AN IMPROVED HOUGH TRANSFORM ALGORITHM IN IRIS RECOGNITION SYSTEM

SAEED KHORASHDI ZADEH

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Computer Science (Information Security)

Faculty of Computer Science and Information Systems
Universiti Teknologi Malaysia

AUGUST 2012

AN IMPROVED HOUGH TRANSFORM ALGORITHM IN IRIS RECOGNITION SYSTEM

SAEED KHORASHDI ZADEH

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Computer Science (Information Security)

Faculty of Computer Science and Information Systems
Universiti Teknologi Malaysia

AUGUST 2012

This dissertation is dedicated to my family for their endless support and encouragement.

ACKNOWLEDGEMENT

Special thanks go to my supervisor, Dr. Aboamama Atahar Ahmed, for his help during the course of this research. Without his time and patience much of this work could not have been accomplished.

Besides, I would like to thank Dr. Anazida about her back-to-back support all the way till the very end of this project.

Dr. Bakhtiari and Dr. Kamalrulnizam whom with their help and thoughtful advices have enriched this project significantly.

Thank to my dear classmate, Fatiha for helping out to translate the abstract to Bahasa language.

Last but not least, thank to my dear friends Masi, David, Azin and Iman to support me during hardship moments of doing my research.

ABSTRACT

The security is an important aspect in our daily life whichever the system is considered, security plays vital role. The biometric person identification technique based on the pattern of human iris is suitable to be applied to access control and provides strong e-security. Iris recognition is one of important biometric recognition approaches in human identification is very active topic in research and practical application. Iris Recognition System consists of Acquisition, Localization, Feature Extraction and Feature Matching phases. Localization stage includes Normalization and Segmentation phase. Circular Hough Transform is one the best suitable algorithm in segmentation phase, but as a result of having two for-loops in its structure; CHT algorithm consumes high time processing and uses high storage capacity. These drawbacks make it hardly appropriate for real time applications of iris recognition system. To improve time and storage complexity, firstly, a pre-processing of CUHK iris image dataset is done to eliminate unnecessarily regions and secondly, a radius-table is created based on pupil size variation of CUHK iris image dataset. The results show at least 40% efficiency in time complexity and minimum 20% efficiency in storage complexity.

ABSTRAK

Aspek keselamatan merupakan salah satu aspek penting yang perlu dititik beratkan di dalam kehidupan seharian, termasuklah di dalam mengaplikasikan aspek keselamatan di dalam penggunaan sistem. Teknik pengesanan biometrik berdasarkan corak iris mata manusia merupakan salah satu teknik yang boleh digunakan sebagai untuk mengakses kawalan keselamatan sesuatu sistem, Dewasa ini, teknik pengesanan biometrik berdasarkan corak iris mata manusia merupakan salah satu topik yang hangat di dalam bidang penyelidikan. Selain itu, teknik ini juga giat diperluaskan penggunaannya sebagai untuk mengakses kawalan keselamatan di dalam sistem. Sistem Pengesanan Iris terdiri daripada empat fasa, iaitu Perolehan, Penyetempatan, Pengekstrakan Ciri, Penyepadanan Ciri, manakala di dalam fasa Penyetempatan terbahagi kepada dua fasa iaitu Normalisasi dan juga Segmentasi. *Circular Hough Transform* (CHT) merupakan algoritma yang digunakan di dalam fasa Segmentasi. Tetapi penggunaan algoritma CHT ini akan menyebabkan masa pemprosesan yang di ambil adalah terlalu lama dan juga menggunakan kapasiti simpanan yang tinggi. Dua kelemahan ini menyebabkan algoritma ini tidak sesuai untuk diaplikasikan kepada sistem yang menggunakan *real time application* seperti Sistem Pengesanan Iris ini. Beberapa langkah telah diambil untuk menangani masalah ini. Pertama,, pra-pemprosesan dataset untuk imej iris CUHK telah dilakukan untuk membuang mana mana kawasan yang tidak diperlukan. Kedua, *radius-table* telah dibuat berdasarkan variasi saiz anak mata dari dataset untuk imej iris CUHK. Berdasarkan keputusan ujikaji, ianya menunjukkan peningkatan sebanyak 40% lebih efisien dari segi kecekapan masa dan 20% lebih efisien untuk ruang penyimpanan untuk data.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF APPENDIX	xv
1	**INTRODUCTION**	
	1.1 Overview	1
	1.2 Problem Background	3
	1.3 Problem Statement	4
	1.4 Aim of the Project	5
	1.5 Project Objective	5
	1.6 Project Scope	5
	1.7 Significant of the Project	6
	1.8 Project Organization	7
2	**LITERATURE REVIEW**	
	2.1 Introduction	8
	2.2 Chapter Structure	8
	2.4 Biometric Context	9

2.4 Iris as a Biometric 11
2.4.1 Advantages 12
2.4.2 Disadvantages 12
2.5 Iris Recognition System Error 13
2.5.1 False Match Rate and False-Non-Match Rate 14
2.5.2 Equal Error Rate 16
2.6 Iris Recognition System 17
2.6.1 Challenges in Iris Recognition 18
2.7 Iris Recognition Algorithm 20
2.7.1 Filter-Based Methods 21
2.7.2 Feature-Based Methods 23
2.8 Iris Recognition Phases 25
2.8.2 Acquisition 25
2.8.2 Segmentation 25
2.8.2.1 Pupil and Iris Localization 26
2.8.2.2 Hough Transform 27
2.8.2.3 Discrete Circular Active Contour Model 28
2.8.2.4 Noise and Artifacts in Iris Images 29
2.8.3 Feature Extraction 31
2.8.3.1 2D Gabor Feature 31
2.8.3.2 Log-Gabor Filter 33
2.8.3.3 2D Hilbert Transform 34
2.8.4 Feature Matching 35
2.8.4.1 Hamming Distance 35
2.8.4.2 Normalized Correlation 36
2.8.4.3 Weighted Euclidean Distance 37
2.9 Circular Hough Transform 37
2.9.1 Accumulator 39
2.9.2 Algorithm 41
2.9.3 Implementation 42
2.9.4 How to Store Data 42
2.9.5 How to Draw Circle in Discrete Space 42
2.9.6 How to Find Circle From the Hough

		Transform Data	43
	2.9.7	Hough Transform Enhancements	44
2.10	Iris Dataset		44
2.11	Edge Detection Techniques		45
	2.11.1	Canny Edge Detection	46
	2.11.2	Sobel Edge Detection	47
	2.11.3	Laplacian of Gaussian Edge Detection	48
	2.11.4	Zero-Cross Edge Detection	49
2.12	Summary		50
3	**RESEARCH METHODOLOGY**		
3.1	Introduction		51
3.2	Phase I: Analysis Current Algorithms in Iris Recognition System		53
	3.2.1	Study Segmentation Algorithms	54
	3.2.2	Study Normalization Algorithms	55
	3.2.3	Study Feature Extraction Algorithms	57
	3.2.4	Study Feature Matching Algorithms	58
	3.2.5	Circular Hough Transform Structural Analysis	58
3.3	Phase II: The Introduction of Pre-processing Iris Image dataset		60
3.4	Phase III: Implementation and Evaluation		61
3.5	CUHK Iris Image Dataset		63
3.6	Performance Measurement		63
3.7	Summary		64
4	**CIRCULAR HOUGH TRANSFORM IMPLEMENTATION**		
4.1	Introduction		65
4.2	Circular Hough Transform Structure		65
4.3	Create Radius-Table to Reduce Loop-II Iteration		66
4.4	Pre-processing Iris Image Dataset		68
4.5	Preparing For Getting Results		70

	4.5.1	Combining All Codes in One Application	71
4.6	Summary		72
5	**RESULTS AND DISCCUSSION**		
5.1	Introduction		73
5.2	Time and Storage Complexity		73
	5.2.1	Time Complexity	74
	5.2.2	Storage Complexity	77
5.3	The Analysis of Edge Detection Techniques		78
	5.3.1	Canny vs. Sobel	81
5.4	Summary		83
6	**CONCLUSION AND RECOMMENDATION**		
6.1	Introduction		85
6.2	The Objective 1: To Study Techniques and Structures of Iris Recognition System		85
6.3	The Objective 2: Pre-processing Iris Image Dataset to Improve Quality of the Input Iris Image		87
6.4	The Objective 3: Develop an Improved CHT Algorithm By Reducing Iteration in Its For-loops Structure in Matlab		87
6.5	Contribution		88
6.6	Future Work		89
6.7	Summary		91
REFERENCES			92
APPENDIX A			98
APPENDIX B			110

LIST OF TABLE

TABLE NO.	TITLE	PAGE
2.1	Iris segmentation, encoding and matching techniques proposed in the literature	24
2.2	Examples of iris noise images	30
4.1	Address time and storage complexity of CHT algorithm	70
5.1	The time complexity comparison of standard CHT and improved CHT aglorithm	75

LIST OF FIGURE

FIGURE NO.	TITLE	PAGE
2.1	Iris segmentation, encoding and matching techniques proposed in the literature	10
2.2	Eye Structure	12
2.3	Biometric System Error Rate	14
2.4	Receiver operating characteristic curve	16
2.5	Block diagram of a typical iris recognition system (Daugman, 2004)	18
2.6	Iris image showing severe specular reflections (Montgomery, 2007)	29
2.7	Phase quantization (Masek, 2003)	33
2.8	The parameter space used for CHT (Rhody, 2005)	39
2.9	A Circular Hough Transform from the *x, y* space (left) to the parameter space (right), for a constant radius (Besag, 1989)	40
2.10	An example of how the accumulator of the CHT looks like in the real world data. (Rhody, 2005)	41
2.11	Circular Hough Transform algorithm	41
2.12	Surface plot of the a, b-plane with radius=20	43
2.13	Kernels are used for convolution	48
2.14	Laplaciane kernel	49
3.1	Research Framework	52
3.2	Iris Recognition System	53
3.3	Structural weaknesses in CHT algorithm along with diverse edge detection methods and iris datasets	59
3.4	Example of unnecessarily regions in some CUHK iris image dataset	61

3.5	Phase III, Implementation and Evaluation	62
4.1	Circular Hough Transform pseudo code	66
4.2	The diverse size of pupil in different iris images	67
4.3	Applying Radius-Table to reduce iteration of Loop-II in CHT algorithm	67
4.4	Iris image '*iris5.bmp*' (CUHK Database)	68
4.5	Pre-processing iris image	69
4.6	CHT pseudo-code after improvement	69
4.7	Graphic User Interface Application	71
5.1	The ratio of Classic CHT to the proposed CHT	75
5.2	Information about iris image number 10.	76
5.3	Time percentage efficiency per iris image.	76
5.4	The size differentiates between the normal iris images to new ones.	77
5.5	How size differentiates can effect on efficiency ratio of CHT algorithm.	78
5.6	Time efficiency comparison between different edge detection techniques	79
5.7	The output of implementing different edge detection methods over the iris image number ten	80
5.8	Compare time processing between edge detection methods in standard CHT algorithm with after implementing the proposed techniques in CHT algorithm	81
5.9	Edge points are found by Canny in left and Sobel in right side form iris image 'iris13.bmp' (CUHK dataset, 2003).	82
5.10	Canny vs. Sobel time complexity by implementing standard CHT algorithm.	82
5.11	Iris image forty-seven (CUHK iris database, 2003) after applying Canny and Sobel.	83
6.1	Illustrates the potential capacity of improvement in the proposed technique.	90
6.2	Miss some edge points as a result of chosen inadequate threshold in Sobel.	90
6.3	Detect lots of edge points as a result of chosen inadequate threshold in Zero-Cross.	91

LIST OF APPENDIX

NO.	TITLE	PAGE
1	Program Source Code	92
2	Application Screenshots	104

CHAPTER 1

INTRODUCTION

1.1. Overview

Biometric technology deals with recognizing the identity of individuals based on their unique physical or behavioral characteristics (Wildes, 1997) Physical characteristics such as fingerprint, palm print, hand geometry and iris patterns or behavioral characteristics such as typing pattern and hand-written signature present unique information about a person and can be used in authentication applications.

The developments in science and technology have made it possible to use biometrics in applications where it is required to establish or confirm the identity of individuals. Applications such as passenger control in airports, access control in restricted areas, border control, database access and financial services are some of the examples where the biometric technology has been applied for more reliable identification and verification.

Iris patterns are formed by combined layers of pigmented epithelial cells, muscles for controlling the pupil, stromal layer consisting of connective tissue, blood vessels and an anterior border layer (Adler, 1965). The physiological complexity of the organ results in the random patterns in iris, which are statistically unique and suitable for biometric measurements (Daugman, 1993). In addition, iris patterns are stable over time and only minor changes happen to them throughout an individual's

life (Flom and Safir, 1987). It is also an internal organ, located behind the cornea and aqueous humor, and well protected from the external environment. The characteristics such as being protected from the environment and having more reliable stability over time, compared to other popular biometrics, have well justified the ongoing research and investments on iris recognition by various researchers and industries around the world. For instance, the developed algorithm by Daugman (1993), which is known as the state-of-the-art in the field of iris recognition, has initiated huge investments on the technology for more than a decade. IriScan Inc. patents the core technology of the Daugman's system and several companies such as IBM, Iridian Technologies, IrisGuard Inc., Securimetrics Inc. and Panasonic are active in providing iris recognition products and services.

The information extracted from an iris is in binary format and it is stored in only 256 bytes to allow creation of nationwide IrisCode databases. The search engine is based on Boolean exclusive-OR operator (XOR) to allow extremely fast comparisons in the matching process. Moreover, the degrees-of-freedom of an IrisCode template, which indicates the statistical complexity of an iris based on the entropy theory of Shannon (2001), is about 249. The number of degrees-of-freedom of the iris templates shows that the complexity of iris patterns is relatively high compared to other biometric measures. The overall characteristics of the proposed algorithm offers real-time and high confidence identification in applications such as passenger control in airports, border control and access control in high-security areas.

The future of biometric technology is believed to be open for more investments based on the new services it has to offer to the society and the new technologies based on face recognition, hand geometry and iris recognition are expected to relatively expand this revenue in near future.

1.2. Problem Background

Iris recognition systems are the most reliable biometric system since iris patterns are unique to each individual and do not change with time. A variety of methods were developed to handle eye data in biometric systems after J. Daugman developed the first commercial system. Eye images used in iris recognition systems require images to be taken under rigid constraints. To obtain a good quality image, subjects cooperation is required like the subject must look straight into camera, still and there should be proper illumination.

These causes inconvenience to the user and are also time consuming. Moreover in cases like criminal investigations images can be taken at any moment of time and thus require unconstrained conditions. In some other cases it is possible that pictures are shot without the knowledge of subject. So images taken under such situations are often “non cooperative” in nature. Conventional techniques require subjects’ cooperation for the accuracy of results. Any unwanted data present in iris images may give false results leading to the rejection of images. Serious noise effects are present in iris images taken under unconstrained condition.

A very well known existing technique, the Circular Hough Transform (CHT) has been implemented for detection of iris and pupil boundaries (Gonzalez and Woods, 2007). Traditional segmentation techniques do not give accurate results with images containing noise. But, the fundamental structure of CHT algorithm is the reason of consuming high processing time and also utilizing high capacity of storage. These drawbacks of CHT algorithm make it hard to employing CHT algorithm for a practical usage that Iris Recognition System needs to apply for millions of users.

Table 1.1 depicts some latest researches of CHT algorithm. Despite of many enhancements that have been offered to enhance Circular Hough Transform, high time and storage complexity still are the main reason of not using the algorithm in vast area.

Table 1.1: Example of latest CHT proposed techniques in different aspects.

Author	Measurment	Solution
Bendel *et al.* (2012)	Time complexity	Use gradiant information
Alioua *et al.* (2011)	Iris detection accuracy	Use eye's morphology
Koh *et al.* (2010)	Iris detection accuracy	Use active contour model
Wang *et al.* (2010)	Time complexity	Use geometrical feature and grayfeatuer of iris

1.3. Problem Statement

Among the four stages in Iris recognition system that are: Acquisition, Segmentation, Feature extraction and Feature comparison, Iris segmentation is one of the most significant steps in iris recognition system. Most of the existing iris segmentation algorithms rely on parametric models of the circle and ellipse to localize the iris. However, when the iris is severely occluded due to the eyelids and the eyelashes, the boundary of the iris may not conform to the circular or elliptical shape. Additionally, iris segmentation is the most contested issue in the iris recognition system, since poor results of this stage will mar or break the iris recognition system effectiveness. Therefore, very careful attention has to be paid in the segmentation process if only an accurate result is expected; this depends on the accuracy of the detected pupil center.

Hough Transform algorithm can be used for detection of any parametric shape (lines, circles, planes, etc.) and have found applications in many areas such as human iris recognition or fingerprint matching. Hough Transform is one the best method in segmentation state to find valid regions, unfortunately, the existing

structure consists of two for-loops that make CHT algorithm not suitable for using in real time applications of Iris Recognition System.

Improving Hough Transform algorithm in term of time complexity and storage complexity makes it much more practical in respect of using in segmentation phase of iris recognition system and as a result the enhancement helps to have more productive iris biometric applications in real world.

1.4. Aim of the Project

To improve performance of Hough Transform algorithm in terms of time complexity and storage utilization.

1.5. Project Objective

In order to achieve the aim of the project, the following objectives must be followed:

i. To study techniques and structures of iris recognition system;
ii. Pre-processing iris image dataset to improve quality of the input iris image.
iii. Develop an improved CHT algorithm by reducing iteration in its for-loops structure in Matlab.

1.6. Project Scope

The research scope is geared towards the limits of the research such as:

i. Circular Hough Transform (CHT) as an algorithm that has been used in segmentation phase of iris recognition system is studied in detail;
ii. Matlab programming is used to get analysis and do comparison;
iii. MacBook pro OSX 10.8 with 2.4 GHz i5 processor and 4 GB DDR3 memory is used for doing the analysis;
iv. The evaluation is measured based on time complexity and storage utilization of Hough Transform algorithm;
v. CUHK iris image dataset is used for experiment. The findings and conclusion made in this study is based on experiments done on this dataset.
vi. A prototype of the proposed CHT has been developed in Matlab.

1.7. Significant of the Project

Considering the algorithm of Circular Hough Transform, the execution speed of this algorithm is highly dependent on the number of edge pixels in the input image. Moreover, decrease in the number of edge pixels generally can effect on reducing storage utilization by the algorithm. The gain in efficiency does not affect the robustness of the technique. Efficiency in terms of time and storage complexity in Circular Hough Transform algorithm can make it a powerful and proper scheme at using in segmentation phase of iris recognition system.

1.8. Project Organization

This research covers six chapters, which are introduction, literature review, methodology, implementation, analysis and discussion and conclusion and recommendation.

Chapter 1 of this report consists of overview of the study, problem background, problem statement, objectives, scopes and significance of this study.

Chapter 2 of this report presents a review of the literature related to study. These literature covers biometric context, iris dataset, Biometric System Error, iris recognition algorithms, iris recognition system and Hough Transform technique.

Chapter 3 consists of wide description on research methodology, which provides a rich discussion about the flow of this research. This includes how the operational and experimental work has been carried out for the study.

Chapter 4 modifications and enhancements of the Circular Hough Transform are explained in this chapter. And the steps to implement an application for getting adequate results are elaborated.

Chapter 5 the overall result of the analysis is displayed and the evaluation of standard Circular Hough Transform algorithm with the proposed techniques are discussed and expanded.

And in chapter 6 the objectives of the project are elaborated and the recommendation of the study are proposed.

REFERENCE

Abhyankar, A., and Schuckers, S. (2010). A novel biorthogonal wavelet network system for off-angle iris recognition. *Pattern recognition*, *43*(3), 987–1007.

Abhyankar, A., and Schuckers, S. (2006). Active shape models for effective iris segmentation. SPIE (Vol. 6202, p. 6202).

Adler, F. H. (1965). Physiology of the Eye. *Academic Medicine*, *40*(7), 720.

Alioua, N., Amine, A., Rziza, M., & Aboutajdine, D. (2011). Eye state analysis using iris detection based on Circular Hough Transform. *2011 International Conference on Multimedia Computing and Systems (ICMCS)* (pp. 1 –5). Presented at the 2011 International Conference on Multimedia Computing and Systems (ICMCS).

Bae, K., Noh, S., and Kim, J. (2003). Iris feature extraction using independent component analysis. *Audio-and Video-Based Biometric Person Authentication* (pp. 1059–1060).

Bendale, A., Nigam, A., Prakash, S., & Gupta, P. (2012). Iris Segmentation Using Improved Hough Transform. In D.-S. Huang, P. Gupta, X. Zhang, & P. Premaratne (Eds.), *Emerging Intelligent Computing Technology and Applications*, Communications in Computer and Information Science (Vol. 304, pp. 408–415). Springer Berlin Heidelberg.

Berman, E. R. (1991). *Biochemistry of the Eye*. Springer.

Besag, J. (1989). Digital Image Processing. *Journal of Applied Statistics*, *16*(3), 395–407.

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.

Brady, N., and Field, D. J. (2000). Local contrast in natural images: normalisation and coding efficiency. *PERCEPTION-LONDON-*, *29*(9), 1041–1056.

Bresenham, J. (1977). A linear algorithm for incremental digital display of circular

arcs. *Communications of the ACM*, *20*(2), 100–106.

Chen, C. (2010). Handbook of pattern recognition and computer vision. World Scientific.

Chen, T., and Chung, K. (2001). An Efficient Randomized Algorithm for Detecting Circles. *Comput. Vis. Image Underst*, *83*, 2001.

Chun Nam Ben (2003), CUHK Iris Image Dataset, Computer Vision Laboratory, Department of Automation & Computer-Aided Engr., The Chinese University of Hong Kong, Hong Kong.

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

Daugman, J. G. (2003). Demodulation by complex-valued wavelets for stochastic pattern recognition, (2003).

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

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

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. (1988). Complete discrete 2-D Gabor transforms by neural networks for image analysis and compression. *IEEE Transactions on Acoustics, Speech, and Signal Processing*, *36*(7), 1169–1179.

Dorairaj, V., Schmid, N. A., and Fahmy, G. (2005). Performance evaluation of iris based recognition system implementing PCA and ICA encoding techniques. *SPIE* (Vol. 5779, pp. 51–58.

Field, D. J. (1987). Relations between the statistics of natural images and the response properties of cortical cells. *Journal of the Optical Society of America A*, *4*(12), 2379–2394.

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

Gonzalez, R. C., & Woods, R. E. (2007). *Digital Image Processing* (3rd ed.). Prentice Hall.

Guo, G., and Jones, M. J. (2008). Iris Extraction Based on Intensity Gradient and Texture Difference. *IEEE Workshop on Applications of Computer Vision, 2008. WACV 2008* (pp. 1 –6). Presented at the IEEE Workshop on

Applications of Computer Vision, 2008. WACV 2008.

Hollingsworth, K., Baker, S., Ring, S., Bowyer, K. W., and Flynn, P. J. (2009). Recent research results in iris biometrics. *SPIE 7306B: Biometric Technology for Human Identification VI*.

Ho, C.-T., and Chen, L.-H. (1995). A fast ellipse/circle detector using geometric symmetry. *Pattern Recognition*, *28*(1), 117–124.

Huang, J., Ma, L., Wang, Y., & Tan, T. (2004). Iris model based on local orientation description. *Proc. Asian Conf. Comput. Vision* (pp. 954–959).

Huang, J., Wang, Y., Tan, T., & Cui, J. (2004). A new iris segmentation method for recognition. *Pattern Recognition, 2004. ICPR 2004. Proceedings of the 17th International Conference on* (Vol. 3, pp. 554–557).

Jain, A. K., Ross, A., and Prabhakar, S. (2004). An Introduction to Biometric Recognition. *IEEE Transactions on Circuits and Systems for Video Technology*, *14*(1), 4–20.

Jain, Anil K. (2005). Biometric recognition: How do I know who you are? *Springer Verlag 2005*, (2005), 1–5.

Joung, B., Chung, C., Lee, K., Yim, W., and Lee, S. (2005). On Improvement for Normalizing Iris Region for a Ubiquitous Computing. In O. Gervasi, M. Gavrilova, V. Kumar, A. Laganà, H. Lee, Y. Mun, D. Taniar, et al. (Eds.), *Computational Science and Its Applications – ICCSA 2005*, Lecture Notes in Computer Science (Vol. 3480, pp. 1213–1219).

Kimme, C., Ballard, D., and Sklansky, J. (1975). Finding circles by an array of accumulators. *Commun. ACM*, *18*(2), 120–122.

Kovesi, P. D. (2000). MATLAB and Octave functions for computer vision and image processing. *School of Computer Science & Software Engineering, The University of Western Australia*.

Koh, J., Govindaraju, V., & Chaudhary, V. (2010). A Robust Iris Localization Method Using an Active Contour Model and Hough Transform. *2010 20th International Conference on Pattern Recognition (ICPR)* (pp. 2852 –2856). Presented at the 2010 20th International Conference on Pattern Recognition (ICPR).

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.

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. *16th International Conference on Pattern Recognition, 2002. Proceedings* (Vol. 2, pp. 414 – 417 vol.2). Presented at the 16th International Conference on Pattern Recognition, 2002. Proceedings.

Tisse, C., Martin, L., Torres, L., Robert, M., & others. (2002). Person identification technique using human iris recognition. *Proc. Vision Interface* (pp. 294–299).

Masek and Kovesi, (2003). Recognition of human iris patterns for biometric identification. *M. Thesis, The University of Western Australia*.

Monro, D. M., and Zhang, Z. (2005). An effective human iris code with low complexity. *Image Processing, 2005. ICIP 2005. IEEE International Conference on* (Vol. 3, p. III–277).

Morse, B. S. (2000). Lecture 15: Segmentation (edge based, hough transform). *Brigham Young University: Lecture Notes*.

Nadernejad, E., Sharifzadeh, S., and Hassanpour, H. (2008). Edge detection techniques: Evaluations and comparisons. *Applied Mathematical Sciences*, *2*(31), 1507–1520.

Park, C. H., Lee, J. J., Oh, S. K., Song, Y. C., Choi, D. H., and Park, K. H. (2003). Iris feature extraction and matching based on multiscale and directional image representation. *Scale Space Methods in Computer Vision* (pp. 576–583).

Park, C. H., Lee, J. J., Smith, M., and Park, K. H. (2003). Iris-based personal authentication using a normalized directional energy feature. *Audio-and Video-Based Biometric Person Authentication* (pp. 1058–1058).

Proenca, H. P. (2006). Towards non-cooperative biometric iris recognition. *University of Beira Interior. Department of Computer Science*.

Rhody, H. (2005). Lecture 10: Hough Circle Transform. *Rochester Institute of Technology*.

Ritter, N., Owens, R., Cooper, J., and Van Saarloos, P. P. (1999). Location of the pupil-iris border in slit-lamp images of the cornea. *Image Analysis and Processing, 1999. Proceedings. International Conference on* (pp. 740–745).

Ritter, N., and Cooper, J. R. (2003). Locating the iris: A first step to registration and identification. *Proc. 9th IASTED International Conference on Signal and*

Image Processing (pp. 507–512).

Shannon, C. E. (2001). A mathematical theory of communication. *ACM SIGMOBILE Mobile Computing and Communications Review*, *5*(1), 3–55.

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

Thornton, J., Savvides, M., and Vijayakumar, B. (2005). Robust iris recognition using advanced correlation techniques. *Image Analysis and Recognition*, 1098–1105.

Tisse, C., Martin, L., Torres, L., Robert, M., and others. (2002). Person identification technique using human iris recognition. *Proc. Vision Interface* (pp. 294–299).

Tsuji, S., and Matsumoto, F. (1978). Detection of Ellipses by a Modified Hough Transformation. *IEEE Transactions on Computers*, *C-27*(8), 777 –781.

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

Wang, L., Yang, G., & Yin, Y. (2010). Fast Iris Localization Based on Improved Hough Transform. In J. Yu, S. Greco, P. Lingras, G. Wang, & A. Skowron (Eds.), *Rough Set and Knowledge Technology*, Lecture Notes in Computer Science (Vol. 6401, pp. 439–446). Springer Berlin / Heidelberg.

Wildes, R. P., Asmuth, J. C., Green, G. L., Hsu, S. C., Kolczynski, R. J., Matey, J. R., and McBride, S. E. (1994). A system for automated iris recognition. , *Proceedings of the Second IEEE Workshop on Applications of Computer Vision, 1994* (pp. 121 –128). Presented at the , Proceedings of the Second IEEE Workshop on Applications of Computer Vision, 1994

Xie, L. P. (2007). Algorithms for recognition of low quality iris images. University of Ottawa.

Xu, L., Oja, E., and Kultanen, P. (1990). A new curve detection method: Randomized Hough transform (RHT). *Pattern Recognition Letters*, *11*(5), 331–338.

Yuan, X., and Shi, P. (2005). Iris feature extraction using 2D phase congruency. *Information Technology and Applications, 2005. ICITA 2005. Third International Conference on* (Vol. 2, pp. 437–441).

Yip, R. K. K., Tam, P. K. S., and Leung, D. N. K. (1992). Modification of hough transform for circles and ellipses detection using a 2-dimensional array. *Pattern Recognition*, *25*(9), 1007–1022.

Zhu, Y., Tan, T., and Wang, Y. (2000). Biometric personal identification based on iris patterns. *Pattern Recognition, 2000. Proceedings. 15th International Conference on* (Vol. 2, pp. 801–804).