

AN IMPROVED SCALING FACTOR FOR ROBUST DIGITAL IMAGE
WATERMARKING SCHEME USING DWT AND SVD

NUR AFEZA AJIRAH BINTI NOOR SAAID

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 Computing Universiti Teknologi Malaysia

SEPTEMBER 2017

ACKNOWLEDGEMENT

Alhamdulillah, in the name of Allah, the Most Gracious and the Most Merciful, my master's thesis has been accomplished.

First of all, I am very grateful to express my sincere thankful to my supervisor, Dr. Mohd Fo'ad Bin Rohani that give advice, guided and encouragement during completing this thesis. I also would like to thank Dr. Satendra Kumar from India because helping me throughout the process completing my project.

The most sincere appreciation to my mother Che Som Binti Man, my father Noor Saaid Bin Abdul Aziz, all my family members and to my husband Muhamad El Hafiz Bin Ayas who have always strengthen and supported me throughout my studies for the whole semester.

I am also grateful to have supportive friends and I would like to thank the staff of University Teknologi Malaysia and especially Faculty of Computing for their kind cooperation.

ABSTRACT

As the internet has becoming very popular for digital media sharing, the digital media is easy to be accessed, downloaded and vulnerable to image processing attacks. Digital watermarking is a technique used to secure information by embedding an additional information known as watermark into the original data. The proposed scheme is approach to improve scale factor for robust image watermarking using two level of Discrete Wavelet Transform with Singular Value Decomposition. The first and second level of DWT decomposition are performed on HL and HL1 sub band respectively. One of the main contribution of this proposed approach is the decomposition of host image using two level DWT decomposition. The aim of this project primarily is to enhance the robustness of watermarking techniques by obtaining the most optimize scaling factor which increased and control the strength of watermarked image. Scale factor is a coefficient that can influence the quality and robustness of watermarked image. To achieve the research objectives, three phases of research framework are fulfilled; First phase is the analysis on scaling factor, DWT and SVD, secondly is the watermark encoding and the generation of scale factor value and lastly is the evaluation of watermarked image quality and robustness based on the scale factor. The highest PSNR recorded is 69.2112 with best scale factor 0.01. The experimental result shows significant improvement on the quality and robustness of the watermarked image using this proposed scheme.

ABSTRAK

Oleh kerana internet telah menjadi suatu medium yang sangat popular untuk perkongsian media digital, media digital mudah diakses, dimuat turun dan terdedah kepada serangan pemprosesan imej. *Digital watermarking* adalah teknik yang digunakan untuk memasukkan maklumat tambahan yang dikenali sebagai *watermark* ke dalam data asal. Pendekatan yang dicadangkan dalam penyelidikan ini adalah untuk memperkenalkan faktor skala yang lebih baik untuk teknik *watermarking* dengan menggunakan *Discrete Wavelet Transform* dan *Singular Value Decomposition*. Tahap pertama dan kedua *DWT decomposition* dilakukan pada HL dan HL1 sub band masing-masing. Salah satu sumbangan utama pendekatan yang dicadangkan ini ialah penguraian imej asal menggunakan dua peringkat *DWT decomposition*. Tujuan projek ini terutamanya adalah untuk meningkatkan keteguhan teknik *watermarking* dengan mendapatkan faktor skala yang paling optimum untuk meningkatkan kualiti dan mengawal kekuatan *watermarked image*. Faktor skala adalah koefisien yang dapat mempengaruhi kualiti dan ketahanan *watermarked image*. Untuk mencapai matlamat penyelidikan, tiga fasa rangka penyelidikan dipenuhi; Fasa pertama adalah analisis faktor skala, *DWT* dan *SVD*, kedua ialah pengkodan *watermark* dan penjanaan nilai faktor skala dan akhirnya adalah penilaian kualiti *watermarked image* dan kekukuhan berdasarkan faktor skala. Nilai *PSNR* tertinggi adalah 69.2112 dengan menggunakan factor skala 0.01. Hasil keputusan menunjukkan peningkatan yang ketara terhadap kualiti dan keteguhan imej *watermarked image* dengan menggunakan skema cadangan ini.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENT	vi
	LIST OF TABLE	ix
	LIST OF FIGURES	x
	LIST OF ABBREVIATIONS	xii
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Background of the problem	2
	1.3 Statement of Problem	6
	1.4 Research Aim	7
	1.5 Research Objectives	8
	1.6 Scopes	8
	1.7 Expected Contribution of the Project	9
	1.8 Organization of the Thesis	9
2	LITERATURE REVIEW	10
	2.1 Introduction	10
	2.2 Overview of Watermarking	11

2.3	General Framework of Digital Watermarking	12
2.4	Features of Digital Watermarking	13
2.5	Application of Watermarking	15
2.6	Watermarking Attacks	16
2.7	Types of Watermark	17
2.8	Watermark Principle	18
2.9	Factors Contributing to Watermark Effectiveness	20
2.10	Techniques on Watermarking	20
2.10.1	Discrete Wavelet Transform (DWT)	21
2.10.2	Singular Value Decomposition (SVD)	22
2.10.3	Chirp-Z-Transform (CZT)	23
2.10.4	Discrete Cosine Transform (DCT)	24
2.10.5	Discrete Fourier Transform (DFT)	24
2.11	Scaling Factor	25
2.12	Related work	26
2.13	Comparative Analysis of Related Work	29
2.14	Summary	31
3	RESEARCH METHODOLOGY	32
3.1	Introduction	32
3.2	Research Objectives	33
3.3	Research Framework	34
3.3.1	Phase I	35
3.3.2	Phase II	35
3.3.3	Phase III	36
3.4	Software and Hardware Requirements	37
3.4.1	Software Requirement	37
3.4.2	Hardware Requirement	37
3.5	Measuring and Evaluation Performance	38
3.6	Image Processing Attacks	39
3.7	Summary	41

4	DESIGN AND IMPLEMENTATION	42
	4.1 Introduction	42
	4.2 Implementation of First Research Objective	42
	4.3 Proposed Approach	44
	4.3.1 Watermark Embedding	44
	4.3.2 Experimental Result Approach	45
	4.4 Data Set	46
	4.5 Initial Result	48
	4.6 Summary	49
5	EXPERIMENTAL RESULT	50
	5.1 Introduction	50
	5.2 Implementation of Proposed Approach (2 Level DWT Decomposition)	50
	5.3 Implementation of Proposed Approach (1 Level DWT Decomposition)	54
	5.4 Implementation of Proposed Approach without Singular Value Decomposition (SVD)	55
	5.5 Experimental Results	56
	5.6 Different Data Set	70
	5.7 Summary	73
6	CONCLUSION	74
	6.1 Introduction	74
	6.2 Concluding Remarks	78
	6.3 Research Contribution	76
	6.4 Future Work	77
	REFERENCES	78
	APPENDIX A-E	82-86

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Comparative Analysis of Related Work	29
5.1	Scale factor, PSNR and NC without any Image Processing Attack using One Level of DWT Decomposition	55
5.2	Scale factor, PSNR and NC without any Image Processing Attack using One Level of DWT Decomposition	56
5.3	Scale factor, PSNR and NC without any Image Processing Attack	58
5.4	Normalized Correlation Values of Extracted Watermarks against Different Attacks	61
5.5	Normalized Correlation Values of Extracted Watermarks against Gaussian Noise with Different Standard Variance	62
5.6	Normalized Correlation Values of Extracted Watermarks against Salt & Pepper with Different Noise Density	62
5.7	Comparison of Extracted Watermark Images with SF 0.01 and 0.09	68
5.8	Scale factor, PSNR and NC without any Image Processing Attack	72
5.9	Normalized Correlation Values of Extracted Watermarks against Different Attacks	72

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Problem Characteristics of Robust Watermarking Technique based on Scaling Factor	5
2.1	Block Diagram of Watermarking in Digital Image	12
2.2	Digital Watermarking System Framework	13
2.3	Encoding Watermark Process	19
2.4	Decoding Watermark Process	19
2.5	One Level DWT Decomposition	21
3.1	Research Framework	34
3.2	Formula of Normalized Correlation	39
4.1	Outline on Research Topic	43
4.2	Normalized Correlation Formula	46
4.3	Lena Image	47
4.4	Camerman image	47
5.1	One Level of DWT Decomposition on Host Image	51
5.2	Inverse DWT on sub bands	52
5.3	Two Level of DWT on HL sub band	53
5.4	Watermarked Image	57
5.5	Watermarked Image with Scale Factor 0.09	59
5.6	Corruption of Watermarked Image	59
5.7	PSNR versus Scale Factor	60
5.8	NC of Extracted Watermark Image against Histogram Equalization versus Scale Factor	63

5.9	NC of Extracted Watermark Image against Salt & Pepper versus Scale Factor	64
5.10	NC of Extracted Watermark Image against Median Filtering versus Scale Factor	65
5.11	NC of Extracted Watermark Image against Gaussian Noise (GN) versus Scale Factor	66
5.12	NC of Extracted Watermark Image against Resize Attack versus Scale Factor	67
5.13	Host Image (Mandrill.png)	70
5.14	Watermark Image	70
5.15	Watermarked Image of Different Data Set	71

LIST OF ABBREVIATIONS

CZT	- Chirp-Z-Transform
DCT	- Discrete Cosine Transform
DFT	- Discrete Fourier Transform
DWT	- Discrete Wavelet Transform
MSE	- Mean Square Error
NC	- Normalized Correlation
PSNR	- Peak Signal to Noise Ratio
SVD	- Singular Value Decomposition

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rapid development of computer technologies and network communications make the distribution of multimedia data via the internet become very popular and crucial. People get to share their life moments and uploaded on social networking. Thus, the availability of multimedia data on the network is free to be access and download. The internet is an open system which means internet is accessible, has no boundary and vulnerable to attack. Due to the circumstances, transmitted data via internet is easily modified, altered and stolen. Therefore, copyright and ownership protection has becoming a very serious issue in these past years. As a way to resolve this issue, watermarking technique is introduced. Digital watermarking is a technique to secure information by embedded additional information known as digital signature or watermark into original content (Mohamed & Sujatha, 2010).

There are two main processes in watermarking technique; encoding and decoding (Mahmoud *et al.* 2010). The encode process involve the reading of the host image (H) and using mark image (W) to generate the watermark image (HW). While decode process is the extraction of the mark image from the watermarked image.

As the technologies keep advancing throughout the year, the attacks toward watermarking are increasing. The most common attacks in watermarking are removal attacks, simple attack, detection-disabling attacks and ambiguity attacks (Sanyam *et al*, 2015). Further discussion about watermarking attacks will be provided in the next chapter.

1.2 Background of the Problem

Social networking has widely been used for information sharing these days. People always share their life moments as images and uploaded it on the social networking. Thus, the images are freely to be accessed and downloaded. Unfortunately, people who have bad intention could download the images and they might make modification to the images illegally. Thus, one of the solution to this problem is using digital watermarking techniques.

As been mentioned earlier, digital watermarking is a technique to secure information by embedding additional information known as digital signature or watermark into original content (Mohamed & Sujatha, 2010). The applications of watermarking technique are numerous such as copyright protection, digital fingerprinting, content authentication, broadcast monitoring, temper detection and localization, ID card, time stamping and miscellaneous applications.

Even though watermarking technique is used to secure information by protecting the ownership and copyright protection, there are some security issues unsolved until today. Generally, watermarking has five important features that considered in the most practical application. Those five features are imperceptibility, robustness, capacity,

security and false positive (Tao *et al*, 2014). Imperceptibility is an important condition for digital watermarking; that is the visual similarity between the embedded watermark image version and original (host) image one of the media element and the perceptual quality of the original signal should be transformed imperceptibly by the insertion of the watermark.

One of the reasons to keep the imperceptibility of the original image after being encode with watermark is to ensure with presence or absence of a watermark, the original image could not be distinguish with watermarked image. In addition, any suspicious perceptible object may give a clue to attacker to detect the watermark and perhaps its precise location could be detected. Watermarking is said to be robust when it has the ability to resist against attacks that attempt to remove or destroy the watermark without degrading the quality of watermarked image (Khaled, 2013). Watermark must be robust to prevent any distortions applied to the watermarked signal when it is being transmitted across the internet. But unfortunately, it is impossible for watermark to be robust against all signal processing operations.

In watermarking technique, scale factor influence the strength of watermark by making it invisible with different value of scaling factors. Next, capacity is defined using the largest quantity of information that inserted watermarks are capable of hiding, and embedded watermarks can be extracted credibly for the purposes of authentication and copyright safeguard. The capability relies on the size of original data. If more original pattern is attainable, more bits can be embedded. The forth feature of watermarking is the security. All existing watermarking algorithms must be safe and robust thus it can be used for copyright protection, data authentication or tracking the illegal distribution of digital content. Lastly, false positive refers to the non-existing watermark in the process of watermark detection. It is actually refers to the number of false positive that is predictable to occur during running of the detector.

Figure 1.1 shows the problem characteristic of robust watermarking technique based on scaling factor. Brief explanation about the scenario in robust image watermarking, existing watermarking technique, the gaps, trend and attack, limitation of existing techniques and desired solution are provided in the figure.

In this study, the features of watermarking will be focusing on the robustness as well as the quality of the watermarked image. To achieve the robustness of the watermarked image, the selection of the scaling factor is important. This is because, scaling factor determine the quality and robustness of watermarked image by selecting ratio that mix the host image and watermark image (Irshad & Pant, 2014).

Scaling factor should not be too low because it will reduce the quality of watermark robustness hugely. Similarly, it should not be too high as well as it will reduce the quality of watermark image in the aspect of imperceptibility (Irshad & Pant, 2014). Thus, there is a need for optimal selection of scaling factor in order to balancing between robustness and imperceptibility. To measure the quality of the watermarked image, the Peak Signal to Noise Ratio (PSNR) is used and to evaluate the robustness of the watermarking scheme against image processing attacks, Normalized Correlation (NC) is used (Ramanjaneyulu & Rajarajeswari, 2010).

PSNR of an image can be calculated using the mean squared error (MSE). The PSNR block computes the peak signal-to-noise ratio, in decibels, between two images. This ratio usually used to measure the quality between original and a compressed image. The higher the PSNR, the better the quality of the compressed image. While, the MSE represents the cumulative squared error between the compressed and the original image, whereas PSNR represents a measure of the peak error. The lower the value of MSE, the lower the error. Meanwhile, NC is used to evaluate the robustness of the proposed scheme. Further discussion about PSNR and NC calculation will be discuss in Chapter three.

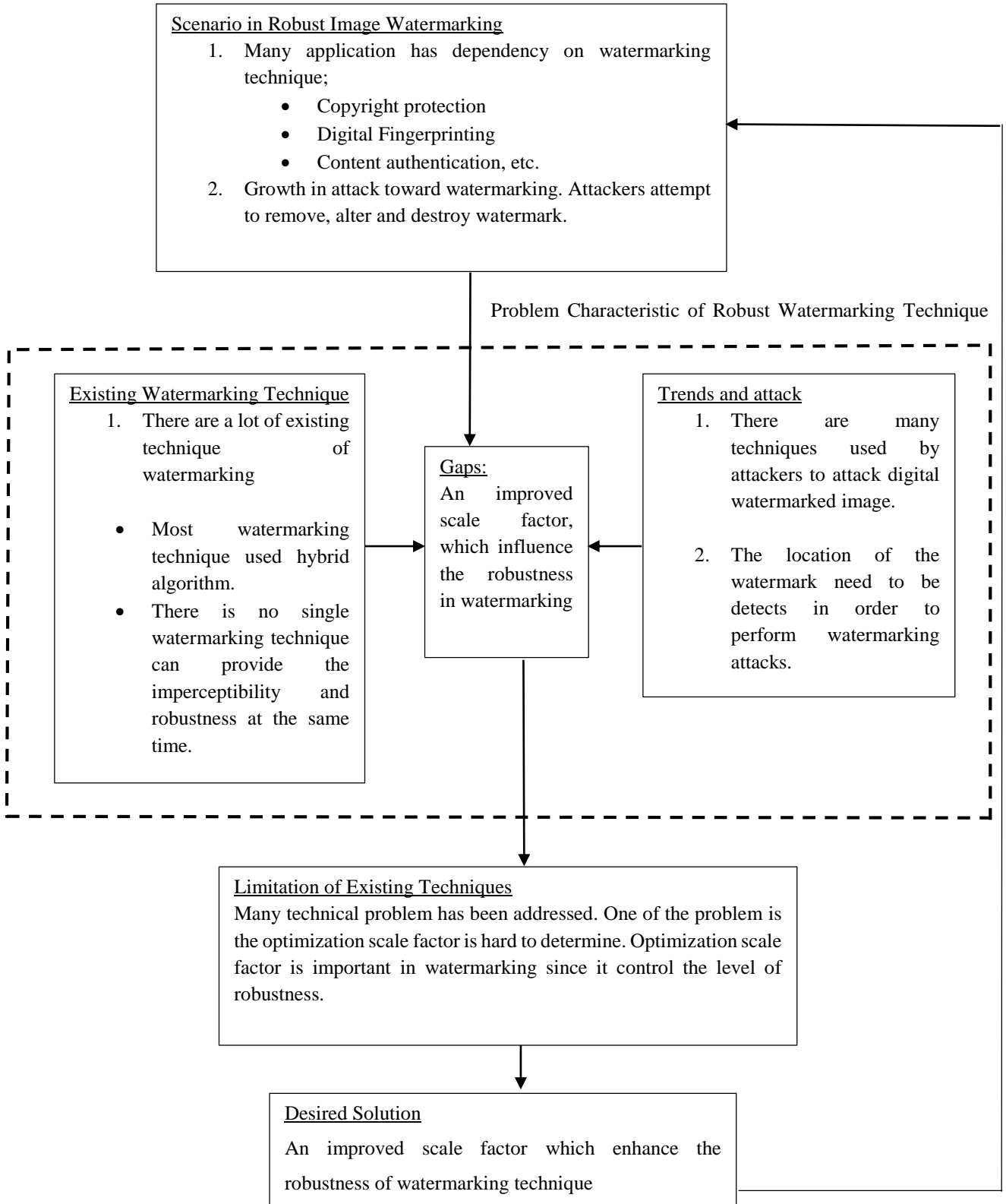


Figure 1.1 Problem Characteristics of Robust Watermarking Technique Based on Scaling Factor

1.3 Statement of Problem

The exchange of digital documents became a very easy task these days. With extraordinary technology revolution digital documents are facing with confidentiality and copyright issues. Digital documents such as images, videos and audios are easily duplicated, modified and illegally attacked without failure. Thus, digital images need to be protected and watermarking technique was introduced. Watermarking should be robust. In term of robustness, watermarking algorithm has three classification; fragile, semi-fragile and robust. Robust watermarking should be able to resist against attacks that attempt to remove or destroy the watermark without degrading the quality of watermarked image. However, the robustness is controlled by a single scaling factor (SSF). Unfortunately, determining the optimal values of the scaling factors is difficult problem. Scaling factor α controls the strength of watermark image. Thus, optimum value of scale factor should be used in watermarking to ensure the watermark is robust. Therefore, further study on the selection on optimize scaling factor is conducted and the value of optimize scale factor for this proposed scheme is proposed.

Thus, the main research question to be answered in this study is:

“Does the robustness of watermarking will be strengthened if the improvement of scaling factor is obtained through the implementation of Discrete Wavelet Transform and Singular Value Decomposition on embedding watermarking process?”

To ensure the main research question above to be answered at the end of this study, by answering additional research question follow would be helpful:

- i. Does scaling factor influence the robustness of watermarking in digital image?
- ii. How to obtain the improved value of scale factor using DWT and SVD technique algorithm?
- iii. Does the proposed scaling factor in this proposed scheme enhance the robustness of watermarking technique in digital image?

1.4 Research Aim

The aim of this research to enhance the robustness of watermarking techniques using DWT and SVD by the selection of optimize scale factor.

1.5 Research Objectives

- i. To study the effect of scaling factor on robust watermarking technique using DWT and SVD algorithm on digital image.
- ii. To propose an improved scaling factor that can enhance the robustness on watermarking technique in digital image.
- iii. To evaluate the quality of watermarked image and the robustness of the watermarking scheme based on scaling factor using PSNR and NC.

1.6 Scopes

- i. Watermarking technique : Discrete Wavelet Transform (DWT)
: Singular Value Decomposition (SVD)
- ii. This research study will focusing on the robustness as well as the quality of watermarked image.
- iii. Test data : Host image (Lena image)
: Host image (Mandrill image)
: Watermark image (Cameraman image)
: Watermark image (Flower image)
- iv. Image format : .png

1.7 Expected Contribution of the Research

- i. The presentation considerations, definitions and discussion on related topic of watermarking.
- ii. Enhancement of robust digital image based on the selection of improved scale factor using DWT and SVD.
- iii. Achievement of good quality watermarked image and robust proposed scheme.

1.8 Organization of the Thesis

This thesis is organized into five chapters. Chapter 1 is the introduction of this research. Chapter 2 is the presentation of literature review that discusses on watermarking, existing techniques and related works. In addition, the summarization of issues and research gap also stated in this chapter. Chapter 3 discussed the research methodology of this study which consist of three phases. Chapter 4 will discuss the design and implementation of proposed algorithm. Chapter 5 discussed the detailed of experimental result. Finally, Chapter 6 is the conclusion of this research.

REFERENCES

- Agoyi, M., Celebi, E., and Anbarjafari. (2015). A watermarking algorithm based on chirp z-transform, discrete wavelet transform and singular value decomposition. *Signal Image and Video Processing*, 9,735-745.
- Anilkumar, K., Swati, P., and Mahesh, G. (2011). Journal of Information Engineering and Applications www.iiste.org ISSN 2224-5758 (print) ISSN 2224-896X (online) Vol 1.
- Anumol, J., and Anusudha, K. (2013). International Journal of Signal & Image Processing, Robust watermarking based on DWT SVD Issue. 1, Vol. 1.
- Arun, R., Madhu, S., Nair, R., Vrinthavani and Rao, T. (2011). An Alpha Rooting Based Hybrid Technique for Image Enhancement. Online publication in IAENG.
- Arun, K. R., Sai K. D., and Venkat N. R. (2016). International Journal of Computer & Organization Trends (IJCOT). Digital Image Watermarking Based on Genetic Algorithm Approach. Volume 38 Number1.
- Baisa L Gunjal and Suresh N. M. (2014). MEO based secured, robust, high capacity and perceptual quality image watermarking in DWT-SVD domain.
- Chin, S., Shieh, Hsiang C. H., Feng H. W., and Jeng S.P. (2004), “Genetic watermarking based on transform-domain techniques”, *Pattern Recognition*, Vol. 37, No. 3, pp. 555-565.
- Harshita, R., Ashwani, K., and Satendra, K. (2013). International Journal of Computer Applications. Robust Digital Image Watermarking Scheme for Copyright Protection (0975 – 8887) Volume 75– No.18.
- Heena. S., Mohd.Imran Khan and Yashovardhan, K. (2012). A Robust DWT Digital Image Watermarking Technique Basis On Scaling Factor International Journal of Computer Science, Engineering and Applications (IJCSEA). Vol.2, No.4.

- Huang C-H and Wu J-L (2000). Watermark optimization technique based on genetic algorithms. *Security and Watermarking of Multimedia Contents II*, January 2000, San Jose, Calif, USA, *Proceedings of SPIE 3971*: 516-523.
- Irshad, A. A., and Pant, M. (2014). *Advances in Intelligent Systems and Computing. Proceedings of Fourth International Conference on Soft Computing for Problem Solving. Volume (336)*.
- Jagadeesh, B. S., Kumar, S., and Rajeswari K. R. (2010). Image watermarking scheme using singular value decomposition, quantization and genetic algorithm, *Signal Acquisition and Processing, 2010. ICSAP '10. International Conference on*, 9–10, pp. 120–124.
- Khaled, L. (2013). Image Watermarking Algorithm Based on Multiobjective Ant Colony Optimization and Singular Value Decomposition in Wavelet Domain. *Journal of Optimization. Volume 2013 (2013), Article ID 921270*, 10 pages.
- Kociołek, M., Materka, A., Strzelecki, M., and Szczypiński, P. (2001). Discrete wavelet transform – derived features for digital image texture analysis, *Proc. of Interational Conference on Signals and Electronic Systems*, 18-21 September 2001, Lodz, Poland, pp. 163-168.
- Li, Q., and Memon, N. "Security models of digital watermarking." *Multimedia content analysis and mining (2007)*: 60-64.
- Liu, R., and Tieniu, T. T., (2002). "A SVD-based watermarking scheme for protecting rightful ownership", *IEEE transactions on multimedia*, vol. 4, pp 121-128.
- Mahmoud, E., Zaidan, A. A., Zaidan, B. B., Mohamed, E., Sharif, and Hamdan.O. A. (2010). *Journal of computing. Volume 2, issue 2, february 2010, issn 2151-9617*.
- Mohamed, M.S., and Sujatha, S. S. (2010). *International Journal of Advanced Science and Technology Advanced Science and Technology Advanced Science and Technology Vol. 24 Vol. 24*.
- Neeraj, B., Sharma, M.M., Garhwal, A. S., and Manish, M. (2012). *International Conference on Radar, Communication and Computing (ICRCC), SKP Engineering College, Tiruvannamalai, TN., India. 21 – 22, pp.185-189*.
- Potdar, V.M, Han, S., and Chang, E., (2005). *A Survey of Digital Image Watermarking*

Techniques. *Proceedings of the IEEE Industrial Informatics*.

- Pratibha, Sharma and Shanti, S. (2013). "Digital Image Watermarking Using 3 Level Discrete Wavelet Transform." *Conference on Advances in Communication and Control Systems*. Vol. 24.
- Raman, M., and Himanshu, A. (2010). A Comprehensive Review of Image Enhancement Techniques, *Journal of Computing*, Vol. 2, Issue 3, March 2010, ISSN 2151-9617.
- Raju U.S.N, Kamalakanta, S., Sunaina. C., and Priyanka, J. (2015). A New Hybrid Watermarking Technique using DCT and DWT based on Scaling Factor International conference on futuristic trend in computational analysis and knowledge management (ABLAZE 2015). Vol 1.
- Ramanjaneyulu and Rajarajeswari, K. (2010). "An Oblivious And Robust Multiple Image Watermarking Scheme Using Genetic Algorithm". *The International journal of Multimedia & Its Applications*, Vol. 2, No. 3, pp. 19-38.
- Raunak, P., Rucha, M., Sampurna, M., and Pratik, P. (2013). Digital Image Watermarking using DCT and ZIP Compression Technique. *Global Journal of Computer Science and Technology Graphics & Vision* Volume 13 Issue 3 Version 1.0.
- Rosline, G, B., VijayaKumar, L., Sumalatha, and Krishna V. V. (2009). Secure and Robust Digital Watermarking on Grey Level Images. *International Journal of Advanced Science and Technology* Vol. 11.
- Sanyam, A., Priyanka and Usha, P. (2012). *International Journal of Scientific & Engineering Research*, Volume 6, Issue 1, January-2015 841 ISSN 2229-5518.
- Satendra, K., Jaydeep, K., and Nitin, A. (2012). Enhanced Digital Image Watermarking Scheme based on DWT and SVD. *International Journal of Computer Applications* (0975 – 8887) Volume 57– No.11.
- Murty, S., & Kumar, R. (2010). A Robust Digital Image Watermarking Scheme Using Hybrid DWT-DCT-SVD Technique. *IJCSNS International Journal of Computer Science and Network Security*, VOL.10 No.10.
- Snehal, O. M., and Shandilya, V. K. (2012). Spatial and Transformation Domain Techniques for Image Enhancement. *International Journal of Engineering Science and Innovative Technology (IJESIT)* Volume 1, Issue 2.
- Soo, C. P., Ja, H. C., Jian, J. D., and Ming, Y. C. (2008), "Eigenvalues and Singular Value

- Decompositions of Reduced Biquaternion Matrices. *Proceedings of the IEEE Transactions on Circuits And Systems*, Vol. 55, No. 9.
- Sukhraj, K., and Navjot, K. (2015). Improved Invisible Watermarking Using DWT, CZT and Negative Selection Algorithm Based SVD. ISSN: 2277-3754 ISO 9001:2008 Certified International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, Issue 12.
- Swanirbhar, M., Madhusudhan, M., and Dinamani, A. S. (2008). A Hybrid SVD and Wavelet based Watermarking. 2nd National Conference Mathematical Techniques: Emerging Paradigms for Electronics and IT Industries.
- S.Ramakrishnan, T.Gopalakrishnan and K.Balasamy (2011). SVD Based Robust Digital Watermarking For Still Images Using Wavelet Transform. CCSEA 2011, CS & IT 02, pp. 155–167.
- Takaya, K., Ma and T.N (1990). Application of Image Reconstruction by Means of Chirp Z-Transform. In IAPR Workshop on Machine Vision Application, pp. 77-80.
- Tao H, Chongmin L, Jasni Mohamad Zain and Ahmed N. Abdalla (2014). Robust Image Watermarking Theories and Techniques: A Review. 2014. Volume 2. 122-138.
- Taylor, P (2009). Text-to-Speech Synthesis, pp. 297-308. Cambridge University Press, Cambridge, MA.