhattacharya *et al.*, 2013).

Normalization is done to remove the effects of sensor noise and iris pressure differences. Let $I(x, y)$ denote the gray level of pixel (x, y) , M_i and V_i , the estimated mean and variance of the cell, respectively, and $N_i(x, y)$, the normalized gray level value of pixel (x, y) . For all the pixels in the cell, the normalized image is defined as in the following equations:

The mean and variance of a gray level iris image (I) are as given:

$$M(I) = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} I(x, y) \quad (2.14)$$

where

M : The Mean of Gray Level.

I : Iris Image.

x : Image Pixel.

y : Image Pixel.

$$VAR(I) = \frac{1}{N^2} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (I(x, y) - M(I))^2 \quad (2.15)$$

where

VAR : Variance of Gray Level.

I : Iris Image.

Let $N(x; y)$ represent the normalized gray-level value at pixel (x, y) . The normalized image is defined as:

$$N(x, y) = M_0 + \sqrt{\frac{VAR_0(I(x, y) - M(I))^2}{VAR}} \quad \text{if } I(x, y) > M \quad (2.16)$$

$$N(x, y) = M_0 - \sqrt{\frac{VAR_0(I(x, y) - M(I))^2}{VAR}} \quad (2.17)$$

where

M_0 and VAR_0 are the desired mean and variance respectively. Normalization is pixel-wise operation. It does not change the clarity of the iris structures.

The main purpose of normalization is:

- (i) To have images with similar characteristics.
- (ii) To remove the effect of the sensor noise.
- (iii) To reduce the variation in gray level values.

If normalization is done on the entire image, then it cannot compensate for the intensity variations in the different parts of the iris due to iris pressure differences. Normalization of each cell separately alleviates this problem (Attarchi *et al.*, 2008). The standard deviation of intensity in each filtered cell is treated as a feature value. Let $F_{i\theta}(x, y)$ be the component image corresponding to θ for each cell. A feature $V_{i\theta}$ is defined as standard deviation of each cell with the following equation:

$$V_{i\theta} = \sqrt{\sum_{Ki} (F_{i\theta}(x, y) - P_{i\theta})^2} \quad (2.18)$$

where

$V_{i\theta}$ is defined as standard deviation, K_i is the number of pixels in each cell and $P_{i\theta}$ is the mean of the pixel values in $F_{i\theta}$. The final normalized image is used for other features extraction. In fact, more information is derived from the image in order

to obtain more accuracy. The distribution of gray level among the structure of iris image will be used for further features extraction (Attarchi *et al.*, 2008).

2.9 Gray-Level Co-occurrence Matrix (GLCM)

This part of features extraction is based on the distribution of GLCM, as proposed by Haralick and Shanmugam (Haralick *et al.*, 1973). The section below explains each one in detail.

- (a) **Correlation:** It is a measure of how correlated a pixel is to its neighbour over the whole image. In another words, it determines the similarities between two images or objects. The range for GLCM is given by [-1,1]. Correlation is 1 or -1 for a perfectly positively or negatively correlated image. Correlation is NaN (Not-a-Number) for a constant image. It is given by the following equation (Selvarajah & Kodituwakku, 2011).

$$Correlation = \sum_{i=1}^N \sum_{j=1}^M \frac{(i-\mu_i)(j-\mu_j)P(i,j)}{\sigma_i\sigma_j} \quad (2.19)$$

where

- $\sigma_i\sigma_j$: The Variance of Image.
- μ_i : The Mean of Image.
- i : Image Pixel.
- j : Image Pixel.
- p : Probability Density of Gray Level.

- (b) **Contrast:** It is a measure of the intensity contrast between a pixel and its neighbour over the whole iris image and it is given by equation (Selvarajah & Kodituwakku, 2011). The range for GLCM is given as [0, (size (GLCM,1)-1)^2], and the contrast is zero for a constant image.

$$Contrast = \sum_{i=1}^N \sum_{j=1}^M (|i-j|)^2 P(i,j) \quad (2.20)$$

where

- i : Image Pixel.

j : Image Pixel.
 p : Probability Density of Gray Level.

- (c) Energy: It is the sum of squared elements in the GLCM and given by the equation below. The range for GLCM is given by [0,1], Energy is 1 for a constant image (Selvarajah & Kodituwakku, 2011).

$$Energy = \sum_{i=1}^N \sum_{j=1}^M P(i, j)^2 \quad (2.21)$$

where

i : Image Pixel.
 j : Image Pixel.
 p : Probability Density of Gray Level.

- (d) Homogeneity: It is a value that measures the closeness of the distribution of elements in the GLCM to the diagonal and it is given by the equation below (Selvarajah & Kodituwakku, 2011). The range for GLCM is [0,1], whereby homogeneity is 1 for a diagonal GLCM.

$$Homogeneity = \sum_{i=1}^N \sum_{j=1}^M \frac{P(i, j)}{(1+(i-j))} \quad (2.22)$$

where

i : Image Pixel.
 j : Image Pixel.
 p : Probability Density of Gray Level.

- (e) Entropy: The entropy or average information of an image is determined approximately from the histogram of the iris image. A Shannon entropy value is calculated from each sub bands obtained from the second level wavelet packet tree and Gabor / PCA. Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image (Selvarajah & Kodituwakku, 2011). Shannon entropy criteria find the information content of signal 'S' using the equation below. The histogram shows the different gray

level probabilities in the image. The entropy is useful for image focusing. The wavelet energy signatures reflect the distribution of energy along the frequency axis over scale and orientation and have proven to be very powerful for texture characterization.

$$Entropy = - \sum_{i=1}^N P(x_i) \log_b P(x_i) \quad (2.23)$$

where

$P(x_i)$ is the probability that the difference between 2 adjacent pixels is equal to i , and \log_b is the base 2 logarithm.

Image entropy is a quantity which is used to describe the status of an image for example, the amount of information which must be coded by a compression algorithm. Low entropy images, such as those containing a lot of black sky, have very little contrast and large runs of pixels with the similar values. An image that is perfectly flat will have entropy of zero value. Consequently, they can be compressed to a relatively small size. On the other hand, high entropy images such as an image of heavily cratered areas on the moon, have a great deal of contrast from one pixel to the next and consequently, cannot be compressed as much as low entropy images (Selvarajah & Kodituwakku, 2011). From this information about entropy, it is proposed as one of the features to differentiate between two set of objects/iris.

2.10 Normalization of Features Extracted

Let X denotes these to raw matching scores from a specific matcher, and let $x \in X$. The normalized score of x is then denoted by x' . These normalization schemes can be used with Euclidian distance for improving the accuracy (Ross *et al.*, 2005).

This kind of normalization maps the raw matching scores to interval $[0,1]$ and retains the original distribution of matching scores, except for a scaling factor (Ross *et al.*, 2005). Given that $\max(X)$ and $\min(X)$ are the maximum and minimum values of the raw matching scores respectively, the normalized score is calculated as:

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