UNIVERSITI PUTRA MALAYSIA

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By

EMHEMAD MOHAMED SAFFOR

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DEDICATION

I dedicate this dissertation to my parents
and my wife

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

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Faculty : Engineering

Medical imaging is a powerful and useful tool for radiologists and consultants, allowing them to improve and facilitate their diagnosis. Worldwide, X-ray images represent 60% of the total amount of radiological images, the remaining consists of more newly developed image modalities such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound (US), Positron Emission Tomography (PET), Single Photon Emission Computerized Tomography (SPECT), Nuclear Medicine (NM), and Digital Subtraction Angiography (DSA).

Image communication systems for medical images have bandwidth and image size constraints that result in time-consuming transmission of uncompressed raw image data. Thus image compression is a key factor to improve transmission speed and storage, but it risks losing relevant medical information. The radiology standard Digital Imaging and

Communications in Medicine (DICOM3) provides rules for compression using lossless Joint Photographic Expert Group (JPEG) methods. However, at the moment there are no rules for acceptance of lossy compression in medical imaging and it is an extremely subjective decision. Acceptable levels of compression should never compromise diagnostic information. Wavelet technology has emerged as a promising compression tool to achieve a high compression ratio while maintaining an acceptable fidelity of image quality.

The objective of this thesis is to evaluate a variety of wavelet filters using Wavelet toolbox for selecting the best wavelet filter to be used in compressing and decompressing selected medical images. Two-dimensional wavelet decomposition, quantization and reconstruction using several families of filter banks were applied to a set of medical images. Furthermore, the technique of quantifying the effect of wavelet compression using low and high contrast test object on digitized radiographic chest and abdomen images and Computed Tomography (CT) images is discussed. A test strip simulating low and high contrast objects was constructed using Visual Basic programming environment. LuraWave Smart Compression software was used to compress and reconstruct selected images with different compression ratios. Ten observers, from the Department of Radiology at the University of Malaya Medical Center (UMMC) evaluated the results. Objective and subjective methods were used for evaluating our results, which include Peak Signal to Noise Ratio (PSNR), Receiver Operating Characteristic (ROC) analysis and rank sum test.

The results show that no specific wavelet filter performs uniformly better than others except for the case of Daubechies and bi-orthogonal filters, which are perhaps, the best wavelet filters for selected medical images. These filters, give very small (≈ zero) Maximum Absolute Error (MAE). These wavelet filters were able to produce perfect reconstruction, even if the level of wavelet decomposition increases. Using LuraWave Smart Compression software, the results show that PSNR which represents the quality of reconstructed images, was between 36 to 42 dB and 28 to 36 dB for chest and abdomen images respectively. All these images were compressed and decompressed up to 500:1. For CT images the PSNR was between 36 to 57 dB for chest image, 34 to 52 dB for abdomen image and 40 to 57 dB for CT brain image. All these images were compressed and decompressed up to 30:1 compression ratio. The ROC analysis, which represents the diagnostic quality of digitized chest X-ray images, indicated that compression ratio 100:1 is still acceptable for digitized chest and abdomen X-ray image, whereas for CT images, the results indicated that compression ratio 30:1 is acceptable for chest and abdomen images and 20:1 for brain image. The investigations using a quantitative low and high contrast object module serving as a reference for each clinical image indicated that clinical images should be compressed according to their diagnostic content. Certain images can receive greater rates of compression than others and still retain all diagnostic information.

The use of image compression (lossy compression) makes Picture Archiving and Communications System (PACS) a more economically viable alternative to analog film-based systems by reducing the bit size required to store and represent images while maintaining relevant diagnostic information.

In this thesis, the results of the statistical tests showed that there was no significant difference between the original and reconstructed images for compression ratios up to 20:1 for CT images (brain, chest and abdomen) and 50:1 for digitized X-ray images (chest and abdomen), at a 95% of confidence level. Moreover, the results of ROC analysis suggested that compression ratios using LuraWave Smart Compression software for digitized X-ray images might be as high as ≈ 100:1, without adverse effect on clinical diagnostic performance.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMAAMPATAN HILANG TERHADAP IMEJ PERUBTAN BERDASARKEN TEKNIK WAVELET

Oleh

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Pengimejan perubatan merupakan satu alat dan kaedah yang berguna dan sangat berkuasa bagi ahli radiologi dan pakar runding, yang membolehkan mereka meningkatkan diagnosis sekaligus membantu menjalankan diagnosis tersebut. Di selurnhduria, pengimejan X-ray mewakili 60% dari keseluruhan pengimejan radiologi dan selebihnya adalah pengimejan yang lebih baru dibangunkan antaranya adalah Tomografi Terkomput (CT), Pengimejan Resonan Magnetik (MRI), ultrasound(US), Tomografi Pancaran Positron (PET), Tomografi Berkomputer Pancaran Proton Tunggal (SPECT), Nuklear Perubatan(NM) dan Angiografi Penolakan Digital (DSA).

Sistem komunikasi imej bagi pengimejan perubatan mempunyai kekangan pada lebar jalur dan saiz imej yang mengakibatkan penghantaran imej mentah tanpa mengambil masa yang lama. Maka pemampatan imej dalah faktor utama untuk meningkatkan celajnan penghantaran dan storan, tetapi mempunyai risiko kepada kehilangan data yang relevan. Piawaian radiologi DICOM 3 telah menetapkan peraturan pemampatan dengan

Piawaian radiologi DICOM 3 telah menetapkan peraturan pemampatan dengan menggunakan teknik JPEG tanpa hilang. Walau bagaimanapun pada masa ini tidak ada peraturan untuk kaedah mampatan hilang dalam pengimejan perubatan dan merupakan keputusan yang subjektif. Tahap penerimaan ini tida Ksepatutnya dikompromi dengan maklumat diagnostik. Teknologi wavelet telah muncul dan menjanjikan satu cara untuk mencapai kadar mampatan yang tinggi dan dalam masa yang sama ketepatan kualiti imej dikekalkan pada tahap yang boleh diterima pakai.

Objektif tesis ini merangkumi penilaian kepelbagaian penuras Wavelet dengan menggunakan kotak alatan (toolbox) Wavelet untuk memilih penuras terbaik bagi memampat dan menyahmampatkan imej perubatan yang dipilih. Penguraian Wavelet dua-dimensi, pengkuantitian dan pembinaan semula mengggunakan beberapa kelompok penuras dan turasan telah dilakukan ke atas set imej perubatan tersebut. Tambahan lagi, teknik pengkuantiti kesan mampatan Wavelet menggunakan cara ujian objek kontras tinggi dan rendah ke atas imej abdomen dan radiografik dada digital dan imej Tomografi terkomput. Satu jalur ujian simulasi objek kontras tinggi dan rendah dibangunkan dalam persekitaran pengaturcaraan Visual Basic. Perisian Lurawave Smart Compression telah digunakan untuk memampat dan membina semula imej yang terpilih dengan kadar mampatan yang berbeza. Sepuluh pemerhati dari Jabatan Radiologi di Pusat Perubatan Universiti Malaya (UMMC) telah menilai keputusan-keputusan yang telah dihasilkan. Kaedah objektif dan subjektif telah digunakan untuk menilai keputusan-keputusan tersebut ialah Nisbah Puncak Isyarat Kepada Hingar (PSNR), ROC dan ujian jumlah pangkat (Rank Sum test).

Keputusan yang diperolehi menunjukkan tidak ada penuras Wavelet yang secara seragamnya lebih baik dari yang lain kecuali dalam kes penuras Dauhechieus dan dwi-ortogon yang mana ianya adalah terbaik. Penuras ini memberi nilai Ralat Mutlak Maksima (MAE) yang sangat kecil (menghampiri sifar). Penuras Wavelet ini mampu menghasilkan pembinaan semula imej yang sempurna walaupun tahap uraian meningkat. Dengan menggunakan perisian Lurawave Smart Compression, keputusan yang diperolehi menunjukkan PSNR iaitu perwakilan kepada kualiti imej binaan semula adalah antara 36 dB hingga 42 dB untuk imej dada dan 28 dB hingga 36 dB untuk imej abdomen. Kesemua imej ini telah dimampatkan dan dinyahmampatkan dengan kadar sehingga 500:1. Untuk imej CT, PSNR adalah di antara 36 dB ke 57 dB untuk imej dada, 34 dB ke 52 dB untuk imej abdomen dan 40 dB dan 57 dB untuk imej otak. Kesemua imej ini dimampat dan dinyahmampatkan dengan nisbah 30:1. Analisis ROC yang menerangkan kualiti imej diagnostik X-ray digital menunjukkan nisbah mampatan 100:1 masih boleh diterima pakai iaitu untuk imej dada manakala imej CT menunjukkan nisbah mampatan 30:1 masih boleh diterima pakai untuk pengimejan dada dan abdomen manakala nisbah 20:1 untuk imej otak. Kajian penggunaan modul pembezaan objek kontras tinggi dan rendah secara kuantitatif menjadi rujukan untuk setiap imej klinikal menunjukkan bahawa setiap imej perlu dimampatkan mengikut kandungan diagnosis. Sesetengah imej boleh menerima kadar mampatan yang tinggi berbanding yang lain dan ia masih mampu mengekalkan maklumat diagnosis.

Penggunaan kaedah pemampatan imej (pemampatan bilangan) menjadikan Sistem penyimpanan dan Komunikasi Gambar PACS suatu alternatif yang lebih berdaya maju dan ekonomi berbanding sistem analog berdasarkan filem dengan mengurangkan bilangan bit yang diperlukan untuk menyimpan dan menunjukkan imej sementara menyelenggarakan maklumat diagnosis yang berkaitan dalam tesis ini. Keputusan ujian statistik menunjukkan bahawa tidak ada perbezaan yang ketara di antara imej asal dan imej yang diubahsuai untuk nisbah pemampatan sehingga 20:1 bagi imej CT (otak, dada dan abdomen) dan 50:1 unutk imej sinar-X terdigit (dada dan abdomen), pada 95% tahap keyakinan. Selain itu, keputusan analisis ROC mencadangkan supaya nisbah pemampatan menggunakan perisian LuraWave Smart Compression untuk imej sinar-X terdigit mungkin setinggi ≈100:1, tanpa kesan negatif pada prestasi diagnosis. Kajian klinikal yang lebih mendalam diperlukan sebelum penemuan ini dapat diaplikasikan kepada modaliti imejan dan aplikasi perubatan.

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