ROBUST WATERMARKING FOR MAGNETIC RESONANCE IMAGES WITH AUTOMATIC REGION OF INTEREST DETECTION

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To my beloved family

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ABSTRACT

Medical image watermarking requires special considerations compared to ordinary watermarking methods. The first issue is the detection of an important area of the image called the Region of Interest (ROI) prior to starting the watermarking process. Most existing ROI detection procedures use manual-based methods, while in automated methods the robustness against intentional or unintentional attacks has not been considered extensively. The second issue is the robustness of the embedded watermark against different attacks. A common drawback of existing watermarking methods is their weakness against salt and pepper noise. The research carried out in this thesis addresses these issues of having automatic ROI detection for magnetic resonance images that are robust against attacks particularly the salt and pepper noise and designing a new watermarking method that can withstand high density salt and pepper noise. In the ROI detection part, combinations of several algorithms such as morphological reconstruction, adaptive thresholding and labelling are utilized. The noise-filtering algorithm and window size correction block are then introduced for further enhancement. The performance of the proposed ROI detection is evaluated by computing the Comparative Accuracy (CA). In the watermarking part, a combination of spatial method, channel coding and noise filtering schemes are used to increase the robustness against salt and pepper noise. The quality of watermarked image is evaluated using Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM), and the accuracy of the extracted watermark is assessed in terms of Bit Error Rate (BER). Based on experiments, the CA under eight different attacks (speckle noise, average filter, median filter, Wiener filter, Gaussian filter, sharpening filter, motion, and salt and pepper noise) is between 97.8% and 100%. The CA under different densities of salt and pepper noise (10%-90%) is in the range of 75.13% to 98.99%. In the watermarking part, the performance of the proposed method under different densities of salt and pepper noise measured by total PSNR, ROI PSNR, total SSIM and ROI SSIM has improved in the ranges of 3.48-23.03 (dB), 3.5-23.05 (dB), 0-0.4620 and 0-0.5335 to 21.75-42.08 (dB), 20.55-40.83 (dB), 0.5775-0.8874 and 0.4104-0.9742 respectively. In addition, the BER is reduced to the range of 0.02% to 41.7%. To conclude, the proposed method has managed to significantly improve the performance of existing medical image watermarking methods.

ABSTRAK

Penandaan genang imej perubatan memerlukan pertimbangan khas berbanding dengan kaedah penandaan genang biasa. Isu pertama ialah pengesanan bahagian penting imej yang dikenali sebagai *Region of Interest* (ROI) sebelum memulakan proses penandaan genang. Kebanyakan prosedur pengesanan ROI sedia ada berasaskan kaedah manual, manakala kaedah segmentasi secara automatik yang mantap terhadap serangan hingar yang disengajakan atau tidak disengajakan tidak mendapat perhatian yang meluas. Isu kedua berkaitan kemantapan penandaan genang yang terkandung terhadap pelbagai serangan. Kelemahan umum daripada kaedah penandaan genang sedia ada ini adalah kelemahan terhadap hingar garam dan lada. Penyelidikan yang dijalankan dalam tesis ini menangani isu-isu pengesanan ROI secara automatik untuk imej resonans magnetik yang mantap terhadap serangan terutamanya hingar garam dan lada dan mereka bentuk kaedah penandaan genang baharu yang dapat bertahan daripada hingar garam dan lada pada ketumpatan yang tinggi. Dalam bahagian pengesanan ROI, gabungan beberapa algoritma seperti pembinaan semula morfologi, pengambangan dan pelabelan adaptif digunakan. Algoritma penapisan hingar dan blok pembetulan saiz tetingkap kemudiannya diperkenalkan untuk penambahbaikan selanjutnya. Prestasi pengesanan ROI yang dicadangkan dinilai dengan mengira Kejituan Perbandingan (CA). Dalam bahagian penandaan genang, skim gabungan kaedah ruangan, pengekodan saluran, dan penapisan hingar diguna untuk menambah kemantapan terhadap hingar garam dan lada. Kualiti imej penandaan genang dinilai menggunakan Nisbah Puncak Isyarat ke Hingar (PSNR) dan Indeks Persamaan Struktur (SSIM), dan kejituan penandaan genang yang diekstrak ditaksir dengan Kadar Ralat Bit (BER). Berdasarkan eksperimen, CA untuk lapan jenis serangan (hingar bintik, penapis purata, penapis tengah, penapis Wiener, penapis Gaussian, penapis penajaman, hingar bergerak, dan hingar garam dan lada) adalah di antara 97.8% hingga 100%. CA untuk pelbagai ketumpatan hingar garam dan lada (10%-90%) adalah dalam julat antara 75.13% hingga 98.99%. Dalam bahagian penandaan genang, prestasi kaedah yang dicadangkan di bawah pelbagai ketumpatan hingar garam dan lada yang diukur dengan jumlah PSNR, ROI PSNR, jumlah SSIM dan ROI SSIM masing-masing telah bertambah daripada julat 3.48-23.03 (dB), 3.5-23.05 (dB), 0-0.4620 dan 0-0.5335 kepada 21.75-42.08 (dB), 20.55-40.83 (dB), 0.5775-0.8874 dan 0.4104-0.9742. Di samping itu, BER telah berkurangan kepada julat daripada 0.02% kepada 41.7%. Kesimpulannya, kaedah yang dicadangkan telah dapat memperbaiki prestasi kaedah sedia ada dengan begitu nyata sekali.

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LIST OF SYMBOLS

a	-	Numerical coefficient for converting ASCII to binary
a_i	-	Old coordinates of ROI
a_i'	-	New coordinates of ROI
A	-	Image used in morphological operation
A^c	-	Complement of A
AVG	-	Average of pixel values in noise-filtering method
b	-	Each bit in binary stream **Ɓ**
Ɓ	-	Binary stream of watermark bits
B	-	Structuring element used in morphological operation
$(B)_z$	-	Translation of structuring element B by point or vector z
$(\widehat{B})$	-	Reflection of structuring element B
$(\widehat{B})_z$	-	Translation of $(\widehat{B})$ by point or vector z
c_1	-	Constant coefficient for computing SSIM
c_2	-	Constant coefficient for computing SSIM
CB	-	Number of correct bits in extracted watermark
C_{Max_RONI}	-	Maximum embedding capacity in the RONI
C_p		Correction parameter in window size correction method
DB	-	Number of error bits in extracted watermark
E_{depth}	-	Number of bits used for embedding in each pixel
E_k	-	Energy of DWT levels
$F(.\ ,.)$	-	DFT coefficient
$\|F(.,.)\|$	-	Magnitude spectrum in polar format of Fourier transform
$G(.\ ,.)$	-	DCT coefficient
h	-	Difference value of two neighbor pixels in DE method
h'	-	Modified difference value of two neighbor pixels in DE method

H	-	Height of image
I	-	Imaginary part of Fourier transform
I_k	-	Coefficients of DWT subbands
I_w	-	Watermarked image
k	-	Maximum number of bits in an image pixels
k_0	-	First coefficient in window size correction method
k_1	-	Second coefficient in window size correction method
l	-	Average value of two neighbor pixels in DE method
L	-	Dynamic range of image pixel values
L_{EPR_Encod}	-	Length of the address after encoding a EPR bit by ROI
N_{EMB_bits}	-	Number of embedded watermark bits inside the image
N_{EPR_Char}	-	Number of EPR characters in ASCII format
N_{Gen_Wat}	-	Total number of generated watermark bits
$N_{Repetition}$	-	Number of repeating the embedding process
N_{ROI_Pixel}	-	Number of ROI pixels
N_{RONI_Pixel}	-	Number of RONI pixels
N_{Total_Pixel}	-	Total number of pixels in image
MAX	-	Maximum pixel value
min	-	Minimum operator
mod	-	Operator for dividing two numbers
NB	-	Total number of watermark bits
NORM	-	Normalizing operator
O_R	-	Opening by reconstruction
Q	-	Total number of images in each database in this thesis
R	-	Real part of Fourier transform
$\mathbb{R}_A^D$	-	Reconstruction by dilation of image A
S	-	Diagonal matrix in SVD transform
T_{avg}	-	Average threshold value
Ti	-	Threshold value of block i
u_i	-	*i*-th eigenvector of matrix *U* in SVD transform
U	-	Left orthogonal matrix in SVD transform
v_i	-	*i*-th eigenvector of matrix *V* in SVD transform
V	-	Right orthogonal matrix in SVD transform

$\mathcal{W}$	-	Width of image
W(. , .)	-	Original watermark
W'(. , .)	-	Extracted watermark
x	-	Pixel value in DE method
x'	-	Pixel value after embedding a watermark bit (b) in DE method
y	-	Pixel value in DE method
y'	-	Pixel value after embedding a watermark bit (b) in DE method
z	-	Point or vector in morphological operation
α	-	Constant coefficient in DCT transform
γ	-	Correction parameter
б	-	Standard deviation
δ_i	-	Singular values of diagonal matrix (S) in SVD transform
σ_I^2	-	Variance of non-watermarked image
$\sigma_{I_W}^2$	-	Variance of watermarked image
λ	-	Salt and pepper noise density
μ_I	-	Average of non-watermarked image
μ_{I_W}	-	Average of watermarked image
$\phi(u, v)$	-	Phase spectrum of polar format of Fourier transform
$\ominus$	-	Erosion operator
$\cap$	-	Intersection of two sets
$\emptyset$	-	Null set
$\oplus$	-	Dilation operator
$\widehat{(.)}$	-	Reflection operator
$\circ$	-	Opening operator
$\bullet$	-	Closing operator

LIST OF ABBREVIATIONS

2D	-	Two-dimensional
3D	-	Three-dimensional
MSB	-	Most Significant Bit
AR	-	Accuracy Ratio
BER	-	Bit Error Rate
CRC	-	Correlation Coefficient
CT	-	Computed Tomography
DCT	-	Discrete-Cosine Transform
dB	-	Decibel
DE	-	Difference Expansion
DFB	-	Directional Filter Banks
DFT	-	Discrete Fourier Transform
DICOM	-	Digital Imaging and Communications in Medicine
DTCWT	-	Dual Tree Complex Wavelet transform
DWT	-	Discrete Wavelet Transform
EMD	-	Empirical Mode Decomposition
EPR	-	Electronic Patient Record
HVS	-	Human Visual System
IF	-	Image Fidelity
IWT	-	Integer Wavelet Transform
LBP	-	Local Binary Pattern
LPD	-	Laplacian Pyramid Decomposition
LSB	-	Least Significant Bit
MAC	-	Message Authentication Code
MRI	-	Magnetic Resonance Imaging
MSE	-	Mean Square Error
NC	-	Normalized Correlation Coefficient

NULC	-	New upper left corner
NRMSE	-	Normalized Root Mean Square Error
NVF	-	Noise Visibility Function
PSNR	-	Peak Signal-to-Noise Ratio
ROI	-	Region of Interest
RONI	-	Region of Non-Interest
SIM	-	Similarity Measure
SSIM	-	Structural Similarity
SVD	-	Singular Value Decomposition
US	-	Ultrasound
ULC	-	Upper left corner
WPSNR	-	Weighted Peak Signal-to-Noise Ratio

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CHAPTER 1

INTRODUCTION

1.1 History of Watermarking

The watermarking concept goes back to the 13th century when the Italians tried to form a watermark by sewing a transparent layer onto a paper mould [1]. From a historical point of view, currency and stamps were usually watermarked. The advantage of currency watermarking is still being in use.

The term digital watermarking has become popular since the early 1990s, concurrent with the popularity of the World Wide Web, as traders searched for ways to protect ownership of their digital media as it circulated throughout the digital network.

Digital watermarking is a procedure for embedding information (the watermark) into a host object in a way that the watermark can be detected by authorised people [2]. The host media can be continuous, such as audio, video or animation, or it may be discrete such as an image, text, etc. The watermark can be an image logo, serial number, owner's ID, name, or any other information, which shows the ownership of the host signal, and should usually be converted into a binary sequence before embedding into the host signal.

1.2 Importance of Watermarking for Medical Images

The widespread emergence of computer networks and the popularity of electronic management of medical records has made it possible for digital medical images to be shared across the world for services such as telemedicine, teleradiology, telediagnosis, and teleconsultation. The ability to instantly diagnose and understand a particular disease, as well as a reduction in the number of misdiagnoses, has had extensive social and economic impact, clearly showing the need for efficient sharing of patient information between specialists at different hospitals. When handling medical images, the main priority is to protect a patient's documents against any act of tampering by unauthorised individuals. The main concern of any existing electronic medical system is thus to develop a standard solution to preserve the authenticity and integrity of the content of medical images [3,4].

Accordingly, one solution for tackling the above issue is the use of digital watermarking for medical images. Watermarking can enhance the security of medical images by inserting special information, called a watermark or hidden data, in a non-conspicuous way. Watermark information is usually inserted in a binary format to the pixel value of the host image. This information can later be retrieved and checked to determine whether the medical image was distributed with the actual source (authenticity), or any modification has been made to the medical image (integrity) [5].

1.3 Problem Statements

When watermarking medical images, a crucial issue is preserving the quality of an important part of the image called the Region of Interest (ROI). Since this region is used by physicians for diagnostic purposes, even a small distortion in this area cannot be tolerated, as it may cause misdiagnosis [6]. Each ROI and RONI (Region of Non-Interest) can be used for different purposes. For instance, the ROI can be used for authentication and integrity verification [7] by embedding the fragile watermark in it, while the RONI can be used for hiding the Electronic Patient Record

(EPR) robustly [8,9], in order to increase the security of this information against unauthorised users. In medical watermark embedding in either the ROI or RONI region or both, it is therefore essential to separate these two regions prior to starting the watermarking procedure.

The other issue in medical watermarking is robustness. In contrast to fragile watermarking, robustness implies resistance against a variety of intentional or unintentional media processing, known as attacks. Cropping, resizing, compression and noise addition are different examples of attacks which may be used by invaders to disable a watermark. Generally, any watermarking technique is developed to be robust against a group of attacks, but it cannot be designed to resist all groups of attacks. For instance, an embedded watermark in the magnitude component of the Discrete Fourier Transform (DFT) is robust against scaling and translation attacks [10], and DFT phase-based watermarking methods are robust against compression schemes such as JPEG [11], which is related to the inherent characteristic of the magnitude and phase elements of DFT transforms.

1.3.1 Problems of ROI Detection Systems for Medical Images

Most existing ROI detection methods for watermarking application described in the literature are manual-based [12-21]. This means that the ROI is selected manually prior to starting the watermarking procedure. Furthermore, the robustness against intentional or unintentional attacks in automatic methods has not been considered extensively [8,22,23]. For non-automatic and non-robust ROI detection applied in watermarking application, the coordinates of the ROI need to be hidden in a specific part of the RONI during the embedding procedure.

During transmission between hospitals or specialists through the network, or when archiving in hospital databases, image contents may be changed intentionally by an unauthorised person, or accidentally for unknown reasons. In both cases, it is assumed that the watermarked image has been attacked by noise. By modifying the contents of medical images, the embedded ROI vertices may also be changed thus give the wrong ROI boundaries to the extractor system. This means that the embedded watermark inside the ROI or RONI cannot be extracted correctly and this is the weakness of the scheme.

A solution to this problem is to use a similar automatic ROI segmentation process in both embedding and extraction, instead of hiding the ROI vertices information in the medical images. In this case, the vital matter is generating a unique result for ROI coordinates in embedding and extraction operations, even after attacks on the content of medical images. Designing an automatic and robust ROI detection system to fulfil this requirement is thus desirable.

1.3.2 Problem of Robust Watermarking Methods against the Salt and Pepper Noise

In most previous watermarking methods, the transform domain is chosen to increase the robustness of embedded data against different attacks [10,24-32]. For instance, Multiband Wavelet transform and Empirical Mode Decomposition (EMD) in [33], Discrete Wavelet Transform (DWT) in [28,32], Contourlet and Discrete-Cosine Transform (DCT) in [26], Integer Wavelet Transform (IWT) in [25], Contourlet in [24,31], Multilayer Difference Expansion in [29] and DFT in [10] perform the watermarking operation in the transform domain. A common point between these methods, however, is their weakness against salt and pepper noise.

Spatial domain watermarking is another solution for increasing the robustness of embedded data against attacks. Although these methods are not congenitally robust, their combination with channel coding methods [30] can solve this problem. The effect of this procedure is only in reducing the Bit Error Rate (BER) of the extracted data without enhancing any quality of the watermarked image that is influenced by attacks.

The solution for increasing the robustness against the salt and pepper noise, as well as partly retrieval of the visual quality of a watermarked image, is incorporation a salt and pepper noise-filtering block with a spatial watermarking method and channel-coding scheme. By integrating these three blocks, not only is the BER of the extracted watermark after salt and pepper noise reduced, but the quality of the watermarked image after attack can also be increased.

1.4 Project Objectives

The aim of this work is to develop a robust watermarking system with the following goals:

1. To design and evaluate an automatic ROI segmentation method for MRI images which is robust against different attacks, especially salt and pepper noise.

2. To develop and evaluate a watermarking method that protects the embedded EPR in the RONI against different densities of salt and pepper noise.

1.5 Project Scope

The scope of this study involves the following.

1. The developed method is for medical images with a single integrated ROI. In other words, medical images with more than one separate ROI are outside the scope of this work.

2. The developed method is to be performed on images with enough space in the RONI such that the watermark information can be embedded.

3. As previously described in Section 1.2, the importance of watermarking for medical images cannot be denied, and so the scope of this research is restricted to medical images. The method is intended for grayscale MRI medical images stored in DICOM (Digital Imaging and Communications in Medicine) format since DICOM is the standard representation for medical images and the generated medical images by medical devices are in DICOM format.

4. Five different medical databases with 179 MRI images are utilized in this work.

5. In ROI segmentation part, the Comparative Accuracy (CA) is used for evaluating the robustness of the proposed segmentation method against different attacks.

6. In watermarking part, Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) are used for evaluating the quality of watermarked image and Bit Error Rate (BER) is applied to assess the accuracy of extracted watermark.

7. MATLAB software is used to implement the proposed method.

8. Even though the focus is on the salt and pepper noise, this research does cover other attacks such as JPEG 2000, DICOM JPEG 2000 and DICOM RLE.

1.6 Significance of Study

The significant of this study can be generalised into the following.

1. Development of an automatic and robust ROI selection that is not reported in any previous works. There are two-fold benefits for using the proposed method: embedding capacity in the embedding process can be saved; and errors during the extraction part can be reduced. This is because the proposed method is able to generate unique coordinates for the ROI during the embedding and extraction processes even after being attacked.

2. Enhancement to the security of the embedded information inside the RONI by means of ROI.

3. Development of a watermarking method that is proven robust against the high density of salt and pepper noise.

1.7 Thesis Outline

This thesis consists of five chapters which are organised as follows:

Chapter 1: This chapter is an introduction to watermarking, the importance of watermarking for medical images, problem statements, objectives, scope and the significance of the study.

Chapter 2: In this chapter, a valuable literature survey of different concepts of watermarking methods are presented, including different types of digital watermarking; the application of digital watermarking; differences between steganography, cryptography and watermarking; different kinds of attacks; and the difference between medical and non-medical watermarking. Different types of attacks, advantages, requirements, benchmarks and techniques of medical image watermarking are investigated. Literature on previous ROI segmentation methods in the field of watermarking is presented.

Chapter 3: The proposed method for robust and automatic ROI segmentation as well as the robust watermarking method is given in this chapter.

Chapter 4: Implementation, analysis and discussion of the proposed method and a comparison with other methods are explained in this chapter.

Chapter 5: Conclusion and future works are presented in this chapter.

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