

ROBUST COLOR IMAGE WATERMARKING USING DISCRETE WAVELET
TRANSFORM, DISCRETE COSINE TRANSFORM AND CAT FACE
TRANSFORM

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UNIVERSITI TEKNOLOGI MALAYSIA

ROBUST COLOR IMAGE WATERMARKING USING DISCRETE WAVELET
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DEDICATION

To my dear parents who understand me and give me this
opportunity for continuing my study.

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In preparing this thesis, I contacted many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, AP.Dr.Mohd Shahidan Bin Abdullah, for encouragement, guidance, critics and friendship.

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ABSTRACT

The primary concern in color image watermarking is to have an effective watermarking method that can be robust against common image processing attacks such as JPEG compression, rotation, sharpening, blurring, and salt and pepper attacks for copyright protection purposes. This research examined the existing color image watermarking methods to identify their strengths and weaknesses, and then proposed a new method and the best embedding place in the host image to enhance and overcome the existing gap in the color image watermarking methods. This research proposed a new robust color image watermarking method using Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), and Cat Face Transform. In this method, both host and watermark images decomposed into three color channels: red, green, and blue. The second level DWT was applied to each color channel of the host image. DWT decomposed the image into four sub-band coefficients: Low-pass filter in the row, Low-pass filter in the column (LL) signifies approximation coefficient, High-pass filter in the row, Low-pass filter in the column (HL) signifies horizontal coefficient, Low-pass filter in the row, High-pass filter in the column (LH) signifies vertical coefficient, and High-pass filter in the row, High-pass filter in the column (HH) signifies diagonal coefficient. Then, HL_2 and LH_2 were chosen as the embedding places to improve the robustness and security, and they were divided into 4×4 non-overlapping blocks, then DCT was applied on each block. DCT turned a signal into the frequency domain, which is effective in image processing, specifically in JPEG compression due to good performance. On the other hand, the Cat Face Transform method with a private key was used to enhance the robustness of the proposed method by scrambling the watermark image before embedding. Finally, the second private key was used to embed the watermark in the host image. The results show enhanced robustness against common image processing attacks: JPEG compression (3.37%), applied 2% salt and pepper (0.4%), applied 10% salt and pepper (2%), applied 1.0 radius sharpening (0.01%), applied 1.0 radius blurring (8.1%), and can withstand rotation attack. In sum, the proposed color image watermarking method indicates better robustness against common image processing attacks compared to other reviewed methods.

ABSTRAK

Perhatian utama dalam penandaan gambar warna adalah mempunyai kaedah penandaan air yang berkesan yang kuat terhadap serangan pemprosesan gambar biasa seperti pemampatan JPEG, putaran, penajaman, pengaburan, dan serangan garam dan lada untuk tujuan perlindungan hak cipta. Penyelidikan ini mengkaji kaedah penandaan gambar warna yang ada untuk mengenal pasti kekuatan dan kelemahan mereka, dan kemudian mencadangkan kaedah baru dan tempat penyematan terbaik dalam gambar hos untuk meningkatkan dan mengatasi jurang yang ada dalam kaedah penandaan gambar warna. Penyelidikan ini mencadangkan kaedah penandaan air gambar warna yang baru menggunakan *Discrete Wavelet Transform* (DWT), *Discrete Cosine Transform* (DCT), dan *Cat Face Transform*. Dalam kaedah ini, gambar hos dan tanda air diuraikan menjadi tiga saluran warna: merah, hijau, dan biru. DWT tahap kedua diterapkan pada setiap saluran warna dari gambar hos. DWT menguraikan gambar menjadi empat pekali sub-band: Penapis lulus rendah di baris, penapis lorong rendah di lajur (LL) menandakan pekali penghampiran, penapis lulus tinggi di baris, penapis lorong rendah di lajur (HL) menandakan pekali mendatar, saringan lulus rendah di baris, saringan lulus tinggi di lajur (LH) menandakan pekali menegak, dan saringan lulus tinggi di baris, penapis lulus tinggi di lajur (HH) menandakan pekali pepenjur. Kemudian, HL_2 dan LH_2 dipilih sebagai tempat penyisipan untuk meningkatkan ketahanan dan keselamatan, dan mereka dibahagikan kepada blok 4×4 yang tidak bertindih, kemudian DCT diterapkan pada setiap blok. DCT mengubah isyarat menjadi domain frekuensi, yang efektif dalam pemprosesan gambar, khususnya dalam pemampatan JPEG disebabkan oleh prestasi yang baik. Sebaliknya, kaedah *Cat Face Transform* dengan kunci peribadi digunakan untuk meningkatkan kekuatan kaedah yang dicadangkan dengan menggegarkan gambar tanda air sebelum menyisipkannya. Akhirnya, kunci peribadi kedua digunakan untuk menanam tanda air pada gambar hos. Hasilnya menunjukkan kekuatan yang lebih baik terhadap serangan pemprosesan gambar yang biasa: Mampatan JPEG (3.37%), menggunakan garam dan lada 2% (0.4%), aras 10% garam dan lada (2%), aras 1.0 pengasahan radius (0.01%), diterapkan 1.0 radius kabur (8.1%), dan berupaya menahan serangan putaran. Ringkasnya, kaedah penandaan gambar warna yang dicadangkan menunjukkan ketahanan yang lebih baik terhadap serangan pemprosesan gambar biasa berbanding kaedah tinjauan lain.

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LIST OF ABBREVIATIONS

RGB	-	Red, Green, Blue
HR	-	Host image Red color channel
HG	-	Host image Green color channel
HB	-	Host image Blue color channel
DWT	-	Discrete Wavelet Transform
IDWT	-	Inverse Discrete Wavelet Transform
RDWT	-	Redundant Discrete Wavelet Transform
DCT	-	Discrete Cosine Transform
IDCT	-	Inverse Discrete Cosine Transform
WR	-	Watermark image Red color channel
WG	-	Watermark image Green color channel
WdR	-	Watermarked image Red color channel
WdG	-	Watermarked image Green color channel
WdB	-	Watermarked image Blue color channel
EWR	-	Extracted Watermark image Red color channel
EWG	-	Extracted Watermark image Green color channel
EWB	-	Extracted Watermark image Blue color channel
FRT	-	Finite Ridgelet Transform
ABC		Artificial Bee Colony

LIST OF SYMBOLS

\oplus	-	Exclusive or - XOR
μ	-	Population Mean
σ	-	Standard Deviation

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CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, by growing internet technology, the common popularity of the internet, and fast development of multimedia technology, sending and receiving digital data has been increased (Bajracharya and Koju, 2017; Su and Chen, 2017). Due to this, the main focus of researches' activities in the last two decades was on multimedia security, such as tamper detection, copyright protection, and authentication of digital data; furthermore, find methods to prevent the illegal sharing of digital data and tampering with it (Su *et al.*, 2017b). Many researchers have proposed many methods to improve digital data safety; for this reason, digital watermarking is considered a powerful method to overcome copyright protection problems, among other methods (Su and Chen, 2016).

Digital Watermarking is one method used to attain copyright protection and authentication of digital data (Bajracharya and Koju, 2017). It provides a promising way for protecting multimedia data from illegal manipulation and duplication since its main idea is to permit access to the host image by inserting a visible or an invisible watermark into it. The insertion of the watermark is based on the concept of the controlled confusion of the host image. According to their ability to resist attacks, there are two types of watermarking: robust and fragile. Depends on what sort of information is needed during the watermark extraction phase, the watermarking algorithm is either blind, semi-blind, or non-blind. In the blind watermarking algorithm, neither the original image nor the watermark is needed during the watermark detection and extraction process. The watermark bit sequence and secret key(s) are needed during the watermark detection and extraction process in the semi-blind watermarking algorithm. In the non-blind watermarking algorithm, either the host image or original watermark is required to extract the watermark. In other words, those who have a copy

of the secret key(s) and the host image can only extract the watermark image. Moreover, either transform methods or spatial methods can be used for digital watermarking of images. Transform methods are complex but robust, whereas spatial methods are simple but not robust (Su *et al.*, 2016).

1.2 Problem Background

In the past few years, a high data growth rate has funded the new outlook of e-commerce like electronic marketing, publishing, transmission, and distribution of real-time multimedia data in the form of video, audio, image, and so on. Although there are numerous advantages for multimedia contents to be digitized compared to the analog equivalent, the service providers are too careful to offer the services in their digital structure because they freely copy and distribute copyright resources. Over the last decade, various methods proposed by researchers to protect multimedia data and digital watermarking methods are one of the best methods compared to other methods like steganography, encryption, cryptography, and others (Gupta *et al.*, 2015a).

On the other hand, unauthorized access becomes digital data vulnerability because digital data can be distributed everywhere by a widespread transmission medium. Thus, to protect digital data, intellectual property considers extra attention to them. One of the optimistic methods to protect digital data copyright is digital watermarking. The watermark in digital watermarking is an identification code that carries data about the work inventor, the ownership copyright, legal customer, and so on (Vaishnavi and Subashini, 2015). Watermarks are used to keep safe digital media from unauthorized use, piracy, and any other illegal actions. In the watermarking method, watermark data is embedded into the host signal by modifying its content (Laur *et al.*, 2015).

Moreover, the fast development of multimedia technology and the internet causes many digital data problems such as illegal modifying digital copyright, tampering, and copying. Therefore, many methods, such as digital watermarking, have been proposed to address these problems and maintain information safety. The

effectiveness of a digital watermarking depends on the following characteristics (Su and Chen, 2018):

- (1) **Imperceptibility:** The watermark needs to be invisible or inaudible in watermarked “image/video” or “digital music,” respectively. Human perception must be maintained about the host object after extra data (watermark) has been embedded in it. Imperceptibility evaluation is usually based on a subjective test with specified procedures or an objective measure of quality called Peak Signal-to-Noise Ratio (PSNR) (Su and Chen, 2018).
- (2) **Robustness:** Unauthorized distributors should not eliminate or remove the embedded watermark by using common image processing operations such as cropping, compression, quantization, and filtering (Su and Chen, 2018).
- (3) **Security:** The watermarking procedure should depend on secret keys to ensure security so that attackers could not be able to remove or detect watermark by statistical analysis from a set of multimedia files or images. An unauthorized user who may even have prior knowledge of the exact watermarking algorithm cannot sense hidden data without having the secret keys used in the embedding procedure (Su and Chen, 2018).
- (4) **Real-time processing:** The embedding procedure must be fast, and without having any delay, the watermark should be quickly embedded into the host object (Su and Chen, 2018).

Furthermore, these days with the rapid development of the internet and mobile devices, digital images can be easily captured and stored everywhere. Also, they can be shared on popular social media like Instagram, Twitter, Facebook, and so on (Huynh-The *et al.*, 2018). Wireless communication channels are generally used to directly upload these images to the internet without any primary protection schemes (Yu *et al.*, 2017). This causes numerous urgent issues relating to copyright protection and authentication in transmission, storage, and image usage. For instance, a personal image that has been shared on social media can be illegally accessed, downloaded,

modified, and reused by others for some intentions like commercial or other purposes (Huynh-The *et al.*, 2018).

To summarize, most of the researchers work on a grayscale image based on copyright protection and authentication. A few researchers work on the color image. Most of these color image watermarking methods use an only one-color channel or each color channel of a color image to embed the watermark data. So, the color image's redundant data cannot be used sufficiently and cause a low ability to resist attacks, which means the method has low robustness against image processing attacks (Xu et al., 2018). This section overviewed the recent works on image watermarking, and it shows that there are not many researchers' works on color image watermarking. Enhance the color image watermarking method is still one of the main concerns in image watermarking.

1.3 Problem Statement

An effective watermarking method that can resist the most common image processing attacks such as JPEG compression, rotation, sharpening, blurring, salt and pepper is the main issue of the color image watermarking addressed by Su and Chen (2018). On the other hand, 92% of the researchers are interested in working on a JPEG compression attack because compression is a tool used by many applications in digital image processing. The embedding method needs to detect the watermark after compression attack, and it should be robust, which means the NCC value must be one or close to one. JPEG compression is one of the most critical procedures for image compression (Najafi, 2017).

Moreover, the digital watermarking effectiveness depends on four characteristics, which are imperceptibility, robustness, security, and real-time processing. Normalized Cross-Correlation (NCC) is used to measure the watermarking method's robustness. According to Bajracharya and Koju (2017), when the NCC value is close to one, there is a high similarity between the original watermark and the extracted watermark after the attack. One is the best value for the NCC, and current

research results show that there is still room for improvement in the robustness of color image.

Su and Chen (2016), Su and Chen (2017), Su *et al.* (2017b), Cheema *et al.* (2020) work on JPEG compression with a quality factor of 30%, and the highest NCC results for Lena host image is 0.9735, and for Avion host image NCC value is 0.9546 which is the highest value in their researches. These NCC values can still be improved and enhanced by the watermarking method to achieve higher NCC value and much closer to one or achieved one, which is the best NCC result.

1.4 Research Questions

- (a) What are the existing robust color image watermarking methods against JPEG compression attacks?
- (b) How to propose an enhanced method for robust color image watermarking against JPEG compression attack?
- (c) What is the proposed method's performance?

1.5 Research Objectives

This research has three objectives, which are listed below:

- (a) To investigate existing robust color image watermarking methods against JPEG compression attack
- (b) To propose an enhanced method for robust color image watermarking against JPEG compression attack

- (c) To evaluate and analyze the proposed method's performance

1.6 Significance of the Research

The significance of this research are as follows:

- (a) Study existing methods for color image watermarking. Then compare them to find out their characteristics, strengths, and weaknesses.
- (b) Proposed a new method by enhancing the watermarking method to improve the robustness against JPEG compression attacks for copyright protection purposes.
- (c) Finding the best embedding place in the host image keeps a tradeoff between capacity, imperceptibility, and robustness.

1.7 Scope of the Research

The Scope of this research is listed below:

- (a) Use 24-bits 512×512 RGB color host image from CVG-UGR image database.
- (b) Use 24-bits 32×32 Peugeot logo as RGB color watermark image.
- (c) This research is limited to use the combination of three methods only which are Discrete Wavelet Transforms (DWT), Discrete Cosine Transforms (DCT), and Cat Face Transform (Arnold Transform).
- (d) The watermarked image quality will be evaluated by using Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index Measure (SSIM) only.
- (e) The proposed method robustness will be evaluated by using the Normalized Cross-Correlation (NCC) only.
- (f) Using Matlab for implementation.

1.8 Thesis Organization

This thesis is divided into six chapters, where first, chapter one introduces the existing problem and objectives. In this chapter, watermarking is presented as the method to be used in the research. Second, the literature review clarifies watermarking basics, various types of watermarking, its applications, and its characteristics. It also explains the advantages of watermarking, the difference expansion method, and the application using it. Third, chapter three describes the research methodology, design, and procedures. Fourth, chapter four describes the implementation of the proposed embedding and extraction methods. Fifth, chapter five illustrates the result analysis of the proposed method. In conclusion, the novelty of the proposed method, contribution, and future work are provided.

REFERENCES

- Abraham, J., and Paul, V. (2016). An imperceptible spatial domain color image watermarking scheme. *Journal of King Saud University-Computer and Information Sciences*.
- Abubahia, A., and Cocea, M. (2017). Advancements in GIS map copyright protection schemes-a critical review. *Multimedia Tools and Applications*, 76(10), 12205-12231.
- Abutabenjeh, S., and Jaradat, R. J. T. P. A. (2018). Clarification of research design, research methods, and research methodology: A guide for public administration researchers and practitioners. 36(3), 237-258.
- Ahmad, F., and Cheng, L.-M. (2018). Authenticity and copyright verification of printed images. *Signal Processing*, 148, 322-335.
- Al-Afandy, K. A., EL-Rabaie, E.-S. M., El-Samie, F. E. A., Faragallah, O. S., ELmhalaway, A., and Shehata, A. (2016). *Robust Color Image Watermarking Technique Using DWT and Homomorphic based SVD*. Paper presented at the the International Congress for global Science and Technology, 9-18.
- Ali A. Alwan, S. M. A., Nilam Nur Amir, Sjarif, Mohammed Mahdi Hashim, Mohd Shafry Mohd Rahim. (2018). A Review and Open Issues of Diverse Text Watermarking Techniques in Spatial Domain. 96(17).
- Almutiri, M. G., and Othman, M. T. B. (2018). Digital Image Watermarking based on LSB Techniques: A Comparative Study. *International Journal of Computer Applications*, 975, 8887.
- Alsayyh, M. A. M. Y., Mohamad, D., Saba, T., Rehman, A., and AlGhamdi, J. S. (2017). A Novel Fused Image Compression Technique Using DFT, DWT, and DCT. *Journal of Information Hiding and Multimedia Signal Processing*, 8(2), 261-271.
- Aqel, M. J., Umar, A., and Agoyi, M. (2019). A performance evaluation of transform domain algorithm in watermarking based on different levels of sub-bands of discrete wavelet transform. *Periodicals of Engineering and Natural Sciences*, 7(2), 546-554.

- Bajracharya, S., and Koju, R. (2017). An improved DWT-SVD based robust digital image watermarking for color image. *International Journal Engineering and Manufacturing*, 1, 49-59.
- Barnouti, N. H., Sabri, Z. S., Hameed, K. L. J. I. J. o. E., and Technology. (2018). Digital Watermarking Based on DWT (Discrete Wavelet Transform) and DCT (Discrete Cosine Transform). 7(4), 4825-4829.
- Bender, W., Gruhl, D., Morimoto, N., and Lu, A. (1996). Techniques for data hiding. *IBM systems journal*, 35(3.4), 313-336.
- Bisla, N., Chaudhary, P. J. I. j. o. a. r. i. c. s., and engineering, s. (2013). Comparative study of DWT and DWT-SVD image watermarking techniques. 3(6).
- Bose, A., and Maity, S. P. (2016). *Improved spread spectrum compressive image watermark detection with distortion minimization*. Paper presented at the 2016 International Conference on Signal Processing and Communications (SPCOM), 1-5.
- Cedillo-Hernández, M., García-Ugalde, F., Nakano-Miyatake, M., and Pérez-Meana, H. M. (2014). Robust hybrid color image watermarking method based on DFT domain and 2D histogram modification. *Signal, Image and Video Processing*, 8(1), 49-63.
- Chaw-Seng, W. (2007). *Digital image watermarking methods for copyright protection and authentication*. Queensland University of Technology.
- Cheema, A. M., Adnan, S. M., and Mehmood, Z. (2020). A Novel Optimized Semi-Blind Scheme for Color Image Watermarking. *IEEE Access*, 8, 169525-169547.
- Cichowski, J., Czyżewski, A., and Kostek, B. (2013). Analysis of impact of audio modifications on the robustness of watermark for non-blind architecture. *Multimedia Tools and Applications*, 1-21.
- Cox, I. J., Kilian, J., Leighton, F. T., and Shamoon, T. J. I. t. o. i. p. (1997). Secure spread spectrum watermarking for multimedia. 6(12), 1673-1687.
- Cox, I. J., and Linnartz, J.-P. J. I. J. o. s. a. i. c. (1998). Some general methods for tampering with watermarks. 16(4), 587-593.
- Craver, S., Memon, N., Yeo, B.-L., and Yeung, M. M. J. I. J. o. S. a. i. C. (1998). Resolving rightful ownerships with invisible watermarking techniques: limitations, attacks, and implications. 16(4), 573-586.

- Dey, E., Majumder, S., and Mazumder, A. N. (2017). *A new approach to color image watermarking based on joint DWT-SVD domain in YIQ color space*. Paper presented at the Electrical Information and Communication Technology (EICT), 2017 3rd International Conference on, 1-6.
- Farrell, J. E. J. C. i. v., and technology. (1999). Image quality evaluation. 285-313.
- Farzaneh, M., and Toroghi, R. M. (2020). Robust Audio Watermarking Using Graph-based Transform and Singular Value Decomposition. *arXiv preprint arXiv:2003.05223*.
- Feig, E. (1990). *Fast scaled-DCT algorithm*. Paper presented at the Electronic Imaging'90, Santa Clara, 11-16 Feb'92, 2-13.
- Feitelson, D. G. J. I. v. h. w. c. h. a. i. f. e. p. (2006). Experimental computer science: The need for a cultural change.
- Gupta, M., Parmar, G., Gupta, R., and Saraswat, M. (2015a). Discrete wavelet transform-based color image watermarking using uncorrelated color space and artificial bee colony. *International Journal of Computational Intelligence Systems*, 8(2), 364-380.
- Gupta, M., Parmar, G., Gupta, R., and Saraswat, M. J. I. J. o. C. I. S. (2015b). Discrete wavelet transform-based color image watermarking using uncorrelated color space and artificial bee colony. 8(2), 364-380.
- Hartung, F. H., Su, J. K., and Girod, B. (1999). *Spread spectrum watermarking: Malicious attacks and counterattacks*. Paper presented at the Security and Watermarking of Multimedia Contents, 147-159.
- Hossen, M. K., Sarker, S., and Chowdhury, M. S. A. (2018). Hybrid Digital Watermarking Scheme Based on Discrete Wavelet Transform for Copyright Protection. *Advancement in Image Processing and Pattern Recognition*, 1(2), 1-10.
- Huang, R., Liu, H., Liao, X., and Sun, S. (2019). A divide-and-conquer fragile self-embedding watermarking with adaptive payload. *Multimedia Tools and Applications*, 78(18), 26701-26727.
- Huynh-The, T., Hua, C.-H., Tu, N. A., Hur, T., Bang, J., Kim, D., et al. (2018). Selective bit embedding scheme for robust blind color image watermarking. *Information Sciences*, 426, 1-18.
- Jinju, J., Santhi, N., Ramar, K., and Bama, B. S. (2019). Spatial frequency discrete wavelet transform image fusion technique for remote sensing applications.

- Engineering Science and Technology, an International Journal*, 22(3), 715-726.
- Kaur, S., and Sidhu, R. K. J. I. J. E. T. i. E. R. (2016). Robust Digital Image Watermarking for Copyright Protection with SVD-DWT-DCT and Kalman Filtering. *4*(1), 59-63.
- Kocić, J., Popadić, I., and Livada, B. (2016). *Image Quality Parameters-A short review and applicability analysis*. Paper presented at the OTEH 2016-7th International Scientific Conference on Defensive Technologies.
- Kurdi, M. M., Elzein, I. A., and Zeki, A. M. (2016). *Least Significant Bit (LSB) and Random Right Circular Shift (RRCF) in Digital Watermarking*. Paper presented at the 2016 12th International Computer Engineering Conference (ICENCO), 111-116.
- Kutter, M. (1999). *Watermarking resistance to translation, rotation, and scaling*. Paper presented at the Multimedia Systems and Applications, 423-432.
- Laur, L., Rasti, P., Agoyi, M., and Anbarjafari, G. (2015). A robust color image watermarking scheme using entropy and QR decomposition. *Radioengineering*, 24.
- Luo, T., Jiang, G., Yu, M., Xu, H., and Gao, W. (2019). Robust high dynamic range color image watermarking method based on feature map extraction. *Signal Processing*, 155, 83-95.
- Magnier, B., Abdulrahman, H., and Montesinos, P. J. J. o. I. (2018). A Review of Supervised Edge Detection Evaluation Methods and an Objective Comparison of Filtering Gradient Computations Using Hysteresis Thresholds. *4*(6), 74.
- Moosazadeh, M., and Ekbatanifard, G. (2019). A new DCT-based robust image watermarking method using teaching-learning-based optimization. *Journal of Information Security and Applications*, 47, 28-38.
- Najafi, E. J. M. S. (2017). A robust embedding and blind extraction of image watermarking based on discrete wavelet transform. *11*(4), 307-318.
- O'Ruanaidh, J. J., and Pun, T. (1997). *Rotation, scale and translation invariant digital image watermarking*. Paper presented at the Image Processing, 1997. Proceedings., International Conference on, 536-539.
- Ouyang, J., Coatrieux, G., Chen, B., and Shu, H. (2015). Color image watermarking based on quaternion Fourier transform and improved uniform log-polar mapping. *Computers & Electrical Engineering*, 46, 419-432.

- Pal, P., Singh, H. V., and Verma, S. K. (2018). *Study on watermarking techniques in digital images*. Paper presented at the 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), 372-376.
- Park, K.-B., Klaus, P., and Burkart, R. M. (2019). *Spread Spectrum Modulation for LCL Filter Design*. Paper presented at the 2019 20th International Symposium on Power Electronics (Ee), 1-6.
- Prasad, K. L., Rao, T. C. M., and Kannan, V. (2016). A Hybrid LWT-DWT Digital Image Watermarking Scheme using LSVR and QR-factorization. *International Journal of Applied Engineering Research*, 11(6), 4335-4342.
- Qi, Y. L., and Cheng, Z. Y. (2014). *DCT-Domain Blind Detection Watermarking Algorithm*. Paper presented at the Applied Mechanics and Materials, 468-472.
- Roy, A., Maiti, A. K., and Ghosh, K. (2015). *A perception based color image adaptive watermarking scheme in YCbCr space*. Paper presented at the Signal Processing and Integrated Networks (SPIN), 2015 2nd International Conference on, 537-543.
- Saadi, S., Merrad, A., and Benziane, A. (2019). Novel secured scheme for blind audio/speech norm-space watermarking by Arnold algorithm. *Signal Processing*, 154, 74-86.
- Sanjith, S., and Ganesan, R. J. I. J. o. E. R. i. A. (2016). Overview of Image Quality Metrics with Perspective to Satellite Image Compression. 24, 112.
- Saravanan, P., Sreekara, M., and Manikantan, K. (2016). *Digital image watermarking using daubechies wavelets*. Paper presented at the 2016 3rd International Conference on Signal Processing and Integrated Networks (SPIN), 57-62.
- Savakar, D. G., and Ghuli, A. (2019). Robust Invisible Digital Image Watermarking Using Hybrid Scheme. *Arabian Journal for Science and Engineering*, 44(4), 3995-4008.
- Sheidani, S., and Eslami, Z. (2019). *Blind Multipurpose Image Watermarking Based on Secret Sharing*. Paper presented at the 2019 16th International ISC (Iranian Society of Cryptology) Conference on Information Security and Cryptology (ISCISC), 1-8.
- Shojanazeri, H., Adnan, W. A. W., and Ahmad, S. M. S. (2013). Video Watermarking Techniques for Copyright protection and Content Authentication. *International Journal of Computer Information Systems and Industrial Management Applications*, 5, 652-660.

- Shukla, D., Tiwari, N., and Dubey, D. (2016). Survey on digital watermarking techniques. *International Journal of Signal Processing, Image Processing and Pattern Recognition*, 9(1), 239-244.
- Shukla, M. K. M., Mehta, M. A. K. J. I. J. O. E., and Science, C. (2015). A Review on Digital Watermarking Techniques, Applications and Attacks. 4(04).
- Singh, D., and Singh, S. K. (2017). DWT-SVD and DCT based robust and blind watermarking scheme for copyright protection. *Multimedia Tools and Applications*, 76(11), 13001-13024.
- Singh, K. K., and Dwivedi, S. (2014). Digital Watermarking using Asymmetric Key Cryptography and Spatial Domain Technique.
- Singh, P., and Chadha, R. (2013). A Survey of Digital Watermarking Techniques, Applications and Attacks. *International Journal of Engineering and Innovative Technology (IJEIT)*, 2(9).
- Sreenivas, K., and Prasad, V. K. (2018). Fragile watermarking schemes for image authentication: a survey. *International Journal of Machine Learning and Cybernetics*, 9(7), 1193-1218.
- Su, Q., and Chen, B. (2016). An improved color image watermarking scheme based on Schur decomposition. *Multimedia Tools and Applications*, 76(22), 24221-24249.
- Su, Q., and Chen, B. (2017). A novel blind color image watermarking using upper Hessenberg matrix. *AEU-International Journal of Electronics and Communications*, 78, 64-71.
- Su, Q., and Chen, B. (2018). Robust color image watermarking technique in the spatial domain. *Soft Computing*, 22(1), 91-106.
- Su, Q., Niu, Y., Liu, X., and Yao, T. (2013a). A novel blind digital watermarking algorithm for embedding color image into color image. *Optik-International Journal for Light and Electron Optics*, 124(18), 3254-3259.
- Su, Q., Niu, Y., Wang, G., Jia, S., and Yue, J. (2014a). Color image blind watermarking scheme based on QR decomposition. *Signal Processing*, 94, 219-235.
- Su, Q., Niu, Y., Wang, Q., and Sheng, G. (2013b). A blind color image watermarking based on DC component in the spatial domain. *Optik-International Journal for Light and Electron Optics*, 124(23), 6255-6260.

- Su, Q., Niu, Y., Zou, H., and Liu, X. (2013c). A blind dual color images watermarking based on singular value decomposition. *Applied Mathematics and Computation*, 219(16), 8455-8466.
- Su, Q., Niu, Y., Zou, H., Zhao, Y., and Yao, T. (2014b). A blind double color image watermarking algorithm based on QR decomposition. *Multimedia tools and applications*, 72(1), 987-1009.
- Su, Q., Wang, G., Lv, G., Zhang, X., Deng, G., and Chen, B. (2016). A novel blind color image watermarking based on Contourlet transform and Hessenberg decomposition. *Multimedia Tools and Applications*, 76(6), 8781-8801.
- Su, Q., Wang, G., Zhang, X., Lv, G., and Chen, B. (2017a). An improved color image watermarking algorithm based on QR decomposition. *Multimedia Tools and Applications*, 76(1), 707-729.
- Su, Q., Wang, G., Zhang, X., Lv, G., and Chen, B. (2017b). A new algorithm of blind color image watermarking based on LU decomposition. *Multidimensional Systems and Signal Processing*, 1-20.
- Sun, G., Wang, R., Wang, S., Wang, X., Zhao, D., and Zhang, A. (2015). *High-definition digital color image watermark algorithm based on QR code and DWT*. Paper presented at the Industrial Electronics and Applications (ICIEA), 2015 IEEE 10th Conference on, 220-223.
- Swaraja, K., Meenakshi, K., and Kora, P. (2020). An optimized blind dual medical image watermarking framework for tamper localization and content authentication in secured telemedicine. *Biomedical Signal Processing and Control*, 55, 101665.
- Tedre, M., and Moisseinen, N. J. T. S. W. J. (2014). Experiments in computing: A survey. 2014.
- Tirkel, A. Z., Rankin, G., Van Schyndel, R., Ho, W., Mee, N., Osborne, C. F. J. D. I. C., Technology, et al. (1993). Electronic watermark. 666-673.
- Tsang, K. F., and Au, O. C. L. (2001). *Review on attacks, problems, and weaknesses of digital watermarking and the pixel reallocation attack*. Paper presented at the Security and Watermarking of Multimedia Contents III, 385-394.
- Tsougenis, E., Papakostas, G. A., Koulouriotis, D. E., and Karakasis, E. G. (2014). Adaptive color image watermarking by the use of quaternion image moments. *Expert systems with applications*, 41(14), 6408-6418.

- Tyagi, S., Singh, H. V., Agarwal, R., and Gangwar, S. K. (2016). *Digital watermarking techniques for security applications*. Paper presented at the 2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES), 379-382.
- Vaishnavi, D., and Subashini, T. (2015). Robust and invisible image watermarking in RGB color space using SVD. *procedia computer science*, 46, 1770-1777.
- Wang, X.-y., Niu, P.-p., Yang, H.-y., Wang, C.-p., and Wang, A.-l. (2014). A new robust color image watermarking using local quaternion exponent moments. *Information sciences*, 277, 731-754.
- Wang, X.-y., Wang, C.-p., Yang, H.-y., and Niu, P.-p. (2013). A robust blind color image watermarking in quaternion Fourier transform domain. *Journal of Systems and Software*, 86(2), 255-277.
- Wang, Z., Bovik, A. C., Sheikh, H. R., and Simoncelli, E. P. J. I. t. o. i. p. (2004). Image quality assessment: from error visibility to structural similarity. *13*(4), 600-612.
- Xu, H., Jiang, G., Yu, M., and Luo, T. (2018). A Color Image Watermarking Based on Tensor Analysis. *IEEE Access*, 6, 51500-51514.
- Yu, J., Zhang, B., Kuang, Z., Lin, D., and Fan, J. (2017). iPrivacy: image privacy protection by identifying sensitive objects via deep multi-task learning. *IEEE Transactions on Information Forensics and Security*, 12(5), 1005-1016.
- Yuan, X.-g., Zhou, Z. J. C. E., and Science. (2011). A Novel Robust Watermarking Algorithm Based on DWT-DCT-SVD [J]. *1*, 027.
- Zebbiche, K., Khelifi, F., and Loukhaoukha, K. (2018). Robust additive watermarking in the DTCWT domain based on perceptual masking. *Multimedia Tools and Applications*, 77(16), 21281-21304.

LIST OF PUBLICATIONS

Amir Hesam Yaribakht¹, Mohd Shahidan Abdullah², Alireza Ghobadi³. A Novel Color Image Watermarking Method based on Digital Wavelet Transform and Hungarian Algorithms, International Journal of Advanced Trends in Computer Science and Engineering, Volume 8, No.2, March - April 2019. Scopus Index.