WATERMARKING SCHEME USING SLANTLET TRANSFORM AND ENHANCED KNIGHT TOUR ALGORITHM FOR MEDICAL IMAGES

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In memory of my late father

and

To my family with love and eternal appreciation

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ABSTRACT

Digital watermarking has been employed as an alternative solution to protect the medical healthcare system with a layer of protection applied directly on top of data stored. Medical image that is highly sensitive to the image processing and cannot tolerate any visual degradation has become the focus of digital watermarking. However, since watermarking introduces some changes on medical images, it is a challenge for medical image watermarking to maintain high imperceptibility and robustness at the same time. Research to date has tended to focus on the embedding method instead of the sequence of embedding of the watermarking itself. Also, although watermarking has been introduced into medical images as a layer of protection, it still cannot prevent a knowledgeable hacker from retrieving the watermark. Therefore, this research proposes a robust watermarking scheme with high imperceptibility for medical images to increase the effectiveness of the medical healthcare system in terms of perceptibility, embedding technique, embedding region and embedding sequence of the watermarking scheme. To increase imperceptibility of a watermark, this research introduces Dynamic Visibility Threshold, a new parameter that increases visual quality in terms of imperceptibility. It is a unique number which differs for each host image using descriptive statistics. In addition, two new concepts of embedding region, namely Embeddable zone (EBD) and Non-Embeddable zone (NEBD) to function as a non-parametric decision region to complicate the estimate of the detection function are also proposed. The sequence of embedding is shuffled using enhanced Knight Tour algorithm based on Slantlet Transform to increase the complexity of the watermarking scheme. A significant result from the Peak Signal-to-Noise Ratio (PSNR) evaluation showing approximately 270 dB was obtained, suggesting that this proposed medical image watermarking technique outperforms other contemporary techniques in the same working domain. Based on the experimental result using the standard dataset, all host images are resilient to Salt and Pepper Noise, Speckle Noise, Poisson Noise, Rotation and Sharpen Filter with minimum Bit Error Rate (BER) of 0.0426 and Normalized Cross-Correlation (NCC) value of as high as 1. Since quartile theory is used, this experiment has shown that among all three quartiles, the Third Quartile performs the best in functioning as Dynamic Visibility Threshold (DVT) with 0 for BER and 1 for NCC evaluation.

ABSTRAK

Penandaan air digital telah digunakan sebagai penyelesaian alternatif untuk melindungi sistem penjagaan kesihatan perubatan dengan lapisan perlindungan yang diterapkan secara langsung di atas data yang disimpan. Imej perubatan yang sangat sensitif terhadap pemprosesan imej dan tidak boleh bertolak ansur dengan sebarang degradasi visual telah menjadi tumpuan kepada penandaan air digital. Walau bagaimanapun, sejak penanda air memperkenalkan beberapa perubahan pada imej perubatan, menjadi satu cabaran untuk penanda air imej perubatan mengekalkan ketidaknampakan yang tinggi dan ketahanan pada masa yang sama. Penyelidikan setakat ini cenderung untuk memberi tumpuan kepada kaedah penyemakan dan bukannya urutan benaman penanda air itu sendiri. Selain itu, walaupun penanda air telah diperkenalkan ke dalam gambar perubatan sebagai lapisan perlindungan, ia masih tidak dapat menghalang penggodam yang berpengetahuan daripada mendapatkan tanda air. Oleh itu, kajian ini mencadangkan skema penanda air yang mantap dengan ketidaknampakan yang tinggi untuk imej perubatan untuk meningkatkan keberkesanan sistem penjagaan kesihatan perubatan dari segi persepsi, teknik benaman, kawasan benaman dan urutan benaman bagi sesuatu skema penanda air. Untuk meningkatkan ketidaknampakan tanda air yang tertera, kajian ini memperkenalkan *Dynamic Visibility Threshold* (DVT), parameter baharu yang meningkatkan kualiti visual dari segi ketidaknampakan. Ia adalah nombor unik yang berbeza bagi setiap imej hos menggunakan statistik deskriptif. Di samping itu, dua konsep baru kawasan benaman, iaitu *Embeddable zone* (EBD) dan *Non Embeddable zone* (NEBD) berfungsi sebagai kawasan keputusan bukan parametrik untuk merumitkan anggaran fungsi pengesanan juga dicadangkan. Urutan benaman yang dirawakkan dengan algoritma *Knight Tour* yang dipertingkatkan berdasarkan *Slantlet Transform* untuk meningkatkan kerumitan skema penanda air ini. Hasil yang signifikan dari penilaian *Peak Signal-to-Noise Ratio* (PSNR) yang menunjukkan nilai 270 dB diperolehi menunjukkan bahawa teknik penandaan air yang dicadangkan ini mampu mengatasi teknik kontemporari lain dalam domain kerja yang sama. Berdasarkan hasil eksperimen yang menggunakan dataset piawai, semua imej hos berupaya menghalang serangan *Salt and Pepper Noise*, *Speckle Noise*, *Poisson Noise*, Putaran dan penapis menyaring dengan *Bit Error Rate* (BER) 0.0426 *dan Normalized Cross-Correlation* (NCC) setinggi nilai 1. Oleh sebab teori kuartil digunakan, eksperimen telah menunjukkan bahawa antara ketiga-tiga kuartil, Kuartil Ketiga berfungsi paling baik sebagai *Dynamic Visibility Threshold* dengan 0 untuk BER dan 1 untuk penilaian NCC.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
BCH	-	Bose-Chaudhuri-Hocquenghem
BER	-	Bit Error Rate
CC	-	Cross Correlation
CDCS	-	Class Dependent Coding Scheme
CEN/TC	-	European Standardization Committee
CT	-	Computed Tomography
DCT	-	Discrete Cosine Transform
DFT	-	Discrete Fourier transform
DICOM	-	Digital Imaging and Communication in Medicine
DLT	-	Discrete Laguerre Transform
DTT	-	Discrete Tchebichef Transform
DVT	-	Dynamic Visibility Threshold
DWT	-	Discrete Wavelet Transform
EBD	-	Embeddable
EPR	-	Electronic Patient Record
HIPAA	-	Health Insurance Portability and Accountability Act
HIS	-	Hospital Information System
HL7	-	Health Level 7
ISO	-	International Organization for Standardization
JND	-	Just Noticeable Difference
JPEG	-	Joint Photographic Experts Group
LSB	-	Least Significant Bit
LUT	-	Look Up Table
MATLAB	-	Matrix Laboratory

MEDINFO	-	Medical Information
MRI	-	Magnetic Resonance Imaging
MSE	-	Mean Square Error
NCC	-	Normalized Cross-Correlation
NEBD	-	Non-Embeddable
NEMA	-	National Electrical Manufacturers Association
NORC	-	National Opinion Research Center
PACS	-	Picture Archiving and Communication System
PACS	-	Picture Archiving and Communication System
PDF	-	Probability Density Function
PSNR	-	Peak Signal-to-Noise Ratio
ROI	-	Region of Interest
RONI	-	Region of non-Interest
SCO	-	Santa Cruz Operation
SDF	-	Signed Distance Function
SLT	-	Slantlet Transform
SSIM	-	Structural Similarity
UNSW	-	University of New South Wales
VPN	-	Virtual Private Network
WPSNR	-	Weighted Peak Signal to Noise Ratio

LIST OF SYMBOLS

$h_i(n)$	-	low pass filter of SLT Transform
C_{cover}	-	cumulative number of coefficient covered
$Difference_1$	-	absolute difference of HL and LH
$Difference_2$	-	absolute difference of LH and HL
F_1	-	internal force inside contour of the Active Contour
F_2	-	external force inside contour of the Active Contour
I_1	-	original image
I_2	-	watermarked image
K_1	-	bottom-left coefficient, position of Knight
K_2	-	top-left coefficient, position of Knight
K_3	-	top-right coefficient, position of Knight
K_4	-	bottom-right coefficient, position of Knight
NE_1	-	coefficient that interconnected to K_3
NE_2	-	coefficient that interconnected to K_3
NW_1	-	coefficient that interconnected to K_2
NW_2	-	coefficient that interconnected to K_2
R_c	-	subset of RONI
R_d	-	EBD, Union of all ROI with subset of RONI
R_e	-	NEBD
R_i	-	Connected set in a region
R_n	-	ROI region & R_j with no intercept in between
SE_1	-	coefficient that interconnected to K_4
SE_2	-	coefficient that interconnected to K_4
SW_1	-	coefficient that interconnected to K_1
SW_2	-	coefficient that interconnected to K_1
c_1	-	mean of u_0 inside the contour

c_2	-	mean of $u_0$outside the contour
$f_i(n)$	-	adjacent of low pass filter of SLT Transform
$g_i(n)$	-	remaining filter of SLT Transform
u_0	-	binary image of the brain MRI
g		grey level of Gaussian Noise
HH	-	diagonal details in SLT Transform
HL	-	horizontal details in SLT Transform
LH	-	vertical details in SLT Transform
LL	-	approximate details in SLT Transform
M, N	-	dimension of the image
N	-	size of the Slantlet matrix
N		length of EPR bits after extraction
$Q(R_i)$	-	Segmentation measurement for R_i
R	-	Union of all connected set
c	-	contrast comparison
dB	-	decibel
k		number of occurrence of Poisson Noise
l	-	luminance of the image
s	-	structure comparison
λ		average number of occurrences of Poisson Noise
μ		mean
σ		standard deviation

CHAPTER 1

INTRODUCTION

1.1 Overview

In this digital era, a security issue which associated with copyright matter becomes more and more imperative among the net users. In this context, information such as data, picture, and video in digital form which are accessible over the internet and represents the personal information must be secured to prevent any unauthorised accessing, redistribution and modification. Thus, the Medical Information system (MEDINFO) is a multi-functional system which assists people to oversee the medical information of the patient and related data in a very sustainable way. Other than MEDINFO, the medical institution also implements Hospital Information System (HIS) and Picture Archiving and Communication System (PACS) (N. V. Rao & Kumari, 2011; Siegel & Kolodner, 2001) in their infrastructure to upsurge the efficiency of patient management in many ways.

These latest technologies provide a new way for person such as hospital staff to manage the massive patient record in term of storage, accessing, and distribution channel. This technology benefits a lot especially for radiation therapy in diagnosing and image processing for the medical image (Law, Liu, & Chan, 2009). Although it eases people especially patients to access their personal patient record, it also creates a platform for other people such as hackers and third parties to enter the system intently. Hence, there is always a need to secure the digital platform while the conventional internet security are fail to protect the medical image transmission. (Cao, Huang, &

Zhou, 2003). Consequently, network security policies have been employed to address the fore-mentioned internet security problem at the same time allow communication between parties (O'Guin, Williams, & Selimis, 1999). Currently, Virtual Private Network (VPN), data embedding and also data encryption is used to protect the patient records on the internet (Cao, Huang, & Zhou, 2003). VPN allows user transparently connected to the private network and the connection in between be encrypted. Albeit of that, VPN is slower than the convention network (McFarlane, 2010). On the other hand, data encryption is being used on the network as a layer of data protection during transmission. However, the drawback of data encryption is that a key is a necessity (non-blind scheme) to encrypt and decrypt the data for sender and receiver respectively, and things become difficult when the key is missing when during the transmission. In term of data embedding, mainly, consist of passive and active copyright protection where digital watermarking has been proved that can identify the owner of the digital data (Swanson, Kobayashi, & Tewfik, 1998).

Unlike data encryption, data embedding (that is: digital watermarking) able to provide a scheme for embedding integrity control, description, or reference information in a given data. For instance, patient background and medical history can be embedded into the medical image without the overhead associated with additional file or header. All of these problems compromise the efficiency of the hospitality workflow as it eliminates the needs of header file. Medical image digital watermarking not only provide data hiding, integrity control but also introduce authenticity in the biomedical management system. Therefore, digital watermarking is one of the best solution to enhance the security and protection of the digital medical image from being used by other people without permission from the owner.

1.2 Problem Background

Technology nowadays makes a massive change in medical imaging facilities and its' management system. By allowing access to electronic patient records, these advanced technologies help hospital and health care institute improving their services regarding time and quality. Nonetheless, it also exposes a backdoor for hacker and unauthorised parties to access the system and causing legal and ethical issues. Also, deploying such modern technologies in healthcare applications making the patient record vulnerable. For instance, transmission of medical images and Electronic Patient Record over the internet or even intranet, as a result, will have a risk of being vulnerable to corruption by noisy transmission. Hence, security is an essential requirement for healthcare management.

Imperceptibility of a watermarking can be described as the characteristic of hiding a watermark so that it does not degrade the visual quality of the image. Whichever modifications occurred by means of watermark embedding should be below the perceptible threshold. First issue is to maintain balance between imperceptibility, robustness and capacity as increasing one factor adversely effect on other and a good digital watermarking system possess above feature. To achieve good imperceptibility, watermark should be embedded in high frequency component (Garg, 2015).

By using latest image processing software such as Photoshop, hackers can easily modify or edit the medical image for illegal purposes such as false insurance claiming. As reported by Mehta on his report, of all the medical claims an insurer receives between 25% to 30% are manipulated, and ten percent of those claiming is outright fraudulent (Mehta, 2012). Furthermore, a doctor maybe misdiagnose the patient through the medical image if the medical image has been tampered (Tan et al., 2011).

In order to ensure the integrity, confidentiality, and content authentication of the patient record, all necessary data entry need to adhere to the medical information security (Hamidovic, 2011). The standard published by NEMA in 2017 clearly states that the fundamental ISO and a set of controls for protecting the medical information (NEMA, 2017). Moreover, ISO 12052:2017 also specifies the best practice guidelines on how a medical institution is managing their healthcare information system along its security measurement as shown in Figure 1.1.

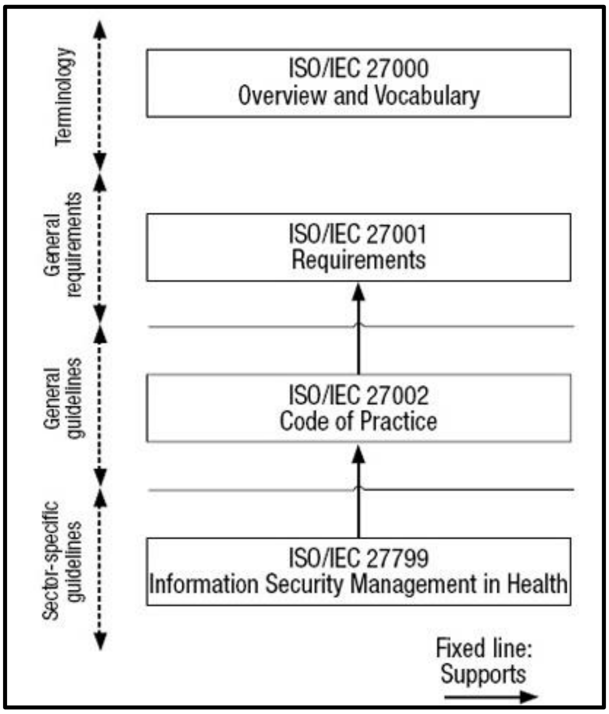

Figure 1.1 Healthcare institution guideline

According to International Organization for Standardization organisation with its publication in the year of 2017 also, ISO 12052:2017 has been developed for cardiology, dentistry, ophthalmology, pathology, radiology, and their closely related image-based diagnosis field, such as radiotherapy and surgery (Technical Committee ISO/TC 215, 2017). Although DICOM follows the standard ISO, there still exists deficiencies in providing enough security to safeguard the image during transmission (Cao, Huang, & Zhou, 2003; G. Coatrieux, Maitre, Sankur, Rolland, & Collorec, 2000; C. Tan et al., 2011).

In terms of embedding sequence, Wakatani use a spiral scanning method to embed the watermarks in medical image (Wakatani, 2002b, 2002a). Nailah & Zain (2007) propose a spiral scan technique of clockwise and anticlockwise embedding sequence for medical image in year of 2007. On the other hand, region of embedding also become the focus of medical image watermarking. Some of the researchers agree that ROI of the medical image is an area that containing vital information which researcher such as (Lee, Kim, Kwon, & Lee, 2005; J. M. Zain, Baldwin, & Clarke,

2004) utilize RONI as the embedding area as researches believe that ROI is the region that cannot be touched at all. Watermark that embedded inside ROI region requires a reversible watermarking scheme, but since EPR information will causing high payload due to its' large size, this is not a practical way to embed the Electronic Patient Record (EPR) inside ROI. Be that as it may, current reversible watermarking scheme did not featured with region-selecting capability (Alattar, 2004; Celik, Sharma, Tekalp, & Saber, 2005; De Vleeschouwer, Delaigle, & Macq, 2003; Goljan, Fridrich, & Du, 2001; Tian, 2003; Z. Zhou, Huang, & Liu, 2005). Coatrieux et al. (2001b) therefore proposed an alternate embedding region by separating the medical image into a protection zone and an insertion zone to avoid compromising any diagnostic capability (Gouenou Coatrieux, Maitre, & Sankur, 2001b). Things become interesting when later in 2009, Guo & Zhuang proposed a ROI-based watermarking scheme using difference expansion of adjacent pixel values and claimed that will not introducing any distortion in the ROI of the medical image (X. Guo & Zhuang, 2009a).

1.3 Problem Statement

In this area of globalisation, itis vital in the case of Digital Imaging and Communications in Medicine (DICOM) which always related to personal info and confidentiality; standard ISO is a good solution to address the international legal requirement for healthcare security (Hamidovic & Kabil, 2011). Thus, a digital watermarking adhering to ISO is being introduced as an alternative solution to resolve the problem. How to achieve a balance point or compromising convey point to achieve the equilibrium between high imperceptibility, robustness, and high security at once for a medical image watermarking scheme is become the centre of research problem. Consequently, a new dynamically digital watermarking scheme for medical images need to be introduced by taking the following views of the latest developments:

i. In between, the embedded watermarking scheme should not produce any degradation in the medical image in human visual and at the same time robust due to diagnosis purposes (Badshah, Liew, Zain, & Ali, 2016; Garg, 2015; Tao, Chongmin, Zain, & Abdalla, 2014). Although many watermarking scheme has been proposed for medical images, but most of the existing watermarking schemes are designed using DWT, SVD, and DCT and have less imperceptibility of watermarked medical images (Thanki, Borra, Dwivedi, & Borisagar, 2017).

ii. Although several data security techniques are used but medical image security still needs to be improved to address the security challenges (Badshah, Liew, Zain, & Ali, 2016). Hackers nowadays are of a very high knowledgeable in retrieving and recovering the watermark (Pérez-Freire, Comesaña, Troncoso-Pastoriza, & Pérez-González, 2006). Hence, a robust watermarking for medical images is the must to prevent third party and unauthorized party from extracting the watermark from the host image (Mousavi, Naghsh, & Abu-Bakar, 2014; Nyeem, Boles, & Boyd, 2013).

iii. As embedding sequence will strengthen a watermarking scheme, a proposed scheme need to emphasise on the different embedding sequence rather than conventional raster scan in the watermarking embedding process (J. Zain, 2005).

iv. Embedding watermark in ROI requires a lossless or reversible watermarking scheme whereby RONI-based watermarking scheme will definitely increasing the chance of hackers recovering the watermarks. In this context, although Pérez-Freire, Comesaña, Troncoso-Pastoriza, & Pérez-González (2006) confirm that using a non-parametric decision region or new area of embedding will be one of the countermeasures to increase avoid third parties from recovering the watermarks, but not much of researcher working on this field.

1.4 Research Question

This research response to the possibility of embedding watermarking in a medical image which answers the following research questions:

i. How to embed the watermarking in a medical image without negative effects in terms of imperceptibility and robustness at the same time?
ii. How to increase the effectiveness of watermarking in terms of embedding sequence?
iii. How to enhance the medical image watermarking scheme in terms of embedding region?

1.5 Aim of the Study

This research aims to propose a watermarking scheme with high imperceptibility for medical images by enhancing the embedding sequence and region of embedding.

1.6 Objectives of the Study

The objectives of this research are:

i. To develop a robust watermarking scheme with high imperceptibility.
ii. To develop a new algorithm for shuffling the embedding sequence of watermark.
iii. To propose a new embedding technique for medical images.

1.7 Scope

To achieve the objectives as stated above, this research is limited to the following scope:

i. This study targeted to perform as an irreversible watermarking scheme.
ii. This study utilizes the Standard Dataset from OsiriX (Grayscale Brain MRI DICOM image).
iii. This study emphasizes on the imperceptibility of the watermarking; hence time complexity is however beyond the scope of this study.
iv. This study only tested for noise attack (Gaussian Noise, Salt and Pepper Noise, Speckle Noise and Poisson Noise), blur filter attack, sharpening and geometric attack for robustness evaluation.

1.8 Benefits of The Study

To conclude, it is imperative to safeguard the content of owner and patient of their medical image and prevent any unauthorised access and redistribution of medical information at the same time maintain the perceptibility in a secure scheme.

1.9 Thesis Organization

This thesis is organised into six chapters and outlined as below:

i. Chapter 2 presents a critical literature review of the contemporary medical image watermarking techniques. The working domain, feature, performance with its strength and weakness of each review method are discussed. Also, the requirement of the watermarking scheme and the performance measurement is being studied. The focus of this chapter is

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