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

by

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بسم الله الرحمن الرحيم

بسم الله الرحمن الرحيم

Dedication

To the soul of my brother, Bashar

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.

ACKNOWLEDGMENT

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.

All Praises be to Allah, Most Gracious and Most Merciful for giving me the strength, guidance and everything else to complete this thesis. I am thankful to my parents, to whom whatever I say or do will never come close enough to expressing my gratitude to them. I to ask Allah to protect them in this life and in the hereafter, and may the knowledge presented in this thesis be of ceaseless charity (Sadaqah Jariyah) to all of us.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ALD	Accumulative Lifting Differences
ASIC	Application Specific Integrated Circuits
BMP	Bitmap Image
CDF	Cohen, Daubechies, and Feauveau
CT	Contourlet Transform
CLB	Control Logic Blocks
CPLD	Complex Programmable Logic Devices
CSF	contrast sensitivity function
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

RDWT	Redundant Discrete Wavelet Transform
RTL	Register Transfer Level
SS	Spread Spectrum
SSIM	Structural Similarity Index
VHDL	(V: Very High Scale Integrated Circuit) Hardware Development Language

LIST OF SYMBOLS

W	Original watermark
$\hat{W}$	Extracted watermark
I	Original image
$\hat{I}$	Watermarked image
$\hat{g}$	Lowpass filter
$\hat{h}$	High pass filter
X_o	Odd input data
X_e	Even input data
D	Detail band
S	Approximation band
In	Noisy image
r	Noise severity controller
EM	Edge mask value
FM	Final mask value
LM	Luminance value
TM	Texture map value
Ev	Embedding value
E_{min}	Minimum embedding value
E_s	Embedding Strength
α	Texture mask weighting variable
β	Edge Mask weighting variable
γ	Luminance mask weighting variable

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'* yang 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 real-time 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).

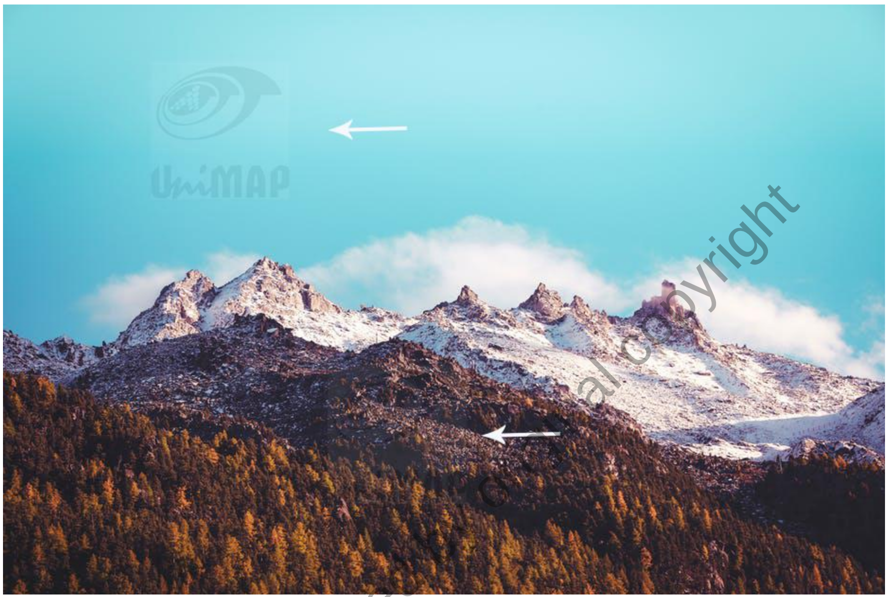

Figure 1.1 Different perceptual evaluations for the same amount of embedded data (Host image from www.pexels.com and UniMAP Logo)

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 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. JND 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).