

ADAPTIVE IMAGE WATERMARKING ALGORITHM BASED ON AN EFFICIENT PERCEPTUAL MAPPING MODEL WITH FPGA IMPLEMENTATION

by

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Dedication

To the soul of my brother, Bashar

5

ten

And all martyrs and dear ones who have left us and passed away...

We pray that Allah will reward you with paradise and gather us there.

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ أَنِ اشْكُرْ لِي وَلِوَالِدَيْكَ إِلَيَّ الْمَصِير

لقمان 14

Be grateful to Me and to your parents; to Me is the [final] destination.

Loqman (31:14)

Alhamdulillah, and prayers and peace upon our prophet, Muhammad,

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TABLE OF CONTENTS

		TABLE OF CONTENTS	PAGE
DEC	LARAT	TION OF THESIS	i
ACK	NOWL	EDGMENT	iii
TAB	LE OF	CONTENTS	iv
LIST	COF TA	ABLES	viii
LIST	OF FI	GURES	ix
LIST	C OF AB	BBREVIATIONS	xi
LIST	OF SY	MBOLS	xiii
ABS'	TRAK		xiv
ABS'	TRACT		XV
СНА	PTER 1	1: INTRODUCTION	1
1.1	Introd	luction	1
1.2	Proble	em Statement	4
1.3	Resea	rch Objective	6
1.4	Resea	rch Scope	6
1.5	AND STRACT xi APTER 1: INTRODUCTION 1 I Introduction 1 2 Problem Statement 2 3 Research Objective 6 4 Research Scope 6 5 Thesis Outline 7		
СНА	PTER 2		9
2.1	Introd	luction	9
2.2	Perce	ptual Mapping	10
	2.2.1	Factors Affecting Perceptual Mapping	11
	2.2.2	Perceptual Mapping Studies	13
2.3	Digita	al Watermarking	16
	2.3.1	History of Watermarking	16
	2.3.2	Digital Watermarking Applications	19
		2.3.2.1 Intellectual Property Rights Protection	20
		2.3.2.2 Verification of Contents	21
		2.3.2.3 Side Channel Information	22
	2.3.3	Watermark Types	23
	2.3.4	Properties of watermarking systems	25
	2.3.5	Image Watermarking Systems	28
		2.3.5.1 Watermark Embedding	29
		2.3.5.2 Watermark Extraction	30

	2.3.6 \$	Spatial and Transform Domain Watermarking	31
	2.3.7 I	Perceptual-Based Watermarking Studies	33
2.4	Embeo	dded Systems and FPGA-Based Image Watermarking	37
	2.4.1	FPGA-Based Embedded Systems	38
	2.4.2	FPGA Programming	41
	2.4.3	FPGA-Based Watermarking Systems	41
		2.4.3.1 FPGA-Based Time Domain Watermarking studies	42
		2.4.3.2 FPGA-Based Transform Domain Watermarking studies	44
	2.4.4	Analysis of FPGA Based Watermarking Studies	47
2.5	Summ	ary	50
CHA	PTER 3	et Transform	51
3.1	Introd	uction	51
3.2	Wavel	let Transform	54
	3.2.1	Wavelet Transform in Compare with Fourier Transform	54
	3.2.2	Implementation of Discrete Wavelet Transform	55
3.3	Lifting	g Wavelet Transform	56
	3.3.1	Lifting Wavelet Transform Implementation	57
	3.3.2	Mathematical representation of Lifting Wavelet Transform	59
3.4	Object	tive Quality Metrics	63
3.5	Percep	otual Mapping Design	65
	3.5.1	Luminance Masking	65
	3.5.2	Texture Masking	66
	3.5.3	Edges Detection	70
	3.5.4	Pooling	72
	3.5.5	Determining Weighting Variables Values	74
3.6	Model	Comparison	79
	3.6.1	Noise Shaping Comparison	79
	3.6.2	Execution Speed Comparison	83
3.7	Summ	ary	84
CHA	PTER 4	: BLIND IMAGE WATERMARKING	86
4.1	Introd	uction	86
4.2	Robus	t Watermark Requirements	87
	4.2.1	Transform domain embedding	87

	4.2.2	Embedding in Perceptually Significant Coefficients	87
	4.2.3	Spread Spectrum Concept	89
4.3	Image	Watermarking Scheme	90
	4.3.1	Watermark Embedding Algorithm	91
	4.3.2	Watermark Extraction Algorithm	94
	4.3.3	Finding Optimal Embedding strength	96
4.4	Exper	imental Results and Comparisons	98
	4.4.1	Imperceptibility Evaluation	98
	4.4.2	Robustness Evaluation	102
	4.4.3	Model Comparison	110
		4.4.3.1 Comparison of Imperceptibility	110
		4.4.3.2 Comparison of Robustness	111
4.5	Embeo	Model Comparison 4.4.3.1 Comparison of Imperceptibility 4.4.3.2 Comparison of Robustness dding in RGB Images ical User Interface Implementation	113
4.6	Graph	ical User Interface Implementation	114
4.7	Summ		117
СНА	PTER 5	: HARDWARE DESIGN AND IMPLEMENTATION OF	118
5.1	Introd	THE WATERMARKING ALGORITHM USING FPGA uction	118
5.2	FPGA	Implementation of LWT	119
5.3		Implementation of The Perceptual Model	132
	5.3.1	Luminance Mask Implementation	132
	5.3.2	Texture Mask Implementation	132
	5.3.3	Edge Detection Implementation	133
	5.3.4	Masks Gathering	134
5.4	FPGA	Implementation of Watermark Embedding	136
	5.4.1	Centre Coefficients Initialization	136
	5.4.2	Watermark Insertion	137
5.5	FPGA	Implementation of Watermark Extraction	142
5.6	Down	loading the Design on FPGA Board	145
5.7	Summ	ary	147
СНА	PTER 6	5: CONCLUSION AND FUTURE RECOMMENDATIONS	148
6.1	Concl	usion	148
6.2	Resear	rch Contributions	149
6.3	Future	Recommendations	150

REFERENCES	151
APPENDIX A	162
APPENDIX B	168
APPENDIX C	177
APPENDIX D	184
LIST OF PUBLICATIONS	186

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LIST OF TABLES

No.		PAGE
2.1	Existing features of current FPGA-based watermarking studies	48
3.1	ALD values for different blocks on Mountain 1 image	68
3.2	ALD values for different blocks on Mountain 2 image	69
3.3	PSNR comparison between different models	82
3.4	Approximate execution time (Sec) for different models	84
4.1	SSIM and PSNR for watermarked images	101
4.2	Recovered watermark with BER and NCC values after applying different attacks	105
4.3	SSIM comparison with Kang et. al	111
4.4	Comparison of BER values of recovered watermark with Kang et.al (2017)	112

LIST OF FIGURES

No.		PAGE
1.1	Different perceptual evaluations of the same amount of embedded data	3
2.1	Different influences of watermarks in sky and grassy areas	13
2.2	Number of papers published annually on watermarking and steganography by IEEE	18
2.3	Watermark embedding process	30
2.4	Watermark extraction process	31
2.5	Conceptual structure of FPGA	40
3.1	Block diagram for entire perceptual based watermarking process	52
3.2	Wavelet transform using filters	56
3.3	Forward lifting wavelet transform	59
3.4	Wavelet transform using filters Forward lifting wavelet transform Inverse lifting wavelet transform Wavelet function of CDF (2,2)	59
3.5	Wavelet function of CDF (2,2)	61
3.6	ALD block calculation	67
3.7	ALD mask for an image with various textured areas 1	68
3.8	ALD mask for an image with various textured areas 2	69
3.9	Extended Sobel operators	71
3.10	Extracted edges using simplified edge detection method	72
3.11	Different chosen blocks for objective evaluation	75
3.12	SSIM value for different blocks	76
3.13	Original and final perceptual mask for different images	78
3.14	Thumbnails of the 15 used images for comparison	80
3.15	Mean square error of different images for the proposed and the four compared models.	81
4.1	LWT bands after a single decomposition	89
4.2	Block diagram of the embedding process	91
4.3	Approximation band sub blocks	93
4.4	Sample of approximation band block coefficients before and after the embedding process	94
4.5	Block diagram of the extraction process	94
4.6	The relationship between embedding strength and PSNR	97
4.7	The relationship between embedding strength and SSIM	97

4.8	Thumbnails of the 15 used images for watermark embedding and evaluation	99
4.9	Binary watermark	99
4.10	Watermarked images	100
4.11	BER average for the extracted watermark after applying different attacks on the model of Kang et.al and the proposed model	113
4.12	Coloured images watermarking	114
4.13	Opening screen of watermarking GUI	115
4.14	GUI for embedding process	115
4.15	GUI for extraction process (untampered watermarked image)	116
4.16	GUI for extraction process (cropped watermarked image)	116
5.1	Block diagram of LWT System	120
5.2	RTL for one level LWT (Part1: input registers initialization)	121
5.3	RTL for one level LWT (Part2: LWT implementation on input data)	124
5.4	Simulation results of LWT application	125
5.5	LWT bands creation	126
5.6	Original 16 ×16 image values	127
5.7	Reading image row by row	127
5.8	Parallel architecture of LWT decomposition	128
5.9	Four bands coefficients after applying LWT on 16×16 image	130
5.10	Produced LWT coefficicients for different bands using VHDL	131
5.11	Approximation band subtracting according vertical Sobel kernel	133
5.12	Perceptual mask implementation	135
5.13	Results of perceptual mask implementation	136
5.14	Block diagram of watermark embedding processes	139
5.15	16×16 Watermarked image values	140
5.16	Waveform output for watermarked image using FPGA	141
5.17	Watermark extraction processes	143
5.18	Watermarked image with watermark value 1011	144
5.19	Extracted watermark	144
5.20	Watermark embedding and extraction on DE2 Cyclone II board	146

LIST OF ABBREVIATIONS

ALD	Accumulative Lifting Differences
ASIC	Application Specific Integrated Circuits
BMP	Bitmap Image
CDF	Cohen, Daubechies, and Feauveau
СТ	Contourlet Transform
CLB	Control Logic Blocks
CPLD	Complex Programmable Logic Devices
CSF	Complex Programmable Logic Devices contrast sensitivity function Discrete Cosine Transform Discrete Wavelet Transform Fast Fourier Transform
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
FFT	Fast Fourier Transform
FPGA	Field Programmable Gate Arrays
HDL	Hardware Descriptive Language
HVS	Human Visual System
IC	Integrated Circuit
IIPA	International Intellectual Property Alliance
JPEG	Joint Photographic Experts Group
JND	Just Noticeable Distortion
LE	Logic Element
LFSR	Linear Feedback Shift Registers
LSB	Least Significant Bit
LWT	Lifting Wavelet Transform
MAE	Mean Absolute Error
NC	Normalized Correlation
PSNR	Peak Signal to Noise Ratio
RCM	Reversible Contrast Mapping

RDWTRedundant Discrete Wavelet TransformRTLRegister Transfer LevelSSSpread SpectrumSSIMStructural Similarity IndexVHDL(V: Very High Scale Integrated Circuit) Hardware Development
Language

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LIST OF SYMBOLS

W Original watermark Ŵ Extracted watermark Ι Original image Î Watermarked image ĝ Lowpass filter ĥ High pass filter by original copyright Xo Odd input data Xe Even input data D Detail band S Approximation band In Noisy image Noise severity controller r EM Edge mask value FM Final mask value LM Luminance value TM Texture map value 0 Ev Embedding value E_{min} Minimum embedding value E_{s} Embedding Strength Texture mask weighting variable α β Edge Mask weighting variable Luminance mask weighting variable γ

Penyesuaian Imej 'Watermark' Berasaskan Model Pemetaan Persepsi Dengan Implementasi FPGA

ABSTRAK

Ketidakjelasan 'watermark' adalah faktor penting untuk mengekalkan imej yang ditanda kelihatan sama dengan yang asal secara persepsi. Ketidakjelasan 'watermark' vang berkesan memerlukan penciptaan model persepsi yang menyerupai sistem visual manusia untuk menyembunyikan bit 'watermark' di tempat di mana mata manusia tidak dapat memerhatikannya. Model persepsi semasa menggunakan pengiraan yang kompleks dan sukar dilaksanakan dalam sistem terbenam atau dalam aplikasi masa sebenar. Dalam tesis ini, pengubah wavelet berasaskan integer terangkat dengan kerumitan rendah digunakan untuk mencipta model pemetaan persepsi yang sebahagian besarnya bergantung pada model pemetaan tekstur baru yang dikenali sebagai perbezaan pengangkat akumulatif (ALD). ALD digabungkan dengan pengesanan pinggir mudah dan model topeng luminan untuk mendapatkan model pemetaan persepsi komprehensif yang mempunyai toleransi hingar yang tinggi dan berdasarkan pengiraan kerumitan yang rendah. Model yang dicadangkan adalah 7% lebih cepat berbanding model yang berasaskan piksel terpantas, dengan peningkatan purata PSNR sebanyak 2.75 dB. Manakala, berbanding dengan model sub-band yang bertoleransi hingar sangat tinggi, model JND yang dicadangkan mempunyai gandaan PSNR sebanyak 1.78 dB dan kelajuan pelaksanaan yang 90% lebih cepat. Model persepsi ini digunakan dalam cadangan algoritma imej 'watermark' untuk menentukan pembenaman keamatan *watermark* yang maksima dan tidak dapat dilihat oleh mata manusia. Keputusan ujikaji menunjukkan bahawa algoritma yang dicadangkan menghasilkan imej *watermark*' yang berkualiti tinggi dengan nilai SSIM lebih besar daripada 0.95 untuk semua imej yang diuji dan ia kukuh terhadap serangan geometrik dan bukan geometri yang berbeza. Untuk sambutan masa nyata, algoritma 'watermark' yang dibentangkan direka, dilaksanakan dan diuji pada peranti Altera® Cyclone-II FPGA menggunakan VHDL. Dengan menggunakan rekabentuk struktur selari sistem ini membolehkan ia dilaksanakan pada kelajuan jam 101.02 MHz, di mana ia sesuai untuk aplikasi masa nyata yang terkini.

Adaptive Image Watermarking Based on an Efficient Perceptual Mapping Model with FPGA Implementation

ABSTRACT

Watermark imperceptibility is a significant factor for keeping watermarked images looking perceptually similar to the original ones. Effective watermark imperceptibility requires the creation of a perceptual model that simulates the human visual system to efficiently hide the watermark bits in places where the human eye cannot observe it. Current perceptual-based watermarking models use complex computations that are difficult to implement in embedded systems or in real time applications. In this thesis, a low-complexity, integer-based Lifting Wavelet Transform (LWT) was utilized to create a perceptual mapping model that is mainly relied on a new texture mapping model called Accumulative Lifting Difference (ALD). The ALD is combined with a simplified edge detection and luminance masking models to obtain a comprehensive perceptual mapping model that has high noise tolerance and it is based on low complexity calculations. The proposed model was 7% faster than the fastest pixel-based compared model, with an enhanced average PSNR gain of 2.75 dB. In comparison to the largest noise tolerance sub-band compared model, the proposed JND model had a PSNR gain of 1.78 dB and an execution speed that was up to 90% faster. The perceptual model is utilized in a proposed image watermarking algorithm to determine the maximum watermark embedding intensity that is not visible to the human eye. The experimental results show that the proposed algorithm produced high quality watermarked images with SSIM value larger than 0.95 for all tested images and it was robust against different geometric and non-geometric attacks. For real time response, the presented watermarking algorithm was designed, implemented and tested on Altera® Cyclone-II FPGA device using VHDL. The parallel structure of the design allowed the system to be executed at a clock speed of 101.02 MHz, which make it suitable for emerging realtime applications.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Copyright protection and authentication for digital media have been some of the most important challenges in the last decade due to the widespread use of digital media throughout the world, especially after the World Wide Web (a global working network with worldwide broadcasting potential) was effectively integrated into public and business domains. The International Intellectual Property Alliance (IIPA) estimated that the annual worldwide trade loss due to copyright piracy reached \$10.2 billion in 2002, excluding Europe and the United States (Seitz, 2005).

70 percent of transmitted data, represented by digital images that are critical parts of network exchanges, can be copied, altered and distributed. The image tracking service, "Pixsy", stated that 64 percent of the work of photographers was stolen in 2016, and 49 percent was misused by social media users and bloggers, i.e. digital images, in addition to commercial businesses and other fields, where digital images play a major role (Salim & Vigneswaran, 2015; Pixsy, 2016).

As a consequence, finding a way to protect the copyright of these images (and videos, since a video is a set of consecutive frames) is a very demanding challenge for researchers and developers. Digital watermarking, by inserting a piece of data like proprietary information of intellectual property rights using an embedding algorithm, is

a good tool for solving the copyright issue (Woo, 2007). Watermarking has other applications such as tampering detection or testing the Quality of Service (QoS) of transmitting channels (Maity & Maity, 2014; Maity, Kundu & Maity, 2009).

The type of watermarking application determines the watermark behaviour. For example, a watermark is referred to as being "robust" if it is resistant to modifications and is still recognizable after being exposed to different image processing operations, this type of watermark is used in copyright protection. A watermark is considered to be "fragile" when it is sensitive to any applied modifications, which is used in discovering tampering.

A watermark can easily be observed by the human eye (visible), or it can be hidden within the original data without affecting its perceptual quality of the original data (invisible). Designing a watermarking system with the two properties of robustness and invisibility is a challenging task. This is because there is a trade-off between the two factors, that is, more robustness means less invisibility since the watermark bits needs to be embedded by intensive values to keep surviving modifications, while choosing limited watermark intensity will create a better appearance but less robustness as the watermark is vulnerable to distortion or removing (Li, Zhang, & Yang, 2013). For this reason, a perceptual evaluation should be made before the watermark is embedded to find the highest intensity of embedding that is not visual to human eye (Cox, Miller, Bloom, Fridrich, & Kalker, 2008). The watermark, which is not preferred to be noticed by human eyes, is considered to be an additive noise in image processing perspective. However, the human visual system (HVS) has a different perceptual evaluation for the same amount of noise if that noise is applied to different images or applied to the same image but in different locations. Figure 1.1 shows two identical logos embedded in the sky and on the surface of the mountain in which different visual effects are observed.

This is because the mountain's surface has more texture than the sky and hence, the watermark is seen to have less of an impact. Researchers have analysed such cases and concluded that the HVS can perceive visual alerts if that pass a certain threshold called the just noticeable distortion (JND) threshold (Wu, Qi, & Shi, 2010).



Figure 1.1 Different perceptual evaluations for the same amount of embedded data (Host image from www.pexels.com and UniMAP Logo)

Therefore, designing a JND estimation model while creating a watermarking system will allow watermark invisibility to be enhanced. As a consequence, a greater embedding intensity will be achieved under high JND threshold areas, i.e., more robustness will be gained while maintaining watermark invisibility. As such, the creation of an efficient perceptual mapping model preceded the watermarking in this thesis.

Watermarking systems can be initiated using software applications that are easy to implement under general purpose operating systems; however, embedded systems that are implemented in hardware-based designs offer advantages over software-based designs in terms of execution time, low power consumption, real-time performance, high reliability and also the ease of integration with the existing consumer electronic devices (Ghosh, 2017). In the last decade, Field-programmable gate array (FPGA) devices have been the choice of many developers for their ability to design almost any type of digital systems, In addition, FPGA devices were popular by virtue of their high re-configurability and ability to be reprogrammed easily and rapidly in the field without having to refer to the manufacturers compared to application specific integrated circuits (ASICs) (Chu, 2008; Ma, Suda, Cao, Vrudhula & Seo, 2018; Maity & Maity, 2014). However, the hardware-based design of watermarking algorithms must have optimum .ded.s cop ted by original cop ted by original consumption of the resources to be implemented in embedded systems and in real-time applications.

1.2 **Problem Statement**

A watermark signal is considered as an additive noise in terms of the visual quality of the image. Hence a perceptual mapping model is used to provide an imperceptible and robust watermarking scheme as it defines the maximum perceptual distortion that cannot be perceived by the HVS (Li, Yang, Li, & Yang, 2011; Zheng & Zhang, 2010, Zhi, Zhang, Yang, & Liu, 2014).

Existing perceptual mapping models are either pixel-based attempts or transform domain attempts. A review of the literature fails to show a comprehensive pixel-based JND model which takes into account all major perceptual factors (Uzair & Dony, 2017). While the implementation of the efficient transform domain models requires more execution time for the high computational complexity that is involved in such implementations; for example, the execution speed of the JND model proposed by Wan, Wu, Xie & Shi (2017) using the orientation regularity within transform domain coefficients was slower by up to 7 times than the direct pixel orientation attempt presented by Wu et al., (2017).

The complexity involved in efficient perceptual models affected the perceptual based watermarking as they possessed the same complexity in addition to embedding calculations. An alternative solution to obtain robust and invisible watermarks is to use hybrid transform domain watermarking as (Hamidi, Haziti, Cherifi, & Hassouni, 2018; Poonam & Arora, 2018; Roy & Pal, 2017); however, in such hybrid studies, computational complexity is on the higher side because of the use of transform domain techniques like DCT and DWT (Roy & Pal, 2017).

Consequently, the complexity of high performance watermarking systems made the hardware implementation and the real time response of such system a difficult task, where the literature of FPGA based hardware watermarking studies shows a lack in the existing of a comprehensive, perceptually adaptive watermarking model in these systems while achieving real time and high-speed computations. Even the studies that aimed to enrol the perceptual considerations in the FPGA watermarking were very limited, for example, the two studies presented by Mohanty et al. (2009) and Mohanty and Kougianos (2011) in creating a visible watermarking system to be used in video watermarking. The perceptual map was with regard to only the intra-frame parameters related to the edges of the DCT but the internal frame calculations had fixed values because of the high complexity and time-consuming tasks that are involved while creating a different perceptual value for each block in each frame.

Accordingly, it will be a significant contribution if an HVS-adaptable, invisible, robust, and blind watermarking algorithm is developed based on efficient and low complexity perceptual mapping model, to be used in embedded systems and real time applications.

1.3 Research Objectives

The main objective of this research was to develop a perceptually adaptive blind image watermarking algorithm based on a low complexity perceptual mapping model that simulates the human visual system and is suitable for integration into embedded systems. The objective consisted of the following sub-objectives:

- i.) To design an efficient perceptual mapping model in terms of noise tolerance and low complexity and relies solely on basic arithmetical operations.
- ii.) To design and implement a comprehensive invisible watermarking algorithm by depending on the previously-created perceptual map for a high ratio of watermark imperceptibility while resisting intended and unintended distortions.
- iii.) To evaluate and test the adaptive, perceptual-based watermarking algorithm on FPGA platform by exploiting the parallelism feature of these devices to achieve real time execution.

1.4 Research Scope

The research algorithm relied significantly on lifting wavelet transform (LWT) presented by Sweldens (1995) to transfer the signals (images in this work) from time domain to frequency domain using integer and low-complexity calculations that are suitable for implementation in limited resource systems. Detail band of the LWT was exploited to create a texture map using a new method referred to as the accumulative

lifting difference (ALD). Due to their high sensitivity to noise, edges were extracted from the textured areas using a simplified method based on extended Sobel operators that were applied to the LWT approximation band. In addition, luminance masking was used to take advantage of the HVS low sensitivity in dark and bright intensities. As a result, the factors of texture, edges and luminance were combined to determine the intensity of the watermark in each image block. The watermark embedding algorithm reused the LWT approximation band to embed the watermark in such a way that it could be detected using totally uninformed extractors. Finally, the entire system was implemented on the FPGA platform using parallel execution.

Tested images for the software implementation were in greyscale and RGB colour spaces with a size of 512×512 , while the watermark was a binary image with a size of 32×32 . For the FPGA hardware implementation, greyscale images were used and read from a memory initialization file, "mif", as binary values with a size of 16×16 and a watermark size of 4 bits. The implementation of the algorithm was achieved by DE2 Cyclone II (EP2C35F672C6) FPGA device; however, the device is used as a platform for testing the design that is coded using VHDL (very high scale hardware descriptive language) and it can be implemented on other devices or platforms.

1.5 Thesis Outline

This thesis has been organized into six chapters. Chapter 1 started with an introduction to the thesis and its motivation, followed by the problem statement, objectives of the work, scope of the research, and ends with the thesis outline.

Chapter 2 focuses on the literature related to the research and the theoretical concepts. The chapter is divided into three parts, starting with an overview of the

perceptual mapping and its related literature. The second part is related to the digital watermarking concepts, applications, and requirements; followed by the literature review of perceptual-based watermarking studies. The final section of this chapter is related to the features of the embedded systems and FPGA hardware, with a review and analysis of different FPGA-based watermarking studies.

Chapter 3 presents an explanation of the perceptual mapping model and its implementation. It starts with the general framework of the entire algorithm. Next, the concepts of the new texture mapping model (ALD) are presented, followed by a simplified edge detection and the luminance masking models. The results of noise tolerance and the execution speed of the proposed perceptual model are listed and compared with recent studies at the end of the chapter.

In Chapter 4, the new blind and adaptive watermarking algorithm based on perceptual mapping is presented. The design and implementation of the embedding and extracting algorithms are tested and explained, followed by the evaluation of the watermarking system in terms of its invisibility and robustness, in addition to a comparison with recent hybrid transform domain model. The chapter ends with the implementation of the algorithm on coloured images using graphical user interface.

Chapter 5 explains the implementation and the testing of the watermarking algorithm using FPGA hardware. The chapter presents the hardware implementation of LWT, explains the implementation of the entire watermarking algorithm using the parallel processing, and depicts the processes of synthesising and downloading the code on Cyclone II board.

Chapter 6 concludes the presented thesis and lists its main contributions. Future recommendations are mentioned in the end of the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Digital watermarking is performed by inserting a piece of data like intellectual property rights or proprietary information inside digital media for different purposes as copyright protection or tampering detection. In digital image watermarking, specifically the invisible form, watermark imperceptibility is an important factor to keep the watermarked image looking perceptually similar to the original one.

Digital watermarking must successfully satisfy the trade-off between imperceptibility and robustness. Therefore, watermarking algorithms should select the appropriate embedding strength for each region to embed watermark with the highest possible intensity to resist different kinds of attacks on condition that the watermark is imperceptible. IND model based on HVS (Human Visual System) that is used to create the perceptual maps provides the effective solution for this problem. Visual threshold represents the maximum image distortion that human eye can tolerate, which is generally a comprehensive reflection of the frequency sensitivity, luminance masking, contrast masking and other characteristics of human vision. In brief, digital watermarking employs JND model to control the embedding position and intensity of watermark, while ensuring the optimal watermarking performance (Li et al., 2013).