

GABOR WAVELETS FOR HUMAN BIOMETRICS

MD. ASHRAFUL AMIN

DOCTOR OF PHILOSOPHY

CITY UNIVERSITY OF HONG KONG

AUGUST 2009

CITY UNIVERSITY OF HONG KONG
香港城市大學

Gabor Wavelets for Human Biometrics
蓋博小波在人體識別中的應用

Submitted to
The Department of Electronic Engineering
電子工程學系
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy
哲學博士學位

by

Md. Ashraful Amin

August 2009
二零零九年八月

Abstract

Wavelets are frequently used in biometric and other image processing based applications. Among different wavelets, Gabor wavelet is of high interest among the researchers. Due to the appropriateness and suitability of Gabor wavelet to explain image decomposition in mammalian vision from both spatial and frequency domain is well established. Gabor wavelet can be used in facial image processing for face and facial expression recognition and analysis. At the earlier part of this thesis we determine the discrimination characteristics of different filters of Gabor wavelet by the means of a face recognition system. At this stage we also study the recognition performance of different summation based Gabor feature representations. Later a facial expression intensity measurement system is implemented using Gabor wavelet and self organizing maps (SOM) which is able to measure intensity of an emotion from a facial expression image in the form of fuzzy-membership values of three intensity classes- less, medium and high. In another application to recognize American Sign Language (ASL) alphabets Gabor wavelet is used as initial feature extractor for hand signed alphabets recognition. Finally at the end of this thesis we propose a method to extract blood vessels from retinal fundus images which can then be used as biometric measure for human identification and authentication. We show that using phase congruency which is acquired applying Log-Gabor wavelet on images can be used to segment retinal blood vessels for human identification. As a whole this thesis studies different aspects of Gabor wavelet referred to different computer vision based human biometric applications.

Table of Contents

<u>Content No.</u>	<u>Content Title</u>	<u>Page No.</u>
-	Abstract	i
-	Certificate of approval by the panel of examiners	ii
-	Acknowledgements	iii
-	Table of Contents	iv
-	List of Figures	vii
-	List of Tables	ix
-	Introduction	x
-	Motivation	x
-	Contributions	xi
-	Organization	xiii
-	Research papers published, submitted and presented	xiv
-	References	xvi
-	-	-
Chapter 1	Origin of Gabor Wavelet by the Means of Vision Science	1
-	Abstract	1
-	Keywords	1
1.1.	Introduction	2
1.2.	From Fourier Transform to Gabor Wavelet	6
1.2.1.	The Fourier Transform	6
1.2.2.	The Windowed Fourier Transform	7
1.2.3.	The Wavelets	8
1.2.4.	The Gabor wavelet	9
1.3.	Implementation of Gabor wavelet	11
1.4.	Gabor Wavelet in Face Recognition Application	13
1.5.	Conclusion	15
-	References	16
-	-	-
Chapter 2	Gabor Wavelet in Biometric Applications: Now and the Future	20
-	Abstract	20
-	Keywords	20
2.1.	Introduction	21
2.2.	Behavioral Biometric	23
2.2.1.	Signature and Handwriting-based Biometrics	23
2.2.2.	Dynamic Facial Feature and Facial Biometrics	25
2.2.3.	Gait, Body-shape and Body-motion Biometrics	27
2.2.4.	Speaker Identification and Sound-based Biometrics	29
2.2.5.	Lip-movement-based User Identification	32
2.2.6.	Painting-style-based Biometrics	33
2.2.7.	Mouse & Keyboard Dynamic-based Biometrics	34
2.3.	Physiological Biometrics	37
2.3.1.	Ear Biometrics	37
2.3.2.	Fingerprint and Palmprint based Authentication	37
2.3.3.	Iris & Retina based Human Identification	39
2.4.	Conclusion	44
-	References	46
-	-	-
Chapter 3	Gabor Wavelet in Face Recognition	58
-	Abstract	58
-	Keywords	58
3.1.	Introduction	59

<u>Content No.</u>	<u>Content Title</u>	<u>Page No.</u>
3.2.	The Face Recognition System	63
3.2.1.	Facial Data Acquisition	63
3.2.2.	Facial Image Pre-processing	65
3.2.3.	Facial Feature Extraction	66
3.2.3.1.	The Gabor Wavelet	66
3.2.3.2.	Gabor Feature Representation	68
3.2.3.3.	Principle Component Analysis (PCA)	72
3.2.4.	Face Recognition/Identification	74
3.2.4.1.	Probabilistic Neural Network (PNN)	74
3.2.4.2.	Support Vector Machine (SVM)	77
3.2.4.3.	Decision Tree (DT)	78
3.3.	Other Types of Gabor Feature Representation	79
3.4.	Results and Discussions	85
3.5.	Conclusion	93
-	Acknowledgements	94
Appendix 3.A.	Equality of “sum of filter responses” & “response of summed filters”	95
Appendix 3.B.	Results for the PNN, SVM and DT at different scales	96
Appendix 3.C.	Results for PNN, SVM and DT at different orientations	99
-	References	102
-	-	-
Chapter 4	Gabor Wavelet in Facial Expression Intensity Characterization	107
-	Abstract	107
-	Keywords	107
4.1.	Introduction	108
4.2.	The Expression Intensity Measurement System	113
4.2.1.	Facial Expression Data Acquisition	113
4.2.2.	Facial Data Pre-processing	114
4.2.3.	Facial Feature Extraction	114
4.2.3.1.	The Gabor Wavelet	114
4.2.3.2.	Principle Component Analysis (PCA)	115
4.2.4.	Expression/Emotion classification	116
4.2.4.1.	Fuzzy Clustering	116
4.2.4.2.	Self Organizing Map	117
4.3.	The Methodology	119
4.4.	Evaluation and Discussion	138
4.4.1.	Qualitative Evaluation	138
4.4.2.	Quantitative Evaluation	142
4.4.2.1.	Sequence Based Approach	142
4.4.2.2.	Frame Based Approach	146
4.5.	Conclusion	149
-	Acknowledgements	150
-	References	150
Chapter 5	Finger Alphabet Recognition and Gabor Wavelet	154
-	Abstract	154
-	Keywords	154
5.1.	Introduction	155
5.1.	The Sign Alphabet Recognition System	158
5.2.1.	Hand-Gesture Data Acquisition	158
5.2.2.	Hand-Gesture Data Pre-processing	159
5.2.3.	Hand-Gesture Feature Extraction	162
5.2.3.1.	The Gabor Wavelet	162

<u>Content No.</u>	<u>Content Title</u>	<u>Page No.</u>
5.2.3.2.	Principle Component Analysis (PCA)	164
5.2.4.	Finger Alphabet Classification	165
5.3.	Experimental Results and Discussion	167
5.4.	Conclusions and Future Works	171
-	Acknowledgements	172
-	References	172
-	-	-
Chapter 6	Retinal Blood Vessel Detection and Log-Gabor Wavelet	175
-	Abstract	175
-	Keywords	175
6.1.	Introduction	176
6.2.	Image Phase Congruency	180
6.3.	Calculating Phase Congruency for an Image using Log-Gabor Wavelet	183
6.3.1.	The Log-Gabor Wavelet	183
6.3.2.	Handling Very Small Cumulative Fourier Amplitude	187
6.3.3.	Handling the Noise	187
6.3.4.	The Case of Unvaried Frequency Spread	188
6.3.5.	Blurred Features	189
6.3.6.	The Orientation of 2-D Filters	190
6.4.	Implementation and Experimentation Details	191
6.4.1.	The Fundus Image and the Database	191
6.4.1.1.	STARE	191
6.4.1.2.	DRIVE	192
6.4.2.	Generating Phase Congruency of a Retinal Image	193
6.4.3.	Optimum Values of the Empirically Determinable Parameters	196
6.5.	Results and Discussion	197
6.5.1.	Performance of the Proposed Method Based on the STARE Database	198
6.5.2.	Performance of the Proposed Method Based on the DRIVE Database	200
6.6.	Comparison with other Methods	201
6.7.	Conclusion	203
-	Acknowledgements	204
-	References	205
-	Conclusion	208

List of Figures

<u>Figure No.</u>	<u>Figure Caption</u>	<u>Page No.</u>
Figure 1.1.	An illustration of fixed sized windowed Fourier transform	7
Figure 1.2.	Illustration of wavelet transform where different sized window is simultaneously applied at a given time or location	8
Figure 1.3.	a) Intensity of Gabor kernels at five different scales. b) Real part of Gabor kernels at eight orientations and five scales.	10
Figure 1.4.	Facial image of an individual	13
Figure 1.5.	a) Gabor magnitude representation. b) Gabor phase representation of a facial image	14
Figure 2.1.	a) Signature of an individual. b) Gabor magnitude representation of the signature data for identification	24
Figure 2.2.	Averaged Gait representation for a gait sequence	28
Figure 2.3.	a) Averaged gait representation. b) Gabor wavelet's magnitude response for the averaged gait representation	28
Figure 2.4.	a) Mel-scale log magnitude spectrogram of an audio signal. b) The real parts of a 2D-Gabor function with $\omega_r/2\pi = -7Hz$ and $\omega_f/2\pi = -0.2\text{ cycle/channel}$. c) Real part of the Gabor filter's response. d) The feature value at $f_0 = 2284Hz$ for the real part. e) Imaginary part of the Gabor filter's response. f) The feature value at $f_0 = 2284Hz$ for imaginary part.	31
Figure 2.5.	a) Right ear image of a subject. b) Gabor representation of the ear image	38
Figure 2.6.	a) A fingerprint image marked with the region of interest. b) Normalized fingerprint image. c) Filter responses for three Gabor filters at three different orientations	39
Figure 2.7.	a) A near infrared iris image. b) The normalized representation of the iris image of (a) following Daugman (1993). c) A Gabor magnitude representation of the normalized iris image of (b). d) A Gabor phase representation of the normalized iris image of (b)	41
Figure 2.8.	a) Anatomy of the retina. b) Normalized retinal image	42
Figure 2.9.	a) Phase congruency acquired from the Gabor based energy calculation. b) Gabor magnitude representation at 40 different scales and orientations of the normalized retinal image.	42
Figure 3.1.	Major components of a face recognition system	63
Figure 3.2.	Sample image of four different sequences, a) side-to-side; b) down-to-up; c) left-to-right, and d) different expressions.	64
Figure 3.3.	Affine transformation to normalize facial geometry and intensity	65
Figure 3.4.	a) Intensity of the filters at 5 different scales, b) Real part of Gabor kernels at eight orientations ($\mu = \{0,1,2,\dots,7\}$) and five scales ($\nu = \{0,1,\dots,4\}$)	67
Figure 3.5.	Gabor magnitude representation of the face of Figure 3.3 as a 4th order tensor	68
Figure 3.6.	Eight pixel sub-sampling of an second ordered tensor (or image)	69
Figure 3.7.	A pictorial representation of the 7th order data tensor created using Gabor response of all the images of the database	70
Figure 3.8.	The progressive sum of the eigenvalues	74
Figure 3.9.	A typical Probabilistic Neural Network	75
Figure 3.10.	Illustration of the Summation based representations of Gabor filter responses	80
Figure 3.11.	Rader plots for Probabilistic Neural Networks classification accuracies	88

<u>Figure No.</u>	<u>Figure Caption</u>	<u>Page No.</u>
Figure 3.12.	Rader plots for Support Vector Machine classification accuracies	88
Figure 3.13.	Rader plots for Decision Tree classification accuracies	89
Figure 3.14.	Radar plots for PNN classification accuracies for CMU database (left) ORL database (right) at three frequencies and eight orientations.	92
Figure 4.1.	A normal-happy image sequence followed by its hypothetical crisp classification and fuzzy classification	111
Figure 4.2.	Two facial expression image sequences for normal-happy	111
Figure 4.3.	A generic facial expression recognition system	113
Figure 4.4.	A pictorial illustration of a 2D SOM with square neighborhood function	118
Figure 4.5.	Methodology of facial expression intensity classification system	119
Figure 4.6.	Affine transformation to normalize both facial geometry and intensity	120
Figure 4.7.	Real part of Gabor kernels at five scales and eight orientations (left) and Gabor magnitude representation of the face from Figure 5.6 (right)	121
Figure 4.8.	The cluster centers for FCM (left) and reference vectors for SOM (right) with the training data for the happy sequence for combinations of PCs in \mathfrak{R}^2	126
Figure 4.9.	Three intensity data sequences (top) with the three cluster centers (top) and their membership curves	128
Figure 4.10.	Three random distortions of the data sequences of Figure 5.9 (top) and their membership curves	129
Figure 4.11.	Membership curves for FCM and SOM followed by the image sequence for the 1 st happy test subject	130
Figure 4.12.	Membership curves for FCM and SOM for the other three happy test subjects	131
Figure 4.13.	Membership curves for FCM and SOM with the image sequence for the first surprised test subject	132
Figure 4.14.	Membership curves for FCM and SOM for the other three surprised test subjects	133
Figure 4.15.	Membership curves for FCM and SOM followed by the image sequence for the first angry test subjects	134
Figure 4.16.	Membership curves for FCM and SOM for the other three angry test subjects	135
Figure 4.17.	Membership curves for FCM and SOM followed by the image sequence for the first sad test subject	136
Figure 4.18.	Membership curves for FCM and SOM for the other three sad test subjects	137
Figure 4.19.	Trajectory of the four happy test sequences (for 3 rd and 4 th PCs) and the three cluster centers (red points)	139
Figure 4.20.	some maximum expression intensity images of the normal-surprise sequence	141
Figure 4.21.	The facial expression image sequence of normal-angry of S022_005	141
Figure 4.22.	A normal-sad sequence with membership curves (above) and crisp classification (bottom)	143
Figure 5.1.	American Sign Language Finger Alphabets	159
Figure 5.2.	An example of raw input image (left) and preliminary cropping of hand based on the joint of fist and rest of the hand	160
Figure 5.3.	Representation of a line in 2D Euclidian space	160
Figure 5.4.	Radon Transform, the plot of line-length vs. corresponding angle	161
Figure 5.5.	Unaligned hand (Left), aligned hand using Radon transform (Middle), and final cropped and intensity normalized finger sign image (right)	162
Figure 5.6.	Gabor filter response of the finger alphabet 'A'	164
Figure 6.1.	A square wave (not-dotted line) and its Fourier decomposition (dotted)	180

<u>Figure No.</u>	<u>Figure Caption</u>	<u>Page No.</u>
Figure 6.2.	Relationship between phase congruency, energy, and the sum of the Fourier amplitudes	182
Figure 6.3.	An illustration of the different stages of the Log-Gabor filter	185
Figure 6.4.	The magnitude of the Log-Gabor kernels at three different scales	185
Figure 6.5.	From left to right, a color retinal fundus image, and it's red, green and blue channel	191
Figure 6.6.	Sample images of the STARE database	192
Figure 6.7.	Sample images of the DRIVE database	193
Figure 6.8.	The phase congruency image of green channel of the image of Figure 6.5	195
Figure 6.9.	The binary image and the ground truth vessel segmentation of green channel of the image of Figure 6.5	195
Figure 6.10.	ROC curve for the second half (images 11-20) of the STARE database, 1st observer to 2nd observer, FPR and TPR are (0.061, 0.903) as dot	198
Figure 6.11.	Phase congruency image of 10 test images (11-20) of STARE database	199
Figure 6.12.	ROC curve for the 20 test images of the DRIVE database, Set-A to Set-B, FPR and TPR are (0.0275, 0.775) as dot	199
Figure 6.13.	Phase congruency image of the 20 test images of DRIVE database	200

List of Tables

<u>Table No.</u>	<u>Table Caption</u>	<u>Page No.</u>
Table 3.1.	Classification accuracy for filter/kernel response of different orientations and different scales	87
Table 3.2.	The classification accuracy of different Orientation featured representations	91
Table 3.3.	The classification accuracy of different Scale featured Gabor representations	91
Table 3.4.	Classification accuracy for different complete Gabor representations	91
Table 4.1.	Accuracy of sequence based classification for the FCM and SOM process	146
Table 4.2.	Accuracy of frame based evaluation of the FCM and SOM methods	148
Table 5.1.	Hypothetical example 1	168
Table 5.2.	Hypothetical example 2	168
Table 5.3.	Confusion matrix of the test data for the first set of test examples for (4 th ,5 th ,6 th ,7 th)	170
Table 6.1.	Optimum value of the empirically determinable parameters	196
Table 6.2.	Comparison based on the performance on STARE and Drive databases	202