UNIVERSITI PUTRA MALAYSIA

DESIGN OF ROBUST AND FRAGILE IMAGE WATERMARKING SYSTEM FOR COPYRIGHT PROTECTION AND AUTHENTICATION USING LIFTING WAVELET TRANSFORM AND BIVARIATE EMPIRICAL MODE DECOMPOSITION TECHNIQUES

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FK 2017 47

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By

NIDAA HASAN ABBAS

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

April 2017

DEDICATION

To my lovely husband, my dearest parents, sisters and brothers for their endless support and encouragement.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

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April 2017

Chairman : Associate Professor Sharifah Mumtazah bt Syed Ahmad Abdul Rahman, PhD
Faculty : Engineering

In this thesis, a dual purpose watermarking system is designed that satisfy both robustness and fragility, and thus combining copyright protection and tamper proofing simultaneously without significantly degrading each other. The proposed copyright scheme is new and effective. Two transforms which are; lifting wavelet transform (LWT) and bivariate empirical mode decomposition (BEMD), are used to decompose the original image to provide flexibility in choosing the robust frequency subband of the original image. LWT, is chosen as it is fast and keeps the integrity of the retrieved watermark. While BEMD could sift the image from the most robust to the least sensitive (fragile) frequency bands. This property is exploited in this thesis to embed the watermark in the robust part of BEMD which is the residue (*r*).

To ensure the integrity and authenticity of digital images, a wide variety of authentication schemes have been proposed in the literature to detect image tampering. However, most of the existing schemes either fail to address this issue or use inaccurate method to evaluate the system performance. For this reason, a procedure to generate a new type of fragile watermark that can detect any tampering is developed in this thesis. The most sensitive subbands of the BEMD which are Intrinsic Mode Function (*IMFs)* are used to derive and embed the watermark bits in the frequency domain and further processed to increase the security and the ability to detect any alteration. Another watermark is generated and embedded in the spatial domain using block wise method and the Least Significant Bits (LSBs) insertion.

The dual-purpose scheme is obtained by combining both the copyright protection and image authentication schemes and has been subjected to robust and fragile attacks. The results demonstrated that the performance of the scheme remains at par or only degrade at an acceptable level after inserting the dual watermarks. The obtained visual quality, Peak Signal to Noise Ratio (*PSNR*), is greater than 48dB and the Normalised Cross Correlation (*NCC*) is greater than 0.97 while the tampering detection rate (*AV*) is greater than 94%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktar Fasafah

REKABENTUK SISTEM *WATERMARKING* IMEJ YANG TEGUH DAN RAPUH UNTUK PERLINDUNGAN HAKCIPTA DAN PENGESAHAN DENGAN MENGGUNAKAN TEKNIK LIFTING *WAVELET TRANSFORM* DAN *BI EMPIRICAL MODE DECOMPOSITION*

Oleh

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Kebanyakkan sistem *watermarking* imej sejenis bertujuan untuk mencapai satu matlamat sahaja, samaada untuk pengesanan pemalsuan atau perlindungan hak cipta. Namun bagi sesetengah aplikasi yang kritikal seperti perdagangan elektronik, pembeli mahu memastikan bahawa imej yang diterima adalah asli dihasilkan oleh pemilik dan tidak diubahsuai. Ini telah membawa kepada pengenalan algoritma pelbagai tujuan *watermark*, dengan objektif utama untuk mencapai kedua-dua matlamat perlinduangan hakcipta dan pengesanan pengubahsuaian pada masa yang sama.

Di dalam tesis ini, dua tujuan sistem *watermarking* telah direkabentuk yang memenuhi kedua-dua keteguhan dan kerapuhan, seterusnya mengabungkan perlindungan hak cipta dan pengesanan pengubahsuaian pada masa yang sama tanpa melemahkan satu sama lain. Skema *watermarking* yang dicadangkan adalah baru dan berkesan. Dua jelmaan iaitu; *lifting wavelet transform (LWT)* dan *bivariate empirical mode decomposition (BEMD*), telah digunakan untuk menguraikan imej asli bagi memberikan fleksibiliti memilih frekuensi subjalur yang teguh di dalam imej asli. *LWT* dipilih kerana ia cepat dan mengekalkan integriti *watermark* yang diperolehi. Manakala Jelmaan *BEMD* boleh menapis imej daripada jalur frekuensi yang paling teguh kepada yang paling sensitif (rapuh). Ciri ini dieksploitasikan di dalam tesis ini untuk membenamkan *watermark* di dalam bahagian *BEMD* yang teguh iaitu pada bakinya (*r*).

Untuk memastikan integriti dan ketulenan imej digital, pelbagai skema pengesahan telah dicadangkan di dalam kajian untuk mengesan mengubahsuaian imej. Namun, kebanyakkan skema yang sedia ada gagal untuk menyelesaikan isu ini atau

menggunakan cara yang tidak jitu untuk menilai prestasi sistem. Di atas sebab inilah, satu prosedur untuk menghasilkan *watermark* rapuh yang baru yang boleh mengesan sebarang pengubahsuaian telah dibangunkan di dalam tesis ini. Subjalur Jelmaan *BEMD* yang paling sensitif iaitu Fungsi Mod yng Intrinsik (*IMF*s) telah digunakan untuk menghasilkan dan membenamkan bits *watermark* di dalam domain frekuensi dan di proses seterusnya untuk meningkatkan keselamatan dan kebolehan bagi mengesan sebarang pengubahsuaian. *Watermark* yang lain dihasilkan dan dibenamkan pula di dalam domain ruang dengan menggunakan kaedah blok dan kemasukkan pada Bit yang Paling Kurang Kepentingan (LSBs).

Skema dua tujuan diperolehi dengan menggabungkan kedua-dua skema perlinduangan hakcipta dan pengesahan imej dan telah menjalani pelbagai serangan keteguhan dan kerapuhan. Keputusan menunjukkan prestasi skema ini kekal atau hanya berkurang pada kadar yang dibenarkan setelah dimasukkan kedua-dua *watermark* (i.e. pengurangan hanya $\leq$ 5%). Kualiti visual yang diperolehi; Nisbah Puncak Isyarat kepada Hingar (*PSNR*) adalah melebihi 48dB dan Norma Kolerasi Silang (*NCC*) adalah melebihi 0.97, manakala Kadar Pengesanan Pengubahsuaian (*AV*) adalah melebihi 94%.

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I certify that a Thesis Examination Committee has met on 17 April 2017 to conduct the final examination of Nidaa Hasan Abbas on her thesis entitled "Design of Robust and Fragile Image Watermarking System for Copyright Protection and Authentication using Lifting Wavelet Transform and Bivariate Empirical Mode Decomposition Techniques" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

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LIST OF ABBREVIATIONS

NCC	Normalized Cross Correlation
FP	False Positive
FN	False Negative
HVS	the Human Visual System
RMSE	Root Mean Square Error
RST	Rotation, Scaling, and Translation
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
DFT	Discrete Fourier Transform
JND	Just Noticeable Distortion
FHT	Fast Hadamard Transform
SVD	Singular Value Decomposition
SVR	Support Vector Regression
NWT	Non-separable Wavelet Transform
HD	Hamming Distance
LWT	Lifting Wavelet Transform
EMD	Empirical Mode Decomposition
IMF	Intrinsic Mode Function
r	Residue
SD	Standard Deviation
FABEMD	Fast and Adaptive BEMD
VQ	Vector Quantisation
LSB	Least Significant Bit

MSB	Most Significant Bit
ST	Slant Transform
QIM	Quantization Index Modulation
ROI	Regions Of Interest
DDWT	Distributed Discrete Wavelet Transform
BEMD	Bivariate Empirical Mode Decomposition
SFFF	Self-Fractional Fourier Function
BVQ	Blind Vector Quantization
ECC	Error Correction Codes
LS	Lifting Scheme
IWT	Integer Wavelet Transform
T	Threshold
RDWT	Redundant Discrete Wavelet Transform
PST	Pinned Sine Transform

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, Internet products that make daily lives easier have grown drastically, such as images, video and audio. At the same time, they have led to the possibility of illegal reproduction, dissemination; and the important issue of copying intellectual property (You, 2009) (Zheng, Shi, & Lv, 2009). Consequently, the 'copyright infringement' problem has led to the need of research in this area. According to (Zhao, 2009), film and music industries lose millions of dollars per annum due to copyright infringement.

In addition to copyright protection, another important issue relates to the authentication and verification of the integrity of an image or other digital content. It is widely recognised that digital contents; especially images, can be manipulated and altered with ease. With the enormous availability of image editing software, like Corel Paint Shop and Adobe Photoshop, even novice users have the ability to modify or manipulate the contents of digital products. Accordingly, for some feasible applications, like news reporting, medical archiving and legal applications, it is particularly essential to verify image integrity where it is required to be certain that the image in question really returns what the scene seems to be at the moment of capture. In order to ensure image integrity, it is not merely necessary to prove that photographic verification remains authentic and unchanged, but in addition, any tampered regions should be localised to identify untrusted image parts (Wong & Memon, 2001) (Zhao, 2009).

Several approaches have to be adopted to ensure controlled manipulation and copyright protection (Gu & Gao, 2012). Two widely used approaches to ensure the security of transferring the digital content over the Internet include data encryption (Baptista, 1998) and digital watermarking (Bender, Gruhl, Morimoto, & Lu, 1996). Data encryption is a traditional mechanism used to protect data from illegitimate use by transforming the data into meaningless code. Cryptography has its drawback, because it does not ban or track digital products against illegal reproduction after it has been decrypted (Zhao, 2009). As a consequence, digital watermarking techniques are an adequate solution, as they can track digital contents after decryption.

Digital watermarking conceals the existence of secret data by embedding additional information into a meaningful host multimedia data file to distract the attention of observers; without introducing perceptual changes (Sukumar, Hemalatha, & Soman, 2009). Watermarking was first introduced at the beginning of the 1990s as a second generation of technical security protection after encryption (K. Loukhaoukha, 2009). This mechanism can be applied to different media formats, such as images, video and audio. Different techniques are used to embed different kinds of watermarks into multimedia contents to achieve various goals. Digital watermarking algorithms are

classified as either robust, semi-fragile, or fragile; and they are employed depending on the application to be used. A robust watermark is used for copyright protection. For this purpose, the embedded watermark must be robust and resistant towards deliberate attacks(Avila & Miyatake, 2010). Semi-fragile watermarks are designed to allow an acceptable level of alteration, such as slight contrast adjustment or low-level lossy compression in images (Jessica Fridrich, 2002). Meanwhile, fragile watermarks, which are used for tampering detection, do not require the same level of robustness as those used for copyright protection; mainly because it needs the capability to detect even the slightest modification to the media (Yeun & Mintzer, 1997). As a result, this type of watermarking is suitable for authentication and tamper localisation applications (P. Lin, Lee, & Chang, 2009).

Most digital watermarking systems perform a single task; either for copyright protection or tampering detection. However, for high-valued applications, such as military satellite images and e-commerce, it is necessary to verify that the image received is in fact authentic and possibly to confirm actual ownership. This trend has driven the launch of multi-purpose watermarking (Yang & Zhang, 2008). Research in this domain has attracted tremendous interest in recent years; mainly due to its challenging nature in effectively satisfying both aims without degrading one another.

1.2 Problem statement

As stated previously, copyright protection watermarking algorithms should be robust under various attacks. Among these geometric and non-geometric attacks which are described in the next chapter. Several watermarking techniques were recently proposed by embedding robust watermark into digital images. In general, most of the algorithms focus only on limited attacks to determine the watermark robustness (Cox, Kilian, Leighton, & Shamoon, 1997); (Kundur & Dimitrios, 1997); (S. Lee, Yoo, & Kalker, 2007); (Senthilkumar & Sarkar, 2012) . In addition, the size of the employed watermark in majority of literature is quite small when compared to that of the host image (Kundur & Dimitrios, 1997); (Raval & Rege, 2003); (Bi, Sun, Huang, Yang, & Huang, 2007). However, the algorithms proposed by Makbol et al., (Makbol & Khoo, 2013) which based on Redundant Discrete Wavelet Transform (RDWT) with the SVD (RDWT–SVD) and Makbol et al., (Makbol & Khoo, 2014) which used the integer wavelet transform based on the Lifting Wavelet Transform with the SVD transform (LWT-SVD) have accomplished a good watermarked imperceptibility with high watermark capacity and are also able to be robust against many forms of attacks; geometric and non-geometric attacks. In this regard, they are used for benchmarking the robust watermarking algorithm proposed in this thesis. The only drawback of Makbol et al. works that the Normalised Cross Correlation (*NCC*) values of the extracted watermarks under the translation attack, scaling attack, JPEG compression attack, wiener attack and median attack, were 0.601, 0.467, 0.732,0.715 and 0.715, respectively, which are less than the acceptable values. In general, an *NCC* value is accepted if it is $\geq$0.75 (Al-Haj, 2007).

Based on the above-mentioned points, the algorithm proposed in this study would try to overcome some of the limitations seen in the published reports. This work focuses primarily on transparency, robustness and high capacity approaches, which are described in the next few chapters.

To ensure the integrity and authenticity of digital images, a wide variety of authentication schemes have been proposed in the literature to detect image tampering. However, most of the existing schemes either fail to address this issue (Yeun & Mintzer, 1997); (Jessica Fridrich, 2002); (X. Zhang, Wang, Qian, & Feng, 2011);(Mandal & Ghosal, 2012) or use inaccurate method to evaluate the system performance (Walton, 1995); (Jessica Fridrich, 2002); (X. Zhang et al., 2011); (Mandal & Ghosal, 2012). For this reason, a procedure to generate an effectual and secure fragile watermarking scheme is developed in this thesis which is able to detect tampering and inculcate localisation without affecting image quality. Moreover, precise and impartial methods are utilised in evaluating and benchmarking the recommended fragile watermarking system against others in terms of critical forging attacks.

The multipurpose system is a new challenging area of research in digital watermarking. It mainly focuses on combining dual watermarks; robust and fragile to achieve content authentication and also copyright protection. However, in most of the recent works only one function has been achieved: either the robustness function has been done at the expense of the fragility or vice versa due to shortcomings in the technique employed for copyright protection or tamper detection (Avila & Miyatake, 2010); (Schlauweg, Pröfrock, Zeibich, & Müller, 2006); (Sharma, Sharma, & Sahula, 2013); (Deguillaume, Voloshynovskiy, & Pun, 2003). In this thesis, a new effective dual purpose watermarking system is proposed. It has been devised to meet the criteria of fragility as well as robustness, while combining the processes of copyright protection and proofing tampering at the same time without significant degradation of each other.

1.3 Objective of the study

The main objective of this thesis is to design a dual purpose image watermarking system that can satisfy both robustness and fragility simultaneously.

The main objective can be broken into several sub-objectives as follows:

i. To design an effective robust image watermarking system that is comparable to or outperforms current robust watermarking techniques.
ii. To design an effective fragile image watermarking system that is comparable to or outperforms current fragile watermarking techniques.
iii. To design an effective mechanism to combine both robust and fragile image watermarking systems designed in item (1) and (2), where the performance remains at par or only degrades at an acceptable level after inserting the dual watermarks.

1.4 Scope of the study

The evaluation of the proposed systems is performed by using the following methods:

i. The proposed robust watermarking system was evaluated in terms of robustness and perceptuality. The critical attacks used to test the robustness of the algorithm are intentional and nonintentional attacks. The parameter used to evaluate the robustness of the proposed algorithm accurately is Normalized Cross Correlation (*NCC*), and represents the correlation between the original and extracted watermarks after the system has been subjected to all possible attacks. The quality of the watermarked image is evaluated using the Peak Signal to Noise Ratio (*PSNR*) and describes the quality of the image after adding the watermark. Furthermore, the proposed algorithm was benchmarked against existing algorithms and was able to outperform them with respect to watermarked image quality and robustness.

ii. The tamper detection ability of the proposed fragile watermark algorithm is evaluated by applying several tampering attacks such as copy paste and deletion attacks. False positive (F_P), False negative (F_N), and Average of detection rate (*AV*) are used to evaluate the tampering detection ability of the authentication algorithm. It is clear that the proposed system can detect even a slight percentage of tampering by achieving a low false positive value with a high detection rate. Furthermore, the system was compared to the existing fragile watermark systems and was able to outperform them with respect to image quality and the ability to detect tampered area.

iii. The proposed dual purpose algorithm was evaluated in terms of robustness and fragility and was subjected to all possible attacks that critically affect the performance of the robustness and fragility algorithms. Furthermore, the performance of the algorithm was compared to the proposed single purpose robust watermark and single purpose fragile watermark in terms of imperceptibility, robustness and fragility. The values of *NCC, PSNR* and *AV* are still high and degrade at an acceptable level after inserting the dual watermarks.

1.5 Thesis layout

The thesis is comprised of five chapters. Chapter one introduces the background and significance of the study, accompanied by the problem statement, objectives and scope of the study. Chapter two presents a review and analysis of previous researches related to the present study. It also covers a review of the literature on robust and fragile watermarking algorithms, including their advantages and disadvantages. Chapter three presents the proposed system and explains the utilized methodologies in detail. Chapter four provides the experimental results and discusses the analysis of the results achieved. Finally, Chapter five reports the most promising research trends along with the conclusions of this thesis.

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