ADAPTIVE NOISE REDUCTION AND CODE MATCHING FOR IRIS PATTERN RECOGNITION SYSTEM

AREZOU BANITALEBI DEHKORDI

UNIVERSITI TEKNOLOGI MALAYSIA

ADAPTIVE NOISE REDUCTION AND CODE MATCHING FOR IRIS PATTERN RECOGNITION

AREZOU BANITALEBI DEHKORDI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Electrical Engineering)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY, 2016

To my beloved parents: “Eng. Gholamreza Banitalebi Dehkordi & Mrs. Rezvan Farzaneh Dehkordi” and my beloved brother “Alireza”

ACKNOWLEDGEMENT

First of all, praise to God for his kindness to let complete this thesis. In the course of this research, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts throughout my research. In particular, I would like to express my sincere appreciation to my supervisor, Associate Professor Dr. Syed Abdul Rahman b. Syed Abu-Bakar for his guidance, critics and supports. I offer my special thanks to Dr. Musa Mohd. Mokji and my friends in CvviP research laboratory.

My warmest gratitude goes to my beloved family for their great patience, encouragement and supports and deep prayers for me. Last but not least, my warm appreciation to all of my friends for their moral and continuous supports.

ABSTRACT

Among all biometric modalities, iris is becoming more popular due to its high performance in recognizing or verifying individuals. Iris recognition has been used in numerous fields such as authentications at prisons, airports, banks and healthcare. Although iris recognition system has high accuracy with very low false acceptance rate, the system performance can still be affected by noise. Very low intensity value of eyelash pixels or high intensity values of eyelids and light reflection pixels cause inappropriate threshold values, and therefore, degrade the accuracy of system. To reduce the effects of noise and improve the accuracy of an iris recognition system, a robust algorithm consisting of two main components is proposed. First, an Adaptive Fuzzy Switching Noise Reduction (AFSNR) filter is proposed. This filter is able to reduce the effects of noise with different densities by employing fuzzy switching between adaptive median filter and filling method. Next, an Adaptive Weighted Shifting Hamming Distance (AWSHD) is proposed which improves the performance of iris code matching stage and level of decidability of the system. As a result, the proposed AFSNR filter with its adaptive window size successfully reduces the effects ofdifferent types of noise with different densities. By applying the proposed AWSHD, the distance corresponding to a genuine user is reduced, while the distance for impostors is increased. Consequently, the genuine user is more likely to be authenticated and the impostor is more likely to be rejected. Experimental results show that the proposed algorithm with genuine acceptance rate (GAR) of 99.98% and is accurate to enhance the performance of the iris recognition system.

ABSTRAK

Antara semua kaedah biometrik, iris menjadi semakin popular kerana berprestasi tinggi dalam mengenali atau mengesahkan individu. Pengiktirafan iris telah diguna dalam pelbagai bidang, seperti pengesahan di penjara, lapangan terbang, bank dan penjagaan kesihatan. Walaupun sistem pengecaman iris mempunyai ketepatan yang tinggi, prestasi sistem ini masih boleh dipengaruhi oleh hingar. Nilai intensiti bulu mata yang rendah atau nilai intensiti kelopak mata yang tinggi serta piksel pantulan cahaya menyebabkan tahap ambang yang tidak sesuai dan ini mengakibatkan ketepatan sistem akan menjadi rendah. Bagi mengurangkan kesan hingar dan meningkatkan ketepatan sistem pengecaman iris, satu algoritma tegar yang terdiri daripada dua komponen dicadangkan. Pertamanya, penggunaan penapis Adaptif Kabur Pensuisan Bunyi (AFSNR). Penapis ini dapat mengurangkan kesan gangguan hingar yang mempunyai ketumpatan hingar yang berlainan. Seterusnya, satu Pemindahan Berat Adaptif Jarak Hamming (AWSHD) dicadangkan yang dapat meningkatkan prestasi tahap pemadanan kod iris dan tahap penentuan sistem. Keputusan menunjukkan penapis AFSNR yang dicadangkan dengan penyubahsuaian saiz tingkap berjaya mengurangkan kesan pelbagai jenis hingar dengan pelbagai ketumpatan. Dengan penggunaan cadangan AWSHD, jarak sepadan dengan seseorang pengguna tulen dapat dikurangkan, manakala jarak penyamar dapat ditingkatkan. Hasilnya, pengguna tulen akan lebih dapat disahkan dan penyamar akan lebih dapat ditolak. Keputusan eksperimen menunjukkan bahawa algoritma yang dicadangkan ini memberikan kadar penerimaan tulen (GAR) setinggi 99.98% dan nilai ini cukup tepat untuk meningkatkan prestasi sistem pengenalan iris.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMNET	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	xv
	LIST OF SYMBOLS	xviii
	LIST OF APPENDICES	xix
1	**INTRODUCTION**	**1**
	1.1 Overview	1
	1.2 Problem Statement	4
	1.3 Research Objectives	5
	1.4 Scope of Research	5
	1.5 Contributions	5
	1.5 Thesis Organization	6
2	**LITERATURE REVIEW**	**7**
	2.1 Eye Anatomy	7
	2.2 Performance of Iris Recognition System	8
	2.3 Background of Iris Recognition System	10

	2.3.1 Early Research in Iris Recognition (1987-2007)	10
	2.3.2 Prototype of Iris Recognition System	14
	2.4 Recent Work in Iris Recognition	16
	2.4.1 Iris Segmentation	17
	2.4.2 Noise Reduction	19
	2.4.2.1 Noise in Iris Recognition	19
	2.4.2.2 Related Work to Noise Recognition	21
	2.4.3 Normalization, Feature Extraction and Feature Encoding	25
	2.4.4 Iris Code Matching	27
	2.4.4.1 Related Work to Iris Code Matching and Hamming Distance	27
	2.4.5 Acquisition, Restoration, Quality Assessment and Image Compression	29
	2.4.6 Database and Evaluation and Performance under Varying Conditions	30
	2.4.7 Multibiometrics	31
	2.4.8 Application and Hardware Implementation	31
	2.5 Fuzzification and Fuzzy Sets	32
	2.6 Summary	35
3	**RESEARCH METHODOLOGY**	**37**
	3.1 Introduction	37
	3.2 Segmentation Stage	40
	3.3 Normalization Stage	40
	3.4 Proposed Adaptive Fuzzy Switching Noise Reduction Method	41
	3.5 Feature Encoding Stage	52
	3.6 Improved Iris Code Matching Using Adaptive Weighted Shifting Hamming Distance	53
	3.6.1 Hamming Distance with Adaptive Length	55
	3.6.2 Weighting Stage	61

		3.6.3 Shifting Stage	65
		3.6.4 Decidability Index	70
	3.7	Brief Descriptions and Statistics of the Iris Image Database	72
	3.8	Summary	74
4	**EXPERIMENTAL RESULTS AND DISCUSSION**		**75**
	4.1	Introduction	75
	4.2	Experimental Setup	75
		4.2.1 CASIA V3.0 Interval Subset	76
		4.2.2 CASIA V3.0 Lamp Subset	77
		4.2.3 CASIA V3.0 Outdoor/Twin Subset	78
		4.2.4 UBIRIS V2 Iris Database	79
	4.3	Experimental Results and Evaluation of Adaptive Fuzzy Switching Noise Reduction Filter	79
		4.3.1 Stage 1: Evaluation on Noise Reduction	80
		4.3.2 Stage 2: Evaluation of Performance of Iris Recognition System	91
	4.4	Experimental and Evaluation on Adaptive Weighted Shifting Hamming Distance	97
		4.4.1 Evaluation on the Performance of the System	98
		4.4.2 Evaluation on Decidability Index of the System	103
	4.5	Conclusion	107
5	**CONCLUTION AND SUGGESTION FOR FUTURE WORKS**		**108**
	5.1	Conclusion	108
	5.2	Suggestions for Future Works	109
REFERENCES			**111**
Appendices A-D			122-127

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Biometrics Technologies	2
2.1	Comparison of reviewed methods related to iris recognition system	13
2.2	Comparison of reviewed method related to noise reduction	24
2.3	Comparison of reviewed method related to iris code matching	29
3.1	Statistics of CASIA-IrisV3	73
4.1	Methods related to reduction of light reflection/eyelid	81
4.2	Methods related to reduction of eyelash	81
4.3	Methods related to reduction of eyelash/eyelid	82
4.4	Comparison of performance of different approaches of noise reduction for eyelid/light reflection	85
4.5	Comparison of performance of different approaches of noise reduction for eyelash texture	85
4.6	Comparison of performance of different approaches of noise reduction for eyelid/eyelash	86
4.7	Comparison of performance of the iris recognition system using different approaches of noise reduction for eyelash/eyelid/light reflection	92
4.8	Comparison of performance of iris recognition system using different approaches of noise reduction for eyelid/light reflection	92
4.9	Comparison of performance of iris recognition system using different approaches of noise reduction for eyelash texture	93
4.10	Comparison of performance of iris recognition system using different approaches of noise reduction for eyelid/eyelash	94
4.11	Different approaches of iris code matching	99
4.12	Comparison of performance of different approaches of iris	100

code matching

4.13 Comparison of the performance of the system using different iris code matching approaches based on the level of decidability 103

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	The eye view, image from CASIA V3.0 Interval database (S1090R01)	8
2.2	Different fields of research in iris recognition	17
2.3	Samples of occluded eye with eyelash texture, S1090R01 (left), S1109L03 (right) from CASIA V3.0 Database	20
2.4	Samples of occluded eye with eyelids, S1175L01 (left), S1087L06 (right) from CASIA V3.0 Database	21
2.5	Samples of occluded eye with specular reflections, S1175L01 (left), S1085L03 (right) from CASIA V3.0 Database	21
2.6	Example of Yes-No Boolean logic set that has a clearly defined boundary. Boolean logic responds with an absolute TALL or NOT TALL response	33
2.7	Example of fuzzy Logic Set, Some people are definitely TALL, some people are TALL to some degree and some people are not very TALL. Fuzzy logic responds with a smooth response.	34
2.8	Membership function of Boolean logic set corresponds to Figure 2.6	34
2.9	Membership function of fuzzy logic set corresponds to Figure 2.7	35
3.1	Flowchart of iris recognition system used in this research	38
3.2	Daugman’s Rubber sheet model for the normalization of the iris region	41
3.3	The overall view of proposed adaptive fuzzy switching noise reduction filter	42
3.4	The classification of the noise and iris patterns in the normalized iris image’s histogram	43
3.5	General flow of multiple thresholding	45

3.6	General flow of expanding filtering window with adaptive size	46
3.7	Fuzzy set adopted by fuzzy switching weighted median filter	49
3.8	Fuzzy set adopted by fuzzy switching weighted median filter	50
3.9	General flow of multiple thresholding	52
3.10	Three steps of Proposed Iris Code Matching	53
3.11	General flow of computing Hamming distance for a Hamming subset with adaptive size	58
3.12	Example of adaptive behavior of proposed method on the left side	60
3.13	Example of adaptive behavior of proposed method on the right	61
3.14	Comparison between WHD and HD	63
3.15	Decision-making based on common HD	66
3.16	Decision-making based on the combination of HD and D	66
3.17	General flow of shifting stage	69
3.18	Iris image (S1090R01) from CASIAV3.0 interval subset	74
4.1	Sample of iris image from CASIA V3.0 interval subset	76
4.2	Sample of iris image from CASIA V3.0 Lamp subset	77
4.3	Sample of the iris images of a twin from CASIA V3.0 twin subset	78
4.4	Sample of iris image from UBIRIS V2 iris database	79
4.5	Evaluation stages with respect to the proposed adaptive fuzzy switching noise reduction method.	80
4.6	Evaluation of performance of AFSNR filter in CASIA V3.0 interval subset and comparison based on size of filtering window	82
4.7	Evaluation of performance of AFSNR filter in CASIA V3.0 Lamp subset and comparison based on size of filtering window	83
4.8	Evaluation of performance of AFSNR filter in CASIA V3.0 Twin subset and comparison based on size of filtering window	83
4.9	Evaluation of Performance of AFSNR filter in UBIRIS V2 database and comparison based on size of filtering window	84
4.10	Results of the reduction of eyelash/pupil and eyelid/light	87

	by applying our proposed AFSNR filter	
4.11	Results of the reduction of eyelash/pupil and eyelid/light by applying our proposed AFSNR filter	88
4.12	Results of the reduction of eyelash/pupil and eyelid/light by applying our proposed AFSNR filter	89
4.13	Results of the reduction of eyelash/pupil and eyelid/light by applying our proposed AFSNR filter	90
4.14	Comparison of receiver operating curves (ROC)	91
4.15	Evaluation stages with respects to the proposed adaptive fuzzy switching noise reduction method	97
4.16	Comparison of receiver operating curves (ROC) of different iris code matching on CASIA V3	101
4.17	Comparison of receiver operating curves (ROC) of different iris code matching on CASIA V3	101
4.18	Comparison of receiver operating curves (ROC) of different iris code matching on UBIRIS V2	102
4.19	Comparison of receiver operating curves (ROC) of different iris code matching on UBIRIS V2	102
4.20	Comparison of distributions of matching results of default system on CASIA V3	105
4.21	Comparison of distributions of matching results of default system on UBIRIS V2	105
4.22	Comparison of distributions of matching results for proposed AWSHD method on CASIA V3	106
4.23	Comparison of distributions of matching results for proposed AWSHD method on UBIRIS V2	106

LIST OF ABBREVIATIONS

1D	-	One Dimension
2D	-	Two Dimension
3D	-	Three Dimension
ACWM	-	Adaptive Canter-Weighted Median Filter
AFSNR	-	Adaptive Fuzzy Switching Noise Reduction
AWSHD	-	Adaptive Weighted Shifting Hamming Distance
bpp	-	Bit per Pixel
CA	-	Cellular Automata
CASIA	-	Chinese Academy of Science Institute of Automation
CCD	-	Charge-Coupled Device
CFFNN	-	Cascaded Feedforward Neural Network
CFS	-	Circular Symmetric Filter
CMOS	-	Complementary Metal-Oxide Semiconductor
CPU	-	Computer Processing Unit
CWT	-	Complex Wavelet Transform
D	-	Difference Distance
d′	-	Decidability Index, Level of Decidability
DBA	-	Decision-Based Algorithm
DCT	-	Discrete Cosine Transforms
DI	-	Decidability Index
DLDA	-	Direct Linear Discriminant Analysis
dZ	-	Zero Crossing Distance
EER	-	Equal Error Rate
EM	-	Expectation Maximization

FA	-	False Acceptance
FAR	-	False Acceptance Rate
FBD	-	Fragile Bit Distance
FFNN	-	Feedforward Neural Network
FIRD	-	fingerprint, Iris, Retina, and DNA Recognition
FIRE	-	Fuzzy Inference Ruled By the Else-Action
FR	-	False Rejection
FRR	-	False Rejection Rate
FPGA	-	Field-Programmable Gate Array
FSM	-	Fuzzy Switching Median
GAR	-	Genuine Acceptance Rate
GHz	-	Giga Hertz
GMM	-	Gaussian Mixture Model
HD	-	Hamming Distance
ICA	-	Independent Component Analysis
ICE	-	Iris Challenge Evaluation Database
IRIS06	-	Iris Recognition Study
ITIRT	-	Independent Testing of Iris Recognition Technology
JPEG2000	-	Joint Photographic Experts Group Standard in 2000
LED	-	Light-emitting Diode
LBP	-	Local Binary Pattern
LVQ	-	Learning Vector Quantization
MF	-	Membership Function
mm	-	Millimeter
MRF	-	Markov Random Field
NAFSM	-	Noise Adaptive Fuzzy Switching Median
NIR	-	Near Infrared
OCS	-	Open-Close Sequence
PC	-	Personal Computer
PCA	-	Principle Component Analysis
POC	-	Phase Only Correlation Function

PUM	-	Posterior Union Model
ROC	-	Receiver Operating Characteristics
SVM	-	Support Vector Machine
TA	-	True Acceptance
TAR	-	True Acceptance Rate
TR	-	True Rejection
UK	-	United Kingdom of Britain
UNHCR	-	United Nations High Commissioner for Refugees
VFC	-	Vector Field Convolution
WED	-	Weighted Euclidean Distance
WHD	-	Weighted Hamming Distance

LIST OF SYMBOLS

Δ	-	Delta
μ	-	Mean value of distribution
σ	-	Standard deviation
θ	-	Angle
π	-	Pi
$\leq$	-	Less than or equal to
$\geq$	-	Greater than or equal to
$^\circ$	-	Degree

APPENDIXES

APPENDIX	TITLE	PAGE
A	List of Publications	122
B	Detailed Experimental Results for Weighting Stage in Proposed AWSHD Method	123
C	Examples to Explain the Effects of Adaptive Weighted Shifting Hamming Distance	124
D	Pseudo-code for Adaptive Behavior of Proposed AWSHD	126

CHAPTER 1

INTRODUCTION

1.1 Overview

Biometric is the combination of two Greek words ‘bio’ and ‘metric’. ‘Bio’ means life and ‘metric’ is measure. Biometrics technologies are methods of authentication that deal with the unique characteristics of human beings. There are several types of biometric technologies: behavioral and physical attributes and those that can only be analyzed in laboratories (Wayman, 2014). Physical biometrics, such as fingerprint (Bharadwaj *et al.*, 2014), face (Jain *et al.*, 2008) , iris (Bowyer *et al.*, 2013), palm/finger vein, retina and hand geometry are the most popular biometrics used for person authentication for either identification or verification, however behavioral biometrics are mostly used for verification (Ross and Jain, 2009)

Table 1.1 shows several biometric technologies, which are grouped in three types. To compare the biometric technologies, several factors in terms of accuracy and uniqueness, cost of the system, ease of use for customers, intrusiveness, robustness of system and ease of deployment should be considered.

Table 1.1: Biometrics Technologies.

Physical Biometric	Behavioral Biometric	Biometrics Technology in Exploratory Stages
Fingerprint	Voice recognition	Ear shape
Face	Gait recognition	Fingernails
Iris	Keystroke	Odor
Palm/finger vein	Signature	
Retina		
Hand geometry		

There is no ideal biometric for all applications. Each biometric has benefits and weaknesses regarding robustness, accuracy, cost of deployment, ease of use, recognition rate, intrusiveness and ease of deployment, which means each biometric is suitable for related application, but not all applications. Biometrics are used in many applications such as in secure access control, international border crossings and in law enforcement. Moreover, biometrics can be integrated into large-scale identity systems (Ross and Jain, 2009). Biometrics have also been used in commercial applications such as in accessing one's computer or mobile phone, grocery stores, Walt Disney World (Harmel, 2006) and airports and government applications, including obtaining a visa for international travelers or to recognize suspected terrorists or criminals in United Arab Emirates, and the US Department of Homeland Security (Jain *et al.*, 2008).

Among all physical biometrics, iris biometric systems are highly secured that work at a low false acceptance rate (FAR). Applications of iris biometrics technology include: identification cards and passports, border control and other government programmes, prison security, database access and computer login, schools, aviation security, hospital security, controlling access to restricted areas, entering buildings and houses (Daugman, 2009b). The United Nations High Commissioner for Refugees (UNHCR) used iris recognition for Afghan refugees (Daugman, 2002). Iris recognition is used in jails for the recognition of prisoners (Hollingsworth, 2010). Airports in the UK (Gomm, 2005), the United State, Canada, the United Arab

Emirates, Singapore, Germany, and the Netherlands all use iris recognition at their borders and immigration control (Al-Raisi and Al-Khouri, 2008; Daugman, 2009b).

Iris biometrics have a number of benefits (Daugman, 2009b) which are briefly mentioned below:

1. Stability over time – which means that the iris pattern does not change over time compared to other biometrics. Glasses, contact lenses, and even eye surgery does not corrupt the appearance and characteristics of the iris patterns (Browning and Orlans, 2014; Daugman and Downing, 2013; Fenker *et al.*, 2013). Voice may change through aging or illness; fingerprint may not work for those individuals with no or few minutiae points. This may be the case for surgeons as they often wash their hands with strong detergents, builders, and people with special skin conditions. In addition, finger ridge patterns can be affected by cuts, dirt, or tears. Finally, the face changes through age, surgery, accidents or make-up (Jain *et al.*, 2008; Ross *et al.*, 2006).
2. Ease of collection – due to the small size of the iris image, a database of the iris images of a large population can be saved on a personal computer or a portable flash memory stick (Tan and Sun, 2015).
3. Uniqueness – There is a large inter-class variability, which means large differences between individuals. Among all biometrics, the iris biometric is the most unique and robust – even the iris patterns of twins are different (Daugman, 2004, 2006, 2007).
4. Large number of features. An iris has more than 200 features, such as rings, furrows, freckles, and the corona. (Daugman, 2004, 2007).
5. Contactless, hygienic and non-invasive (Daugman, 2007, 2009a; He *et al.*, 2008; Jain *et al.*, 2008; Tan and Sun, 2015).
6. High-speed and low error rate, Capable of 1:N (identification) and 1:1 (verification) matching (Daugman, 2006, 2007; Némesin and Derrode, 2014).

1.2 Problem Statement

The consequence of either low-secure or insecure authentication in the banking or corporate environment is both terrible and catastrophic. Such a situation will results in loss of confidential and individual information, money, compromising data, security of systems or the safety of a country (Daugman, 2009b).

Although the iris recognition system has high accuracy with a very low false acceptance rate, the system performance is still vulnerable to noise. In iris recognition, textures such as eyelashes and eyelids, or light reflections in the iris regions are considered as noise (Kong and Zhang, 2003). Very low-intensity value of eyelash pixels or high-intensity value of pixels corresponding to eyelids and light illumination in the iris image can cause inappropriate threshold value, and therefore leads to poor iris region segmentation and feature extraction/encoding stage. This false iris pattern data or unwanted noise will corrupt the generated biometric templates and the iris codes, resulting in poor recognition rates. This unwanted noise will also affect the iris code matching or decision-making which in turn decreases the disagreement distance between the genuine user and impostors. Consequently, the performance in the iris code matching drops and the distribution between the genuine and impostor classes overlaps.

1.3 Research Objectives

The aim of this research is to improve the performance of an iris recognition system based on improving the iris code matching stage and reduction of noise effects such as pupil and eyelashes texture, eyelids and light reflections. In achieving this aim, this research focuses on the following objectives:

1. To reduce the error rate and the effect of noise on the iris recognition system by proposing an adaptive fuzzy switching noise reduction filter (AFSNR).

2. To improve the performance of the iris recognition system by using an improved iris code matching method, using the adaptive weighted shifting Hamming distance metric (AWSHD).

1.4 Scope of Research

Realizing that iris recognition is a huge field by itself, this research will only concentrate on the followings:

1. Noise reduction for eyelash, pupil, eyelid and light illumination.
2. Based on already captured iris image and not on video sequence (offline not online).
3. Improve an existing metric distance for the iris code matching stage.
4. Implementation on gray scale images.
5. Based on *Matlab* mathematical software package.
6. Samples iris are taken from CASIA V3 and UBIRIS V2 databases.

1.5 Contributions

The advantage of the proposed AFSNR filter is the ability to remove two types of noise with different intensity values – eyelash/pupil and light/eyelids – in contrast with other works which are presented to eliminate only one type of noise (Kong and Zhang, 2003; Wang *et al.*, 2012; Zhang *et al.*, 2006). Another advantage of the proposed AFSNR filter is its adaptive window size. The adaptive behavior of the filter performs a better noise reduction for different noise densities compared with a method with a constant window size (Zhang *et al.*, 2006). The proposed AWSHD metric improves the performance of iris code matching in three stages. The proposed AWSHD distance metric has adaptive length of Hamming subset which increases the accuracy of computation. By applying weighting technique the HD corresponding to impostors will be increased while the genuine HD will be decreased. The shifting stage centralizes the distribution of HD. As results of proposed AWSHD distance metric the level of decidability of the system is extremely increased. This research work suggests using the difference distance metric in decision-making.

1.6 Thesis Organization

This thesis presents a research work on improving the performance of the iris recognition algorithm by reducing the effects of noise on iris segmentation and improving the iris code matching performance. Chapter 2 presents a literature review of the iris recognition system and a survey of related works. Chapter 3 describes the methodology and algorithms of the proposed methods in this research, the proposed adaptive fuzzy switching noise reduction filter (AFSNR) and the proposed adaptive weighted shifting Hamming distance (AWSHD), in detail. The proposed AFSNR filter is a combination of the fuzzy switching, adaptive median filter and the filling method. The adaptive size of the filtering window speeds up the system and filters high-density noise. Fuzzy switching behavior enables the filling method to perform noise reduction when the adaptive median filter fails to reduce the noise. AWSHD method computes the Hamming distance with adaptive length of Hamming subset. The weighting and shifting methods is proposed to improve the decidability level of the system. Chapter 4 provides the experimental results of this research and discussion. Finally, chapter 5 concludes the thesis, along with some suggestions for future works.

REFERENCES

Aydi, W., Kamoun, L., and Masmoudi, N. (2013). *A fast and accurate eyelids and eyelashes detection approach for iris segmentation.* World Congress on Computer and Information Technology (WCCIT). 1-6.

Barzegar, N., and Moin, M. S. (2009). A new user dependent iris recognition system based on an area preserving pointwise level set segmentation approach. *EURASIP Journal on Advances in Signal Processing*. 5.

Bazama, A. E., and Hassan, Y. F. (2012). Hybrid System of Cellular Automata, PCA and Support Vector Machine for Noise Reduction and Classification in Human Iris Recognition. *IJIIP: International Journal of Intelligent Information Processing.* 3(4), 47-67.

Bernard, F., Deuter, C. E., Gemmar, P., and Schachinger, H. (2013). Eyelid contour detection and tracking for startle research related eye-blink measurements from high-speed video records. *Computer methods and programs in biomedicine.* 112(1), 22-37.

Bezdek, J. C., and Pal, S. K. (1992). *Fuzzy models for pattern recognition* (Vol. 267): IEEE press New York.

Bharadwaj, S., Vatsa, M., and Singh, R. (2014). Biometric quality: a review of fingerprint, iris, and face. *EURASIP Journal on Image and Video Processing*. (1), 1-28.

Bodade, R. M., and Talbar, S. N. (2009). *Shift invariant iris feature extraction using rotated complex wavelet and complex wavelet for iris recognition system.* Seventh International Conference on Advances in Pattern Recognition (ICAPR'09). 449-452.

Bodade, R. M., and Talbar, S. N. (2014). *Iris Analysis for Biometric Recognition Systems*. Springer.

Boles, W. W., and Boashash, B. (1998). A human identification technique using images of the iris and wavelet transform. *IEEE transactions on signal processing.* 46(4), 1185-1188.

Bowyer, K. W., Hollingsworth, K., and Flynn, P. J. (2008). Image understanding for iris biometrics: A survey. *Computer vision and image understanding.* 110(2), 281-307.

da Costa, R. M., and Gonzaga, A. (2012). Dynamic features for iris recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics.* 42(4), 1072-1082.

Daugman, J. (2003). The importance of being random: statistical principles of iris recognition. *Pattern recognition.* 36(2), 279-291.

Daugman, J. (2004). How iris recognition works. *IEEE Transactions on Circuits and Systems for Video Technology*. 14(1), 21-30.

Daugman, J. (2007). New methods in iris recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*. 37(5), 1167-1175.

Daugman, J., and Downing, C. (2013). No change over time is shown in Rankin et al. Iris recognition failure over time: The effects of texture. *Pattern Recognition.* 46(2), 609-610.

Daugman, J. G. (1993). High confidence visual recognition of persons by a test of statistical independence. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 15(11), 1148-1161.

Daugman, J. G. (1994). Biometric personal identification system based on iris analysis. Google Patents.

Dehkordi, A. B., and Abu-Bakar, S. A. (2013). *Noise reduction in iris recognition using multiple thresholding.* IEEE International Conference on Signal and Image Processing Applications (ICSIPA). 140-144.

Dong, W., Sun, Z., and Tan, T. (2011). Iris matching based on personalized weight map. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 33(9), 1744-1757.

Dozier, G., Bell, D., Barnes, L., and Bryant, K. (2009a). *Refining iris templates via weighted bit consistency.* Proc. Midwest Artificial Intelligence and Cognitive Science Conference (MAICS). 1-5.

Dozier, G., Frederiksen, K., Meeks, R., Savvides, M., Bryant, K., Hopes, D., et al. (2009b). *Minimizing the number of bits needed for iris recognition via bit* *inconsistency and grit.* IEEE Workshop on Computational Intelligence in Biometrics: Theory, Algorithms, and Applications (CIB). 30-37.

Dutta, M. K., Gupta, P., and Pathak, V. K. (2009). Biometric based unique key generation for authentic audio watermarking. *Pattern Recognition and Machine Intelligence*. 458-463.

El-Bakry, H. M. (2001). *Fast iris detection for personal identification using modular neural networks.* IEEE International Symposium on Circuits and Systems, (ISCAS). 581-584.

Flom, L., and Safir, A. (1987). Iris recognition system: Google Patents.

Gan, J.-Y., and Liu, J.-F. (2009). *Fusion and recognition of face and iris feature based on wavelet feature and KFDA.* International Conference on Wavelet Analysis and Pattern Recognition (ICWAPR). 47-50.

Garg, R., Shriram, N., Gupta, V., and Agrawal, V. (2009). *A biometric security based electronic gadget control using hand gestures.* International Conference on Ultra Modern Telecommunications & Workshops (ICUMT'09). 1-8.

Ghodrati, H., Dehghani, M. J., and Danyali, H. (2014). A new accurate noise-removing approach for non-cooperative iris recognition. *Signal, Image and Video Processing.* 8(1), 1-10.

Govindaraju., N. K. R. V. (2008). *Advances in Biometrics Sensors, Algorithms and Systems*. Springer.

Hao, F., Daugman, J., and Zielinski, P. (2008). A fast search algorithm for a large fuzzy database. *IEEE Transactions on Information Forensics and Security.* 3(2), 203-212.

Hassanien, A. E., Abraham, A., and Grosan, C. (2009). Spiking neural network and wavelets for hiding iris data in digital images. *Soft Computing.* 13(4), 401-416.

He, X., Yan, J., Chen, G., and Shi, P. (2008). Contactless autofeedback iris capture design. *IEEE Transactions on Instrumentation and Measurement.* 57(7), 1369-1375.

Hollingsworth, K. P., Bowyer, K. W., and Flynn, P. J. (2009). The best bits in an iris code. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 31(6), 964-973.

Hollingsworth, K. P., Bowyer, K. W., and Flynn, P. J. (2011). Improved iris recognition through fusion of hamming distance and fragile bit distance.

IEEE Transactions on Pattern Analysis and Machine Intelligence. 33(12), 2465-2476.

How the Afghan Girl was Identified by Her Iris Patterns. (2015). 2015. http://www.cl.cam.ac.uk/~jgd1000/afghan.html

Huang, J., Wang, Y., Cui, J., and Tan, T. (2004). *Noise removal and impainting model for iris image.* International Conference on Image Processing (ICIP'04). 869-872.

Ibrahim, H., Kong, N. S. P., and Ng, T. F. (2008). Simple adaptive median filter for the removal of impulse noise from highly corrupted images. *IEEE Transactions on Consumer Electronics.* 54(4), 1920-1927.

Jain, A. K., Flynn, P. J., and Ross, A. A. (2008). *Handbook of biometrics*. London: Springer.

Jain, A. K., Ross, A. A., and Nandakumar, K. (2011). *Introduction to biometrics*. London: Springer.

Johnston, R. (1992). *Can iris patterns be used to identify people?* : Los Alamos National Laboratory. Chemical and Laser Sciences Divisiono.

Joshi, N., Shah, C., and Kaul, K. (2012). *A novel approach implementation of eyelid detection in biometric applications.* Nirma University International Conference on Engineering (NUiCONE). 1-6.

Kalka, N. D., Zuo, J., Schmid, N. A., and Cukic, B. (2010). Estimating and fusing quality factors for iris biometric images. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans.* 40(3), 509-524.

Kang, B. J., and Park, K. R. (2007). Real-time image restoration for iris recognition systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics.* 37(6), 1555-1566.

Karakaya, M., Barstow, D., Santos-Villalobos, H., and Boehnen, C. (2013). *An iris segmentation algorithm based on edge orientation for off-angle iris recognition.* IS&T/SPIE Electronic Imaging. 866108-866113.

Karn, P., He, X. H., Yang, S., and Wu, X. H. (2014). Iris recognition based on robust principal component analysis. *Journal of Electronic Imaging.* 23(6), 063002-063002.

Kim, T.-H., and Youn, J.-I. (2013). Development of a Smartphone-based Pupillometer. *Journal of the Optical Society of Korea.* 17(3), 249-254.

Kim, Y. G., Shin, K. Y., Lee, E. C., and Park, K. R. (2012). Multimodal biometric system based on the recognition of face and both irises. *Int J Adv Robotic Sy*. 9(65).

Kong, W.-K., and Zhang, D. (2003). Detecting eyelash and reflection for accurate iris segmentation. *International Journal of Pattern Recognition and Artificial Intelligence.* 17(06), 1025-1034.

Leonard, D., Pons, A. P., and Asfour, S. S. (2009). Realization of a universal patient identifier for electronic medical records through biometric technology. *IEEE Transactions on Information Technology in Biomedicine.* 13(4), 494-500.

Li, H., Sun, Z., and Tan, T. (2012). *Robust iris segmentation based on learned boundary detectors.* 5th IAPR International Conference on Biometrics (ICB). 317-322.

Li, Y.-h., and Savvides, M. (2009). Fast and robust probabilistic inference of iris mask. *Proceedings of SPIE.* 7306, 730621.

Li, Y.-h., and Savvides, M. (2013). An automatic iris occlusion estimation method based on high-dimensional density estimation. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 35(4), 784-796.

Liam, L. W., Chekima, A., Fan, L. C., and Dargham, J. A. (2002). *Iris recognition using self-organizing neural network.* Student Conference on Research and Development (SCOReD). 169-172.

Lim, S., Lee, K., Byeon, O., and Kim, T. (2001). Efficient iris recognition through improvement of feature vector and classifier. *ETRI journal. 23*(2), 61-70.

Lin, J., Li, J.-P., Lin, H., and Ming, J. (2009). *Robust person identification with face and iris by modified PUM method.* International Conference on Apperceiving Computing and Intelligence Analysis (ICACIA). 321-324.

Lin, M., Ying, H., Haifeng, L., Naimin, L., and Zhang, D. (2014). *A CGA-MRF Hybrid Method for Iris Texture Analysis and Modeling.* International Conference on Medical Biometrics (ICMB). 1-6.

Liu-Jimenez, J., Sanchez-Reillo, R., and Fernandez-Saavedra, B. (2011). Iris biometrics for embedded systems. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*. 19(2), 274-282.

Liu, C., and Xie, M. (2006). *Iris recognition based on DLDA.* 18th International Conference on Pattern Recognition (ICPR). 489-492.

Liu, J., Sun, Z., and Tan, T. (2013). *Recognition of motion blurred iris images.* IEEE Sixth International Conference on Biometrics: Theory, Applications and Systems (BTAS). 1-7.

Luo, W. (2006). Efficient removal of impulse noise from digital images. *IEEE Transactions on Consumer Electronics*. 52(2), 523-527.

Ma, L., Tan, T., Wang, Y., and Zhang, D. (2003). Personal identification based on iris texture analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 25(12), 1519-1533.

Ma, L., Tan, T., Wang, Y., and Zhang, D. (2004). Efficient iris recognition by characterizing key local variations. *IEEE Transactions on Image Processing*. 13(6), 739-750.

Ma, L., Wang, Y., and Tan, T. (2002). *Iris recognition using circular symmetric filters.* Proceedings. 16th International Conference on Pattern Recognition. 414-417.

Masek, L. (2003a). *Recognition of Human Iris patterns for Biometric Identification.* University of Western Australia.

Masek, L. (2003b). *Recognition of human iris patterns for biometric identification.* Master's thesis, University of Western Australia.

McCloskey, S., Au, W., and Jelinek, J. (2010). *Iris capture from moving subjects using a fluttering shutter.* Fourth IEEE International Conference on Biometrics: Theory Applications and Systems (BTAS). 1-6.

Min, T.-H., and Park, R.-H. (2009). Eyelid and eyelash detection method in the normalized iris image using the parabolic Hough model and Otsu's thresholding method. *Pattern recognition letters.* 30(12), 1138-1143.

Miyazawa, K., Ito, K., Aoki, T., Kobayashi, K., and Nakajima, H. (2008). An effective approach for iris recognition using phase-based image matching. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 30(10), 1741-1756.

Moghadam, F. M., Ahmadi, A., and Keynia, F. (2013). A New Iris Detection Method based on Cascaded Neural Network. *Journal of Computer Sciences and Applications*. 1(5), 80-84.

Monro, D. M., Rakshit, S., and Zhang, D. (2007). DCT-based iris recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. *29*(4), 586-595.

Monro, D. M., and Zhang, D. (2005). *An effective human iris code with low complexity.* IEEE International Conference on Image Processing (ICIP). III-277-280.

Munemoto, T., Li, Y.-h., and Savvides, M. (2008). *" Hallucinating Irises"-Dealing with Partial & Occluded Iris Regions.* 2nd IEEE International Conference on Biometrics: Theory, Applications and Systems (BTAS). 1-6.

Newton, E. M., and Phillips, P. J. (2009). Meta-analysis of third-party evaluations of iris recognition. *IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans.* 39(1), 4-11.

Nigam, A., Anvesh, T., and Gupta, P. (2013). Iris classification based on its quality. *Intelligent Computing Theories*. 443-452.

Omelina, L., Jansen, B., Oravec, M., and Cornelis, J. (2013). Feature Extraction for Iris Recognition Based on Optimized Convolution Kernels. *Image Analysis and Processing–ICIAP*. 141-150.

Othman, N., Houmani, N., and Dorizzi, B. (2015). Quality-Based Super Resolution for Degraded Iris Recognition. *Pattern Recognition Applications and Methods*. 285-300.

Park, C.-H., and Lee, J.-J. (2005). Extracting and combining multimodal directional iris features. *Advances in Biometrics*. 389-396.

Pillai, J. K., Puertas, M., and Chellappa, R. (2014). Cross-sensor iris recognition through kernel learning. *IEEE Transactions on Pattern Analysis and Machine Intelligence.* 36(1), 73-85.

Pundlik, S. J., Woodard, D. L., and Birchfield, S. T. (2008). *Non-ideal iris segmentation using graph cuts.* IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). 1-6.

Radman, A., Zainal, N., and Ismail, M. (2013). Efficient Iris Segmentation based on eyelid detection. *Journal of Engineering Science and Technology*. 8(4), 399-405.

Rakshit, S., and Monro, D. M. (2007a). An evaluation of image sampling and compression for human iris recognition. *IEEE Transactions on Information Forensics and Security*. 2(3), 605-612.

Rakshit, S., and Monro, D. M. (2007b). *Medical conditions: Effect on iris recognition.* Proc. IEEE 9th Workshop on Multimedia Signal Processing. 357-360.

Rathgeb, C., Uhl, A., and Wild, P. (2013). Image Compression Impact on Iris Recognition. *Iris Biometrics*. 97-140.

Ring, S., and Bowyer, K. W. (2008). *Detection of iris texture distortions by analyzing iris code matching results.* 2nd IEEE International Conference on Biometrics: Theory, Applications and Systems, (BTAS). 1-6.

Ross, A., and Jain, A. K. (2009). Biometrics overview. Encyclopedia of Biometrics. 168-172.

Ross, A. A., Nandakumar, K., and Jain, A. K. (2006). *Handbook of multibiometrics* .6. London: Springer.

Russo, F., and Ramponi, G. (1996). A fuzzy filter for images corrupted by impulse noise. *IEEE Signal Processing Letters*. 3(6), 168-170.

Ryan, W. J., Woodard, D. L., Duchowski, A. T., and Birchfield, S. T. (2008). *Adapting starburst for elliptical iris segmentation.* 2nd IEEE International Conference on Biometrics: Theory, Applications and Systems (BTAS). 1-7.

Sanchez-Avila, C., and Sanchez-Reillo, R. (2005). Two different approaches for iris recognition using Gabor filters and multiscale zero-crossing representation. *Pattern Recognition.* 38(2), 231-240.

Sanchez-Avila, C., Sanchez-Reillo, R., and de Martin-Roche, D. (2002). Iris-based biometric recognition using dyadic wavelet transform. *IEEE Aerospace and Electronic Systems Magazine.* 17(10), 3-6.

Schuckers, S. A., Schmid, N. A., Abhyankar, A., Dorairaj, V., Boyce, C. K., and Hornak, L. A. (2007). On techniques for angle compensation in nonideal iris recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics.* 37(5), 1176-1190.

Shukri, M., Asmuni, H., Othman, R. M., and Hassan, R. (2013). An improved multiscale retinex algorithm for motion-blurred iris images to minimize the intra-individual variations. *Pattern Recognition Letters.* 34(9), 1071-1077.

Si, Y., Mei, J., and Gao, H. (2012). Novel approaches to improve robustness, accuracy and rapidity of iris recognition systems. *IEEE Transactions on Industrial Informatics.* 8(1), 110-117.

Sun, Z., Tan, T., and Qiu, X. (2005). Graph matching iris image blocks with local binary pattern. *Advances in Biometrics*. 366-372.

Sun, Z., Zhang, H., Tan, T., and Wang, J. (2014). Iris image classification based on hierarchical visual codebook. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 36(6), 1120-1133.

Tan, C.-W., and Kumar, A. (2012). Unified framework for automated iris segmentation using distantly acquired face images. *IEEE Transactions on Image Processing*. 21(9), 4068-4079.

Tan, T., He, Z., and Sun, Z. (2010). Efficient and robust segmentation of noisy iris images for non-cooperative iris recognition. *Image and Vision Computing*. 28(2), 223-230.

Tan, T., and Sun, Z. (2015). CASIA V.3 iris image database version three. 2015. http://www.cbsr.ia.ac.cn.

Tang, R., and Weng, S. (2011). *Improving iris segmentation performance via borders recognition.* International Conference on Intelligent Computation Technology and Automation (ICICTA). 580-583.

Thainimit, S., Alexandre, L. A., and de Almeida, V. (2013). *Iris surface deformation and normalization.* 13th International Symposium on Communications and Information Technologies (ISCIT). 501-506.

Toh, K. K. V., Ibrahim, H., and Mahyuddin, M. N. (2008). Salt-and-pepper noise detection and reduction using fuzzy switching median filter. *IEEE Transactions on Consumer Electronics.* 54(4), 1956-1961.

Toh, K. K. V., and Isa, N. A. M. (2010). Noise adaptive fuzzy switching median filter for salt-and-pepper noise reduction. *IEEE Signal Processing Letters.* 17(3), 281-284.

Uhl, A., and Wild, P. (2012). *Weighted adaptive hough and ellipsopolar transforms for real-time iris segmentation.* 5th IAPR International Conference on Biometrics (ICB). 283-290.

Vandal, N. A., and Savvides, M. (2010). *CUDA accelerated iris template matching on graphics processing units (GPUs).* Fourth IEEE International Conference on Biometrics: Theory Applications and Systems (BTAS). 1-7.

Vatsa, M., Singh, R., and Noore, A. (2006). Reducing the False Rejection Rate of Iris Recognition Using Textural and Topological Features. *International Journal of Signal Processing.* 2(2).

Wang, D., Li, J., and Memik, G. (2009a). *Authentication scheme of DRM system for remote users based on multimodal biometrics, watermarking and smart cards.* WRI Global Congress on Intelligent Systems (GCIS'09). 530-534.

Wang, T., Han, M., Wan, H., and Yin, Y. (2012). A robust and fast eyelash detection basted on expectation maximization and Gaussian mixture model. *Informatics in Control, Automation and Robotics*. 93-97.

Wang, X., Zhao, L., and Kong, Q. (2009b). *Iris recognition system design and development of large animals for tracing source of infection.* International Joint Conference on Computational Sciences and Optimization (CSO). 610-613.

Wang, Z., Li, Q., Niu, X., and Busch, C. (2009c). *Multimodal biometric recognition based on complex KFDA.* Fifth International Conference on Information Assurance and Security (IAS'09). 177-180.

Wayman, J. (2014). Book review: Handbook of Iris Recognition. *IET Biometrics.* 3(1), 41-43.

Wildes, R. P. (1997). Iris recognition: an emerging biometric technology. *Proceedings of the IEEE.* 85(9), 1348-1363.

Wildes, R. P., Asmuth, J. C., Green, G. L., Hsu, S. C., Kolczynski, R. J., Matey, J. R., et al. (1994). *A system for automated iris recognition.* Proceedings of the Second IEEE Workshop on Applications of Computer Vision. 121-128.

Wildes, R. P., Asmuth, J. C., Green, G. L., Hsu, S. C., Kolczynski, R. J., Matey, J. R., et al. (1996). A machine-vision system for iris recognition. *Machine vision and Applications.* 9(1), 1-8.

Wolff, E. (1976). Anatomy of the Eye and Orbit, HK Lewis & Co: Ltd.

Xiao, L., Sun, Z., He, R., and Tan, T. (2013). *Coupled feature selection for cross-sensor iris recognition.* IEEE Sixth International Conference on Biometrics: Theory, Applications and Systems (BTAS). 1-6.

Yadav, D., Kohli, N., Doyle, J., Singh, R., Vatsa, M., and Bowyer, K. W. (2014). Unraveling the Effect of Textured Contact Lenses on Iris Recognition.

Zadeh, L. A. (1965). Fuzzy sets. *Information and control.* 8(3), 338-353.

Zhang, C., Hou, G., Sun, Z., Tan, T., and Zhou, Z. (2013a). Light field photography for iris image acquisition. *Biometric Recognition*. 345-352.

Zhang, D., Monro, D. M., and Rakshit, S. (2006). *Eyelash removal method for human iris recognition*. IEEE International Conference on Image Processing. 285-288.

Zhang, M., Sun, Z., and Tan, T. (2011). *Deformable daisy matcher for robust iris recognition.* 18th IEEE International Conference on Image Processing (ICIP). 3189-3192.

Zhang, M., Sun, Z., and Tan, T. (2012). Perturbation-enhanced feature correlation filter for robust iris recognition. *IET Biometrics.* 1(1), 37-45.

Zhang, M., Sun, Z., and Tan, T. (2013b). *Deformed iris recognition using bandpass geometric features and lowpass ordinal features.* International Conference on Biometrics (ICB). 1-6.

Zhang, P.-F., Li, D.-S., and Wang, Q. (2004). *A novel iris recognition method based on feature fusion.* Proceedings of International Conference on Machine Learning and Cybernetics. 3661-3665.

Zhou, L., Ma, Y., Lian, J., and Wang, Z. (2013). *A new effective algorithm for iris location.* IEEE International Conference on Robotics and Biomimetics (ROBIO). 1790-1795.

Zhu, Y., Tan, T., and Wang, Y. (2000). *Biometric personal identification based on iris patterns.* International Conference on Pattern Recognition. 2801-2801.