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ERROR CONCEALMENT TECHNIQUE USING WAVELET NEURAL NETWORK FOR WIRELESS TRANSMITTED DIGITAL IMAGES

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**ERROR CONCEALMENT TECHNIQUE USING WAVELET NEURAL
NETWORK FOR WIRELESS TRANSMITTED DIGITAL IMAGES**

By

ALAA KHAMEES AL-AZZAWI

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

June 2012

DEDICATION

To

Those who have dedicated themselves in the service of science and humanity, God

will confer them the paradise.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ERROR CONCEALMENT TECHNIQUE USING WAVELET NEURAL NETWORK FOR WIRELESS TRANSMITTED DIGITAL IMAGES

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June 2012

Chairman: Associate Professor M. Iqbal Saripan, PhD

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Continuous flow to send images via encrypted wireless channels may reduce the efficiency of transmission. This is due to the damage or loss of the numerous large-blocks from these images. Therefore, it is difficult to rebuild these blocks from the point of reception. In addition, some packets may be lost via the limited bandwidth networks when congestion occurs. However, compressing of bit-streams of images with variable length coding (VLC) will add another burden to the transmission in cases where these streams are sent via the noisy channels.

Several techniques have been proposed in the past decade, particularly error concealment (EC) algorithms. In this study, attention is focused on the algorithms that have high efficiency to fill-in the damaged patches, for example, Multi-directional interpolation (MDI), neighboring matching EC, etc.

Accordingly, two frameworks are proposed to tackle the following problems: (1) loss of the damaged blocks; (2) artifacts that appear after the process of filling-in (i.e., blockiness and blurring), and (3) white-Gaussian noise.

The first framework is proposed to compensate for the loss of damaged patches. The compensation information includes patches that differ in size and location. Moreover, the concealment includes patches for both smooth and nonsmooth areas. This framework is implemented in three key steps. The first step is devoted to detecting invisible patches. Further, an efficient color contrast scheme is proposed. The goal behind this scheme is to detect invisible patches that are either occurred in a dusky areas of the image or have been deliberately hidden during the encryption process.

Next, a multi-directional interpolation (MDI) technique is proposed. The method is used to estimate the lost coefficients in the wavelet-domain. Accurate values for the weighting coefficients were efficiently calculated to minimize the mean squared errors (MSE) at the top, bottom, left, and right of the missing blocks. The proposed EC schemes in the second step have been used to compensate for the loss of different damaged patches at the geometric information, with minimal artifacts from blurring and blockiness, as well as improving the Peak Signal-to-noise ratio (PSNR).

In the meantime, a new technique called 'wavelet neural network' is proposed and implemented in the third step. This technique merges the estimated matrices' results of the proposed schemes in the second step with an artificial neural network (ANN), with the intention of obtaining results with high accuracy, as well as to overcome all

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the problems that may arise after the process of filling-in (blurring and blockiness artifacts). The neural network architecture that can be used to implement a nonlinear vector predictor, including a multilayer perceptron (MLP), and a radial basis function network.

In the case, where the missing regions of pixels are containing textures, edges, and other image features that are not easily handled by concealment algorithms. It therefore, necessitated to use denoising rather than EC algorithms.

Finally, the proposed second framework is exploited for denoising a chain of images that are affected by white-Gaussian noise to the lowest possible rates, as well as concealing these images. Experimental results demonstrate that the proposed methods simultaneously provide significant improvements in terms of both loss concealment and artifacts, especially those associated with edges. The performance efficiency has been computed in terms of the PSNR, and mean squared error (MSE) yielded 87% accuracy and tested for various images and combinations of lost blocks (CT image). The results are similar to those shown in [3], [98], and [129] with a noticeable interference pattern in the reconstruction from the uniform array. The reconstructed images by our schemes produced PSNR ranges from 33 dB to 37 dB and the lowest MSE values are obtained for percentages near to 50%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Doktor Falsafah

TEKNIK PENUTUPAN RALAT MENGGUNAKAN RANGKAIAN "WAVELET-NEURAL" BAGI PENGHANTARAN IMEJ DIGITAL SECARA WAYARLES

Oleh

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Pengerusi: Professor Madya M. Iqbal Saripan, PhD

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Penghantaran imej secara terus-menerus melalui saluran wayarles yang dienkripkan boleh mengurangkan kecekapan penghantaran. Ini disebabkan oleh kerosakan atau kehilangan banyak blok daripada imej tersebut. Oleh itu, adalah sukar untuk membina semula blok ini di titik penerimaan. Tambahan pula, beberapa paket berkemungkinan hilang menerusi rangkaian lebar jalur yang terbatas apabila kesesakan berlaku. Juga, pemampatan aliran bit imej dengan pengekodan berbeza jarak (VLC) akan menambah lagi beban ke atas penghantaran.

Pelbagai teknik telah dicadangkan sebelum ini, terutamanya algoritma penutupan ralat (EC). Dalam kajian ini, perhatian ditumpukan kepada algoritma yang mempunyai tahap kecekapan yang tinggi untuk mengisi blok yang rosak, sebagai contoh interpolasi pelbagai arah (MDI), EC pemadanan jiran dan sebagainya.

Sehubungan dengan itu, dua rangka kerja telah dicadangkan untuk mengatasi masalah kehilangan blok yang rosak iaitu kemunculan kesan akibat proses pemenuhan (contohnya "*blockiness*" dan kekaburan) dan hingar putih Gaussian.

Rangka kerja pertama dicadangkan untuk menggantikan kehilangan tompokan yang rosak. Maklumat penggantian tersebut termasuklah tompokan yang berbeza dari segi saiz dan lokasi, dan ia boleh terjadi di kawasan licin atau tidak licin.

Rangka kerja ini dilaksanakan melalui tiga langkah utama. Langkah pertama dikhususkan untuk mengenalpasti tompokan tersembunyi. Seterusnya, suatu skim pertentangan warna yang cekap dicadangkan. Skim ini mampu mengesan kedua-dua jenis tompokan yang rosak dari segi saiz dan lokasi di dalam kawasan gelap yang sukar dilihat oleh mata kasar.

Kemudian, transformasi wavelet diskrit (DWT) dengan tiga tahap penguraian Haar-wavelet yang dieksploitasi di dalam analisa imej rosak. Di sini, pekali kehilangan pada sub-jalur frekuensi tinggi bagi setiap tahap penguraian dianggarkan dengan analisa interpolasi menegak dan melintang. Nilai tepat untuk pekali ini diperoleh dengan menghitung ralat min kuasa dua pada bahagian atas dan bawah blok yang hilang. Skim EC yang dicadangkan di dalam langkah kedua telah digunakan untuk menampung kehilangan pelbagai tompokan rosak pada-maklumat geometri, dengan kesan kekaburan dan "*blockiness*" yang minima, serta menambahbaik nisbah isyarat hingar puncak (PSNR).

Seterusnya, teknik baru yang dikenali sebagai rangkaian neural wavelet dicadangkan dan dilaksanakan di dalam langkah ketiga. Teknik ini menggabungkan hasil anggaran matrik yang diperoleh daripada skim yang dicadangkan dalam langkah kedua dengan suatu rangkaian neural buatan (ANN), dengan harapan untuk mendapatkan hasil berketepatan tinggi, serta untuk mengatasi segala masalah yang mungkin timbul setelah proses pemenuhan. Senibina rangkaian neural boleh digunakan untuk melaksanakan suatu jangka vektor tak linear, termasuklah perceptron berbilang lapisan (MLP) dan rangkaian fungsi asas jejari.

Akhir sekali, rangka kerja kedua yang dicadangkan dieksplotasi untuk membuang hingar suatu rantaian imej yang rosak akibat hingar putih Gaussian kepada kadar serendah mungkin, serta memulihkan imej tersebut. Hasil eksperimen menunjukkan bahawa kaedah yang dicadangkan secara serentak menghasilkan penambahbaikan yang signifikan dari segi kedua-dua penutupan kehilangan dan artifak, terutamanya imej yang berpinggir. Prestasi kecekapan dikira dari segi PSNR dan ralat min kuasa dua (MSE) menghasilkan 87% ketepatan dan diuji bagi pelbagai imej dan gabungan blok hilang (Imej CT). Imej yang dipulihkan menggunakan skim kami menghasilkan PSNR dari 33Db kepada 37Db dan nilai MSE yang terendah diperolehi dari peratusan hampir kepada 50%.

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I certify that a Thesis Examination Committee has met on 12, June 2012 to conduct the final examination of **ALAA KHAMEES AL-AZZAWI** on his thesis entitled **ERROR CONCEALMENT TECHNIQUE USING WAVELET NEURAL NETWORK FOR WIRELESS TRANSMITTED DIGITAL IMAGES,** in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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ALAA KHAMEES AL-AZZAWI
Date: 12 June 2012

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LIST OF ABBREVIATIONS

ARQ	Automatic Retransmission Query
ANN	Artificial Neural Network
APIBS	A Priori Information Block Wise Similarity
ADDA	Adjacent Domain Division Algorithm
ART	Adaptive Resonance Theory
AEC	Adaptive Error Concealment
BMA	Boundary Matching Algorithm
BNM	Best Neighbor Matching
BP	Back Propagation
BSC	Binary Synchronous Communications
CQF's	Conjugate Quadrature Filters
CvT	Curvelet Transform
CWT	Continuous Wavelet Transform
CCvT	Continuous Curvelet Transform
DCT	Discrete Cosine Transform
DC	Direct Current
DDC	Difference in Direct Current
DED	Dominate Edge Directions
DFT	Discrete Fourier Transform
DMVE	Decoder Motion Vector Estimation
DP	Decoder Performance
DS	Dominate Sort
DST	Discrete Sine Transform

DWT	Discrete Wavelet Transform
DDO	Discrete Differential Operator
EB	Error Block
EC	Error Concealment
ED	Edge Detection
ER	Error Recovery
ENO	Essential Non-oscillatory
FEC	Forward Error Concealment
FFT	Fast Forward Transform
FIR	Finite Impulse Response
FMV	Forward Motion Vector
GMM	Gaussian Mixer Model
GMRF	Gaussian Markov Random Field
HEC	Hybrid Error Concealment
HVS	High Variance Sort
IWT	Inverse Wavelet Transform
JPG	Joint Photography Group
JPEG	Joint Photography Expert Group
LMS	Least Mean Square
LV	Low Variance
MA	Moving Average
MAP	Maximum A Posteriori
MB	Macro-Block
MD	Multiple Description
MDC	Multiple Description Coding

MDCT	Modified Discrete Cosine Transform
MDI	Multi-Directional Interpolation
MDTC	Multiple Description Transform Coder
MLP	Multilayer Perceptrons
MSE	Mean Squared Error
MPEG	Moving Picture Experts Group
MMA	Motion Vector Averaging
MV	Motion Vector
NFL	Neuro Fuzzy Learning
NMEC	Neighboring Matching Error Concealment
NURBS	Non-Uniform Rational By-splines
PDE	Partial Differential Equation
PFA	Parabola Fitting Algorithm
PSNR	Peak Signal-to-Noise Ratio
QMF's	Quadrature Mirror Filters
ROC	Receiver Operating Characteristics
SAD	Sum Absolute Difference
SEC	Spatial Error Concealment
SER	Spatial Error Recovery
SOM	Self-organizing Map
SSA	Single Spectral Analysis
SSEC	Spatial Split-match Error Concealment
STFT	Short Time Fourier Transform
TEC	Temporal Error Concealment
TER	Temporal Error Recovery

VLC   Variable Length Coding

VP   Verge Point

WMRA   Wavelet Multi-resolution Analysis

WT   Wavelet Transform

WNN   Wavelet Neural Network

CHAPTER 1

INTRODUCTION

1. 1 Background of study

Even the loss of one bit that happen during the transmission of a digital image will lead to the loss of a vital information in an image. The corrupted transmitted image will be facing a further degradation when it undergoes a bit-stream compression process using VLC [1]. Figure 1.1 presents some examples of corrupted images received from wireless channels [2]. As shown in the figure, these images suffer from several damaged patches that reduced the quality of the images.

<p style="text-align:center">(a)   (b)   (c)</p>

Figure 1.1 The received wireless images: (a) Jet (512 x 512 pixels); (b) Lena (512 x 512 pixels), and (c) Peppers (512 x 512 pixels) .

The transmission of bit-stream images via wireless networks is very difficult because of the use of a predictive-encryption technique and the use of VLC in the process of image compression [3]. A bit stream image is a sector-by-sector or bit-by-bit exact

copy of a hard drive, preserving all latent data in addition to the files and directory structures.

There are some approaches that have been introduced to prevent this. They are done by inserting an additional or redundant data into the bit-stream. However, this technique only able to partially solve the problem, since they always involve changes at the encoder level, and therefore the possibility of losing some important information still persists [4, 5]. It should also be noted that a large number of statistical redundancy coefficients at high-frequency subband is removed after the process of quantization [6], when further adapted to those coefficients are achieved. It was shown by Lee, et al. that the coefficients can be efficiently encrypted [7, 8] by preventing the errors from propagating across the block boundaries to a reasonable extent. This follows the recent work by Salama et al. [9] and Wook and Lee [10].

Recently, Zou, et al. [11] have presented a method for estimating the quantization error of each frequency component separately within intra frame coding structure based on the statistical properties of the transformed coefficients at each frequency position under certain prediction mode. Further, the error recovery of VLC in the case where the encoded bit-stream is transmitted over Binary Synchronous Communications (BSC) with arbitrary crossover probability has been estimated in [12]. Therefore, it is often preferred to adopt a more efficient filling-in techniques aim at improving image quality after the process of the loss compensation of the damaged blocks.

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Filling-in the corrupted blocks with the available and limited information from their surrounding neighbors is a method that we could use to overcome the problem. This method is not only useful in an image encoding and wireless image transmission (e.g., reconstructing missing blocks), but could also be used in removal of unwanted features and image restoration (e.g., scratch removal) [13, 14]. This information can be automatically detected as in [15], or hinted by the user as in more classical texture filling techniques [16].

For clarification, the decomposing reconstruction process of all the subscribed approaches for recovering missing blocks introduced some of the aliasing distortions. This problem has been discussed in many papers and resolved using the Quadrature mirror filters (QMFs) [17], or conjugate quadrature filters (CQFs) [17, 18].

The method in [19] can be classified in order to be compatible with the JPEG 2000 image compression, in which the missing blocks in the wavelet-domain were efficiently recovered. Liew and Yan [20] have presented a highly efficient deblocking algorithm for block artifacts suppression. This algorithm can tackle both the blocking and ringing artifacts very successfully.

Chen, et al. [21] present an example-based boundary matching approach (BMA) in which the blockiness effect after applying some of the second order of the Partial differential equation (PDE) reduced. Similar to [21] is the work in [22], where the authors describe an algorithm that used to find the edge directions of a lost block.

EC is a post-processing technique that has been exploited to fill-in damaged blocks after using the implicit redundancies of the decoded received image. Many of the EC

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techniques have the capability to detect damaged blocks before reconstructing them [23]. While others need to support any appropriate conversion format and/or an EC algorithm, to facilitate the detection of damaged blocks [24, 25]. Among these techniques, EC algorithms have been extensively studied for their efficient possibilities in practical applications.

In this context, several methods have been suggested, such as layered coding [26], and automatic retransmission query (ARQ) [27]. In addition, innovative concepts for a variety of interpolations-based spatial EC schemes have been considered. For example, directional interpolation [28], Non-uniform rational B-spline (NURBS) interpolation [10], and block-matching interpolation [22] for consecutive block loss patterns.

Some techniques which take advantage to address such problems have been developed [29, 30]. However, these techniques indicated that EC techniques at the decoders efficiently succeeded in concealing many of the erroneous blocks after the exploitation of the decoded information correctly, without modifying the source that handled both complexity in the off-line design of the quantizer, and feedback requirements in the on-line operation of the system and channel coding schemes that handle circuits of depth.

Accordingly, the EC applications are required to comply with some specific packetizing restrictions that permit packets to be decoded independently. The method in [31] is an EC scheme for JPEG coded image transmission via the wireless networks, in which both spatial redundancy and data-hiding are used.

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There are several EC methods that lagged not only in the detection of the edges, but also in the visual quality of the images. The technique in [32] based on structural alignment, which uses edge gradient as the distortion criterion to achieve better results. Agrafiotis, et al. [33] propose a highly efficient EC scheme for edge-related information that preserves existing edges, as well as to avoid the introduction of new strong ones by switching to a smooth approximation of missing information. The EC methods [34, 35] are based on both joint interpolations of the image graylevels and image gradient directions. Bourdon et al. [36] describe a geometric method to conceal damaged patches of images of multiple resolutions.

Most of the methods that have been presented above failed in tackling both blocking and blurring artifacts, specifically within nonsmooth areas. A posteriori approach aimed to predict the blocks containing edges with a high accuracy, as well as enhancing the quality of images in terms of visual perception. In addition, overcoming all the problems that may arise after the process of filling-in. In this context, features of the theoretical wavelet transformation should be addressed in terms of concepts that contribute to the development of the network construction methods. The basic idea of combining wavelet theory with neural networks has resulted in a new technique known as 'wavelet neural network'. These techniques are characteristically used in the categorization and predefining of problems.

The authors in [37] presented a method to automatically obtaining an optimal training set by resampling the positive samples. While, the authors in [38] have combined the advantages of two neural network models; direct classification model that borrows some features from the adaptive resonance theory (ART), and the

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Kohonen self-organizing feature map (KSOFM) in order to achieve high image quality at high compression ratios.

In the case where the missing blocks are containing textures, edges, and other image features that are not readily handled by EC algorithms, it therefore, necessitated to use denoising rather than EC algorithms. In this case, the missing information is likely recovered under the MSE fidelity metric using the sparsity constraint that a portion of the images transforms coefficients over missing regions are zero or close to zero. A method of denoising images based on spares and redundant representations is developed and reported in [39] and [40].

Crouse, et al. [41] explained that the eventuality exemplars of the wavelet coefficients can be exploited properly if included Gaussian mixture, Gaussian scale mixture [42], and circular-symmetric Laplacian [43].

Methods for removing noise from digital images corrupted by the additive, multiplicative, and the mixed noise had been proposed by Hirakawa and Park [44], and Kervrann and Boulanger [45]. Wu, et al. [46] explained that is very easy to separate the edge curves from each other by applying each of the adjacent domain division algorithms (ADDA) and the parabola fitting algorithms (PFA).

1. 2 Problem Statement

In the encoded block images' systems, parts of bitstreams may be corrupted due to noise or even the loss of one bit often leads to the loss of whole blocks, in the case

where they are sent via wireless communication networks and, specifically, with unreliable channels. Furthermore, we see that some of the packets may be lost via the limited bandwidth networks when congestion occurs. In all cases, there will be a severe reduction in the quality of the received images. However, compressing of bit-streams of image with VLC immediately with a rapid response to noise via a noisy channel will add another burden to the transmission, and also lead to introduce distortion into decoded video information. Consequently, some of these packets are likely to be corrupted because of noise, while others may break due to congestion. These restrictions will also cause severe shortages in the quality of the image to be reconstructed.

From another point of view, the industrial viewpoint, image decryption will also be suffering serious deformation in situations where the compressed bitstream has little damage. In other words, in still images, only the lost blocks can be recovered within the phase of spatial processing. Whereas, artifacts that may appear to be directly associated either with the significant extracted images' edges or within the whole image after the process of filling-in. Therefore, there may be great difficulty in addressing this issue.

There is another important issue that requires investigation. Most of the traditional methods used in the detection of damaged patches of digital images resort to sharp focusing of all the details of these images, with the intention of distinguishing those patches. However, we see that in many cases these methods have failed to detect many of the patches. This might be because they are located in a dusky region, or deliberately concealed during the process of encryption.

EC techniques are used in the creation of bitstreams of the original image, by separating the streams containing errors at the decoder, as well as improving the quality of the receiving images. However, in other cases, an incorrect large neighboring block is recovered with similar large errors, which reflects negatively in the reconstruction of the next ones. This phenomenon is known as recovery dependency.

Finally, in image applications over unreliable channels, the decoder has to contend with data corrupted by channel errors. These error lead to missing rectangular regions, which need to be perfectly estimated by appropriate recovery and concealment algorithms. Further, in the case where the missing regions of pixels are containing textures, edges, and other image features that are not easily handled by EC algorithms, therefore requires appropriate solution to this problem.

1. 3 Objectives

The main goal of this study is to conceal the loss of the encoded damaged blocks with minimal blurring effect, minimal blockiness effect, as well as tackling the white-Gaussian noise. To achieve the main aim, these specific objectives are embarked:

1 - To design and test detection framework that can handle the invisible damaged blocks for medium and high resolution images.

2 - To design and test EC framework that can handle loss of the damaged blocks for medium and high-resolution images.

3 - To design and test EC framework that can handle effects after filling-in process for medium and high-resolution images.

4 - To apply and assess the performance of the proposed EC framework on images corrupted by white-Gaussian noise.

1. 4 Thesis Scope

The flow of the research is illustrated in Figure 1.2. The bold lines represent the direction followed in this thesis to achieve both the goal and objectives, whereas the dotted lines are referring to other research areas that are out of the scope of this work. The loss information in wireless transmission systems, specifically with the encoded block images, part of bitstreams may be corrupted or damaged due to noise and the loss of even one bit. The figure shows that, the loss information can be recovered in several techniques.

In this thesis, the attention focuses on the techniques that have the capability of efficiently compensating for the damaged patches of digital images that are caused by the weaknesses in the channels of transmission. Therefore it requires a focus on the algorithms that use sequential recovery based on the following models; 1) Statistical pixelwise, 2) MDI based on the geometric structure, 3) Best neighborhood matching (BNM), and 4) Spatial split-match error concealment (SSEC). In addition, the possibility of how to remove the blocking artifacts located at the block boundaries of subbands, as well as the performance efficiency of the filling-in is studied. Further, a wavelet neural network (WNN) architecture that supports the processes of filling-in is proposed, with the intention of enhancing image quality.

Finally, the study focuses on how to extract the edges for images corrupted by white-Gaussian noise, to easily providing sparse decompositions over missing regions.
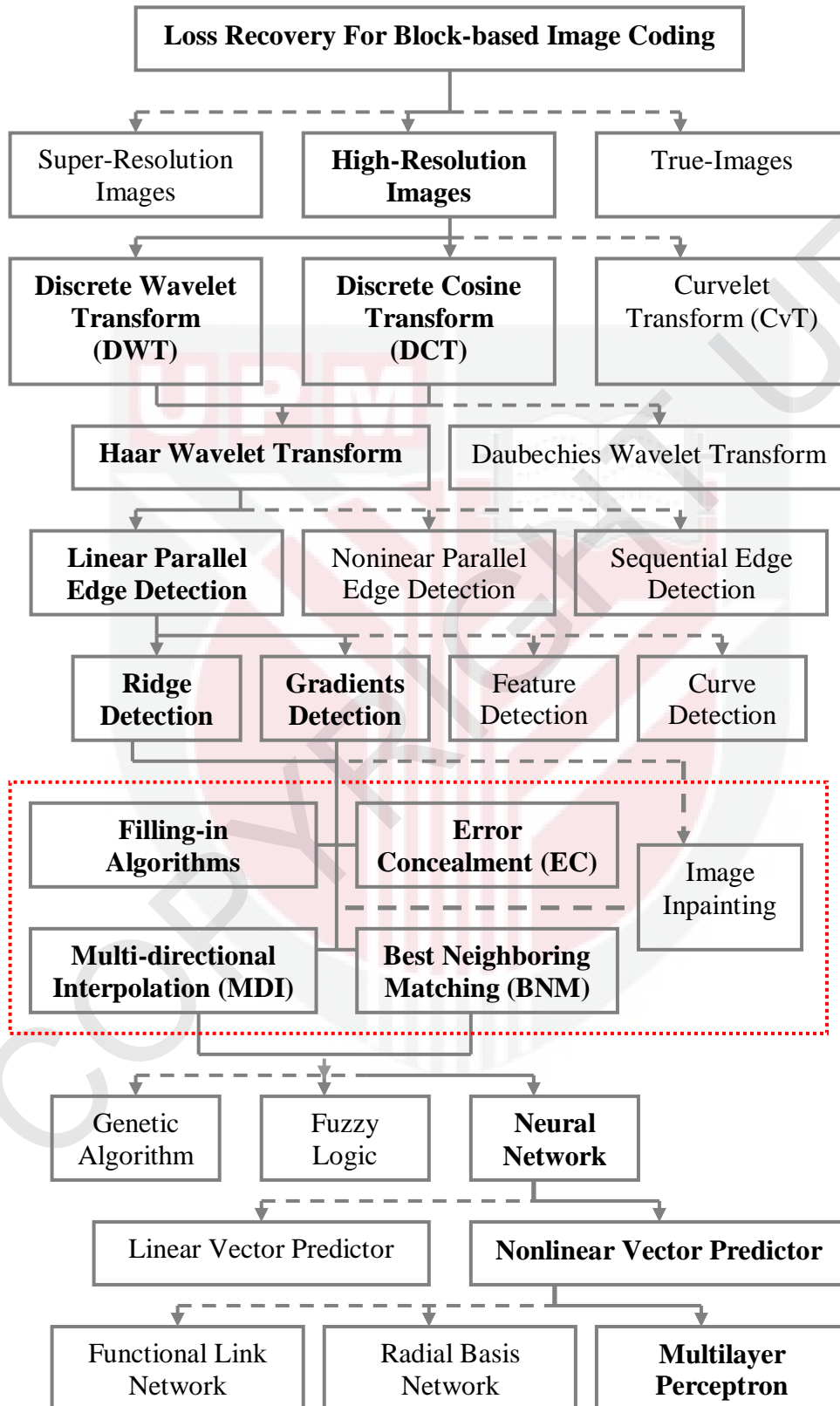
Figure 1.2 Study Module

1.5 Thesis Contributions

The contributions of this thesis are as follows:

1. A framework that can handle the invisible damaged patches for medium and high resolution images was developed. The method can detect both size and location of the damaged patches in the dusky areas that normal eyesight could hardly detect. The detection is carried out after applying the logarithms to the details of doubled logic images.

2. An error concealment framework that can handle loss of the damaged blocks using the similarity segmentation (i.e., Pixels-to-Feet conversion) was proposed.

3. A wavelet neural network technique (WNN) to handle both the blockiness and blurring artifacts after filling-in process for high-resolution images was proposed. The motivation behind the proposed WNN is to predict the blocks containing edges with a high accuracy, as well as enhancing the quality of images in terms of visual perception.

4. A technique to enhance images that are affected by white-Gaussian noise was developed. The best extraction method for both the vertical and horizontal image gradients is achieved after changing the magnitude of the threshold. These are extracted from the histogram of those gradients.

1. 6 Thesis outline

This thesis contains five chapters and is organized as follows:

Chapter 1 is the introduction, which presents the background of the study, the problem statement at hand, thesis objectives, thesis scope and study module, and thesis outline.

Chapter 2 presents the background of the subjects related to the methodology in this thesis and discusses another literature related to the design schemes of interpolation analysis, algorithms to conceal damaged patches, algorithms to improve the quality of the images to be reconstructed, and methods used to extract image gradients.

Chapter 3 presents an introduction to the methodology and brief discussion of the proposed frameworks is given. Further, a comprehensive description to the proposed EC schemes is outlined. On the other hand, this chapter elaborates on the analysis of algorithms, which have been proposed in this study, for example, detection of invisible damaged patches, low-complexity EC scheme, artificial neural network structure, and image de-noising analysis.

Chapter 4 reports experimental simulation and results of a number of standard test images to the following issues; 1) image compression, 2) Haar wavelet decomposition, 3) performance efficiency of the proposed invisible detection scheme, 4) EC schemes, 5) wavelet neural network, and 6) chains of images affected by the white-Gaussian noise.

Chapter 5 presents the conclusion and suggestions for future works.

REFERENCES

[1] G. K. Wallace, "Communications Of The ACM", vol. 34, no. 4, pp. 30-44, 1991.

[2] S. D. Rane, G. Sapiro, D Q G 0 % H U W D O P L R ³ 6 W U X F W X U H Xü of Missing Image Blocks in Wireless Transmiss L R Q D Q G & R P S U H V V L R Q $ S S O IEEE Transactions on Image Processing, vol. 12, pp. 296-303, 2003.

[3] Y. Wang, Q-) = K X ³ (U U R U & R Q W U R O D Q G & R Q F H D O P H Q W) D U H Y L H Z ´ 3 U R F H H G L Q J R I W K H , (((Y R O Q R S S

[4] I.-W. Tsai and C.-L Huang, "Hybid Cell Loss Concealment Methods For MPEG-II-Based Packet Video," Signal Processing: Image Communication, vol. 9, no. 2, pp. 99-124, 1997.

[5] F.-G. B. De Natale, "DCT Information Recovery of Erroneous Image Blocks by a Neural Predictor", IEEE Journal On Selected Areas In Communications, vol. 18, no. 6, 2000.

[6] Y. Guo, Y. Chen, Y- . : D Q J + / L 0 0 + D Q Q X N V H O D D Q G 0 * H 5 H V L O L H Q W & R G L Q J D Q G (U U R U & R Q F H D O P H Q W L Q 6 Transactions on Circuits and Systems for Video Technology, vol. 19, no. 6, pp. 781-795, 2009.

[7] Y-S. Lee, K. -K. Ong, and C- < / H H ³ (U U R U Resilient Image Coding (ERIC) With Smart-IDCT Error Concealment Technique For Wireless Multimedia 7 U D Q V P L V V L R Q actions on Circuits and Systems for Video Technology, vol. 13, no. 2, pp. 176-181, 2003.

[8] X. Lee, Y-Q. Zhang, and A. Leon- * D U F L D ³ , Q I R U P D W L R Q / R V V 5 H Block-Based Image Coding Techniques- $) X]] \ / R J L F $ S S U R D F K ´ , (Transactions on Image Processing, vol. 4, no. 3, pp. 259 ±273, 1995.

[9 @ 3 6 D O D P D 1 % 6 K U R I I (- & R \ O H D Q G (- ' H O S ³ 7 H F K Q L T X H I R U (Q F R G H G 9 L G H R 6 W U H D P V ´ , Q W H U Q D W Processing, vol. 1, pp. 9 ±12, 1995.

[10] J. W. Wook and S. U. L H H ³ 5 H F R Y H U \ R I & R U U X S W H G , P D J H ' D 1 8 5 % 6 , Q W H U S R O D W L R Q ´ , (((7 U D Q V D F W L R Q V R Q & L U Technology, vol. 9, no. 7, pp. 1003-1008, 1999.

[11] F. Zou, O. C. Au, W. Yang, C. Pang, and J. Dai, "Intra Mode Dependent Quantization Error Estimation Of Each DCT Coefficients in H.264/AVC", IEEE Int. Conf. on Multimedia and Expo (ICME), pp. 447-451, 2010

[12] J. Zhou, O. C. Au, X. Fan, and P. H.-W. Wong, "Error Recovery of Variable Length Codes over BSC with Arbitrary Crossover Probability", IEEE Int. Symposium on Information Theory (ISIT), pp. 1188-1192, 2008.

[13] M. Bertalmio, L. Vese, G. Sapiro, and S. Osher, "Simultaneous Structure and Texture Image Inpainting," IEEE Transactions on Image Processing, pp. 882-889, 2003.

[14] E. Y. Chang, "An Image Coding and Reconstruction ... Computing," Lecture Notes in Computer Science ...

[15] M. Bertalmio, G. Sapiro, V. Caselles, and C. Ballester, "Image Inpainting," Comput. Graph. (SIGGRAPH 2000), vol. 35, no. 4, pp. 417–424, 2000.

[16] E. Simoncelli and J. Portilla, "Texture Characterization Via Joint Statistics of Wavelet Coefficient Magnitude," IEEE Int. Conf. on Image Processing, vol. 1, pp. 62-66, 1998.

[17] M. Smith, and D. T. Barnwell, "Exact Reconstruction Techniques for Tree-Structured Sub-band Coders," IEEE Transactions on Acoustics, Speech, Signal Processing, vol. 34, no. 3, PP. 434-441, 1986.

[18] A. N. Skodras, C. A. Christopoulous, and T. Ebrahimi, "The JPEG 2000 Still Image Compression Standard," Pattern, no. 12, PP. 1337-1345, 2001.

[19] S. D. Rane, J. Remus, and G. Sapiro, "Wavelet-Domain Reconstruction of Lost Blocks in Wireless Image Transmission and Packet-Switched Networks," International Conference on Image Processing, vol. 1, pp. 1309-1312, 2002.

[20] A. W-C. Liew and H. Yan, "Blocking Artifacts Reduction in JPEG Images Using Overcomplete Wavelet Representation," International Symposium on Intelligent Multimedia, Video and Speech Processing, pp. 129–132, 2001.

[21] Y. Chen, Y. Hu, O. C. Au, H. Li, and C. W. Chen, "Video Error Concealment Using Spatio-Temporal Boundary Matching and Partial Differential Equation," IEEE Transactions on Multimedia, vol. 10, no. 1, pp. 2-15, 2008.

[22] S-C. Hsia, "An Edge-Oriented Spatial Interpolation For Consecutive Block Error Concealment," IEEE Signal Processing Letters, vol. 11, no. 6, pp. 577–580, 2004.

[23] W-M. Lam and A. R. Reibman, "An Error Concealment Algorithm For Images Subject to Channel Errors," IEEE Transactions on Image Processing, vol. 4, no. 5, pp. 533–542, 1995.

[24] X. Lee, Y-Q. Zhang, and A. Leon-Garcia, "Information Loss Recovery For Block-Based Image Coding Techniques-A Fuzzy Logic Approach," IEEE Transactions on Image Processing, vol. 4, no. 3, pp. 259–273, 1995.

[25] H. Sun and W. Kwok, "Concealment of Damaged Block Transform Coded Images Using Projections Onto Convex Sets," IEEE Transactions on Image Processing, vol. 4, no. 4, pp. 470–477, 1995.

205

[26] R. Aravind, M. R. Civanlar and A. R. Reibman MPEG- Scalable Video Coding Algorithms ´, IEEE Tran Systems for Video Technology, vol. 6, no. 5, pp. 426 ±435, 1996.

[27] M. Wada ³Selective Recovery of Video Packet Loss Using Error Concealment ´, IEEE Journal Selec Communi vol. 7, no. 5, pp. in Co 807 ±814, 1989.

[28] J-W. Suh and Y-S. Ho ³Error Concealment Based Interpolation ´, IEEE Transaction Consumer Elec vol. 43, no. 3, pp. 295-sumer (Elec 302, 1997.

[29] M-C. Chi, M-J. Chen, J-H. Liu and C-T. Hsu ³High Performance Error Concealment Algorithm By Motion Vector Refinement For MPEG- Video ´, IEEE International Symposium on Circuits and Systems, , vol. 3, pp. 2895 ±2898, 2005.

[30] B. W. Wah X. Su and D. Lin ³A Survey Error Concealment Schemes For Real- Time Audio and Video Transmissions Over the Symposium on Multimedia Software Engineering, pp. 17 ±24, 2000.

[31] A. K. Anhari and L. Lampe, ³Error Concealment For New Image Coder - JPEG Transmission Over Wireless Links ´ Canadian Electrical and Computer Engineering, pp. 472-477, 2009.

[32] A.S. Bopardikar, O.I. Hillestad and A. Perkis ³A Temporal Error Concealment Algorithm Based On Structural Alignment For Packet video ´ Proc SPCOM pp. 373 ±377, 2004.

[33] D. Agrafiotis, D. R. Bull and N. Canagarajah ³Enhanced Error Concealment With Mode Selection ´ dge Related Perceptual Considerations ´ Signal vol. 21, no. 2, pp. 130-142, 2006.

[34] C. Ballester, M. Bertalmio, V. Caselles, G. Sapiro, ´ -in By Joint Interpolation of Vector Fields and Gray Image Processing, vol. 10, no. 8, pp. 1200-1211, 2001.

[35] M. Xin S. Li and Y. Songyu ³Adaptive Pixel Interp Concealment ´, IEEE Workshop on Signal Processing 705, 2001.

[36] P. Bourdon B. Augereau C. Chatellier and Geometry-Driven Error Concealment Method For Corrupted Signal Processing: Image Communication, vol. 20, no. 7, pp. 681-694, 2005.

[37] J. Chen, X. Chen, J. Yang, S. Shan, R. Wang, and W. Gao, " Optimization of a training set for more robust face detection", Pattern Recognition, vol. 42, no. 11, pp. 2828-2840, 2009.

[38] H. S. Soliman, and M. Omari, "A neural networks approach to image data compression", Applied Soft Computing, vol. 6, no. 3, pp. 258-271, 2006.

[39] M. Elad, and M. Aharon, "Image denoising Via Learned Dictionaries and Sparse Representation," Int. Conf. on Computer Vision and Pattern Recognition, pp. 17-22, 2006.

[40] M. Elad, and M. Aharon, "Image denoising Via Sparse and Redundant Representation Over Learend Dictionaries," IEEE Trans. Image Process., vol. 15, no. 12, pp. 3736-3745, 2006.

[41] M. S. Crouse, R. D. Nowak, and R. G. Baraniuk, D Q G 5 * % D U D Q L X N ³ % Tree-Structured Image Modeling Using Wavelet-' R P D L Q + L G G H Q 0 D U N R Y 0 R IEEE Transactions on Image Processing, vol. 46, no. 7, pp. 1056 ±1068, 1998.

[42 @ - 3 R U W L O O D 9 6 W U H D O 0 - : D L Q Z U L J K W D Q G (8 V L Q J 6 F D O H 0 L [W X U H V R I * D X V V L D Q V L Q 7 K H : D Y H O H W Image Processing, vol. 12, no. 11, pp. 1338 ±1351, 2003.

[43 @ / 6 H Q G X U , : 6 H O H V Q L F N ³ % L Y D U L D W Based 6 K U L Q N D De- Q R L V L Q J ([S O R L W L Q J , Q W H U V F D O H ' H S H Q G H Q F \ ´ , ((Processing, vol. 50, no. 11, pp. 2744 ±2756, 2002.

[44 @ . + L U D N D Z D D Q G 7 : 3 D U N V ,P D J H ' H Q R L V L Q J 8 V L Q J 7 R W D O / H D V W 6 T X IEEE Transactions on Image Processing, vol. 15, no. 9, pp. 2730-2742, 2006.

[45 @ & . H U Y U D Q Q D Q G - % R X O D Q J H U ³ 2 S W L P D O 6 S D W L D O Based , P D J H ' H Q R L V L Q J ´ , (((7 U D Q V D F W L R Q V R Q ,P D J H 3 U R F H V pp. 2866-2878, 2006.

[46 @ < : X < + H D Q G + & D L ³ 2 S W L P D O 7 K U H V K R O G 6 H Detection Based- R Q : D Y H O H W 7 U D Q V I R U P ´ , P D J H D Q G 9 L V L R Q & R P S 13, pp. 1159 ±1169, 2005.

[47] A. Cohen, I. Daubechies, J.-C. Feauvea U ³ % L R U W K R J R Q D O % D V H V R I & R P S D F W O \ 6 X S S R U W H G : D Y H O H W V ´ & R P P X Q L F D W L R Q V R Q 3 X U H D Q G $ S S O L H G 0 D W K H P D W L F V no. 5 pp. 485-560, 1992.

[48 @ , ' D X E H F K L H V ³ 7 H Q / H F W X U H V R Q : D Y H O H W V 6 , $ 0 6 R F L H W \ I R U , Q G X V W U L D O D Q G Applied Mathematics, pages: 357, Philadelphia, PA, 1992.

[49 @ ' / ' R Q R K R , 0 - R K Q V W R Q H * . H U N \ D F K D U L D Q D Q G ' 3 L F N D U G ³ : D Y H O H W 6 K U L Q N D J H $ V \ P S W R S L D ´ - 5 6 W D W 6 R F % 9 R O R 1995. 6 R F Y R O

[50 @ 6 0 D O O D W ³ $ 7 K H R U \ I R U 0 X O W L U H V R O X W L R Q 6 L J Q D O ' H F R P S R V L W L R Q The Wavelet 7 U D Q V I R U P ´ , (((7 U D Q V D F W L R Q V R Q 3 D W W H U Q $ Q D O \ V L V D Q G 0 D F K L Q H , Q W H O O L J H Q F H no. 11, pp. 674-693, 1989.

[51 @ : % H O O L O & % $ P D U D Q G $ ' $ O L P L ³ 6 \ Q W K H V L V : D Y H O H W 1 H X U D O 1 H W Z R U N V ´ , Q W H U Q D W L R Q D O - R X U Q D O R I & R P S X W H U 6 F L H Q F H (Q J L Q H H U L Q J and Technology, vol. 13, no. , pp. 108-111, 2005.

[52]) ' X E H D X 6 (O P H M G D Q-IX Q5 I R V P Q+WDDUL Z DIYRHO H W V Mathematics and Computation, vol. 159, no. 3, pp. 675-693, 2004.

[53] Y. Wang, S. Wenger, J. Wen, A. K. . D W V D J J H O R V ³ (U U R U 5 H V L O L H Q 7 H F K Q L T X H V ´ , (((6 L J Q D O 3 U R F H V V L Q J 0 D J D] L Q H Y R O

[54] 5 6 ' L O P D J K D Q L $ $ K P D G L D Q 0 * K D Y D P L $ + 0 H G L F D O , P D J H 7 U D Q V P L V V L R Q D Oefs on Signal Processing, R Q ´ , ((vol. 11, no. 10, pp. 806-809, 2004.

[55] . . K H O L O 5 (+ % H N N D $ ' M H D U L D Q G - 0 5 R X Wavelet- % D V H G , P D J H & R G L Q J 8 V L Q J & R U U H O D W L Q J 7 U D Q V Journal on Electronics and Communications, vol. 61, no. 6, pp. 411-417, 2007.

[56] Q. H. Zang, ³Using Wavelet Network in Nonparametric Estimation ´IEEE Trans. Neural Networks, vol. 8, no. 2, pp. 227-236, 1997.

[57] 4 = K D Q J D Q G $ % H Q Y H Q L V W H ³ : D Y H O H W 1 H W Z R Neural Networks, vol. 3, no. 6, pp. 889-898, 1992.

[58] + + 6] X % $ 7 H O I H U D Q G 6 / . D G D P E H ³ 1 H X U D O 1 I R U 6 L J Q D O 5 H S U H V H Q W D W L R Q D Q G & O D V V L I L F D W L R Q 1 1907-1916, 1992.

[59] S. Postalcio J O X . (U N D Q D Q G (' % R O D W -Net For S D U L V R Q 6 \ V W H P 0 R G H O L Q J ´ % R-Based Intelligent Information and Engineering Systems, vol. 3682, pp. 100-107, 2005.

[60] Y. Tadmor and D.J. Tolhurst. Calculating the contrasts that retinal ganglion cells and lgn neurons encounter in natural scenes. Vision Research, 40:3145 ±3157, 2000.

[61] A. Rizzi, T. Algeri, G. Medeghini, and D. Marini. A proposal for contrast measure in digital images. In CGIV 2004 ± Second European Conference on Color in Graphics, Imaging and Vision, 2004.

[62] M. Pedersen, A. Rizzi, J.Y. Hardeberg and G. Simone. Evaluation of contrast measures in relation to observers perceived contrast. Proc. CGIV 2008 4th European Conference on Colour,in Graphics Imaging and Vision, Terrassa, Barcelona (Spain), June 9-13th 2008.

[63] Fattal, R., Lischinski, D., Werman, M.: Gradient domain high dynamic range compression. ACM Transactions on Graphics, Proceedings of ACM Siggraph 21 (2002) 249 ±256.

[64] Prez, P., Gangnet, M., Blake, A.: Poisson image editing. ACM Transactions on Graphics, Proceedings of ACM Siggraph 22 (2003) 313 ±318.

[65] W. Kim, J. Koo and J. Jeong, ³Fine Directional Interpolation for Spatial Error Recovery´, vol. 52, no. 3, pp. 1050-1055, 2006.

[66] A. Buades, B. Coll, and J. M. Morel, ³A review of image denoising algorithms with a new one´, Multiscale Model. Simul. Vol. 4, no. 2, pp. 490-530, 2005.

[67] C. Kervrann and J. Boulanger, ³Optimal Spatial Adaptation for Patch-Based Image Denoising´, IEEE Trans. On Image Processing, vol. 15, no. 10, pp. 974-981, 2006.

[68] J. B. Kim, ³Geometric-Based Error Concealment for Concealing Transmission Errors and Improving Visual Quality´, IEEE Trans. On Circuits and Systems for Video Technology, vol. 16, no. 8, pp. 2866-2878, 2006.

[69] T. Strohmer ³Computationally Attractive Images From Irregular Samples´, IEEE Transactions, no. 4, pp. 540-548, 1997.

[70] J. Jia and C.-. Tang ³Image Repairing: robust Adaptive image Synthesis ND Tensor Voting´, IEEE Conference on Computer Vision, vol. 1, pp. 643-650, 2003.

[71] H. Y. Lee, K. Eom and Y. S. Kim ³Adaptive Reconstruction Blocks Using Difference of DC, Conference on Signal Processing (ICSP 'O4), vol. 1, pp. 853-856, 2004.

[72] A. N. Hirani and T. Totsuka ³Combining Frequency Information For Fast Interactive Image Noise Removal, Graphics and Interactive Techniques (SIGGRAPH '96), pp. 269-276, , 1996.

[73] M. Ancis and D. D. Giusto ³Reconstruction of Missing Transmission´, IEEE Conference on Communication Processing, pp.288 -291, 1999.

[74] R. M. Haralick Step Edges From Zero Crossing of Second Directional Derivatives´, IEEE Transactions on Pattern Analysis, no. 1, pp. 58-68, 1984.

[75] M. O. Shneier ³Extracting Linear Features, IEEE Transactions on Systems, Man and Cybernetics, vol. 12, no. 4, pp. 569-572, 1982.

[76] J. Canny ³A Computational Approach To Edge 'Detection on Pattern Analysis and Machine Intelligence, vol. 8, no. 6, pp. 679-698, 1986.

[77] C. Grigorescu, N. Petkov and M. A. Westenberg ³Contour Detection Improved By Surround Suppression Of Texture Computing, vol. 22, no. 8, pp. 609-622, 2004.

[78] J. Ye, G. Fu, and U. P³Accurax Edge Detection With Blurred Edge Model´, Image and Vision Computing, vol. 23, 2005.

[79] Y.-D. Qu, C.-S. Cui, S.-B. Chen, and J.-Q. Li, ³A Fast Subpixel Edge Detection Method Using Sobel±Zernike Moments Operator´, Image and Vision Computing, vol. 23, no. 1, pp. 11-17, 2005.

[80] M.-Y. Shih, and D.-C. Tseng, ³A Wavelet-Based Multiresolution Edge Detection And Tracking´, Image and Vision Computing, vol. 23, no. 4, pp. 441-451, 2005.

[81] Q. He, and Z. Zhang, ³A New Edge Detection Algorithm For Image Corrupted By White-Gaussian Noise´, International Journal of Electronics and Communications, vol. 61, no. 8, pp. 546-550, 2007.

[82] L.-J. Belaid, M. Jaoua, M. Masmoudi and L. Siala, ³Application Of The Topological Gradient To Image Restoration And Edge Detection´, Engineering Analysis with Boundary Elements, vol. 32, no. 11, pp. 891-899, 2008.

[83] A. A. Novotny, R. A. Feijoo, C. Padra and E. Taroco, ³Topological Sensitivity For Linear Elastic Plane Bending Problems´, Control and Cybernetics, vol. 34, no. 1, pp. 339-361, 2005.

[84] S. Amstutz, I. Horchani, and M. Masmoudi, ³Crack Detection By The Topological Gradient Method´, Control and Cybernetics, vol. 34, no. 1, 2005.

[85] T. Hermosilla, E. Bermejo, A. Balaguer, and L.-A. Ruiz, ³Non-linear Fourth-Order Image Interpolation For Subpixel Edge Detection And Localization´, Image and Vision Computing, vol. 26, no. 9, pp. 1240-1248, 2008.

[86] R. Medina-Carnicer, F.J. Madrid-Cuevas, ³Unimodal Thresholding For Edge Detection´, Pattern Recognition, vol. 41, no. 7, pp. 2337-2346, 2008.

[87] D. R. Martin, C. C. Fowlkes and J. Malik, ³Learning To Detect Natural Image Boundaries Using Local Brightness, Color and Texture Cues´, IEEE Transactions On Pattern Analysis and Machine Intelligence, vol. 26, no. 5, pp. 530-549, 2004.

[88] Z. Zhang, S. Ma, H. Liu and Y. Gong, ³An Edge Detection Approach Based On Directional Wavelet Transform´, Computers and Mathematics with Applications, vol. 57, no. 8, pp. 1265-1271, 2009.

[89] D. Sen, and S.-K. Pal, ³Gradient Histogram Thresholding In A Region Of Interest For Edge Detection´, Image and Vision Computing, vol. 28, no. 4, pp. 677-695, 2010.

[90] S.-A. Coleman, S. Suganthan, and B.-W. Scotney, ³Gradient Operators For Feature Extraction And Character Localization In Range Images´, Pattern Recognition Letters, vol. 31, no. 9, pp. 1028-1040, 2010.

210

[91] E. J. Candes, L. Demanet, D. L. Donoho, and L. Ying, "Fast Discrete Curvelet Transforms," IEEE Transactions on Signal Processing, pp. 861-899, 2006.

[92] E. J. Candes and L. Demanet, "The curvelet representation of wave propagators is optimally sparse," Communications on Pure and Applied Mathematics, vol. 58, no. 11, pp. 1472-1528, 2005.

[93] F. Natterer, The Mathematics Of Computerized Tomography, B. G. Teubner, John Wiley and Sons, 1986.

[94] B.-J. Kim, Z. Xiong, and W. A. Pearlman, "Low Bit-Rate Scalable Video Coding With 3-D Set Partitioning in Hierarchical Trees (3-D SPIHT)," IEEE Transactions on Circuits and Systems For Video Technology, vol. 10, no. 8, pp. 1374–1387, 2000.

[95] J. Kim, R. M. Mersereau, and Y.-S. Ho, "A Novel Unequal Error-Protection And Error-Concealment Algorithm For SPIHT-Coded Video Bit-Streams," IEEE Transactions, vol. 13, no. 12, pp. 1547-1555, signal processing 2004.

[96] L.-W. Kang, and J.-J. Leou, "Two Error Resilient Coding Schemes Based Image Transmission Based on Data Embedding," Journal of Visual Communication and Image Representation, vol. 17, no. 6, pp. 1127-1144, 2006.

[97] S. S. Hemami, and T. H.-Y. Meng, "Transform Coded Image Reconstruction Exploiting Interblock Correlation," IEEE Transactions, no. 7, pp. 1023–1027, 1995.

[98] J. H. Shin, J. H. Jung, and J. K. Paik, "Spatial Interpolation of Images Using Truncated Projections Onto Convex Sets," IEICE Fundamentals, vol. E82-A, no. 6, pp. 887–892, 1999.

[99] S. Tsekeridou and I. Pitas, "MPEG-2 Error Concealment Based on Block-Matching Principles," IEEE Transactions on Circuits and Systems for Video Technology, vol. 10, no. 4, pp. 646-658, 2000.

[100] T. Simchony, R. Chellappa, and Z. Lichtenstein, "Relaxation Algorithms for MAP Estimation of Gray-Level Images With Multiplicative Noise," IEEE Transactions on Information Theory, vol. 36, no. 3, pp. 608-613, 1990.

[101] A. Najaa, T. Talebe and J. Murphy, "Forward Error Correction for Media Streaming Over Wireless Networks," IEEE Communications, vol. 46, no. 1, pp. 72–79, 2008.

[102] C.-M. Fu, W.-L. Hwang, and C.-L. Huang, "Efficient Post-Compression Error Resilient 3D-Scalable Video Transmission For Packet Erasure Channels," IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP '05), vol. 2, pp. 305–308, 2005.

[103] < : D Q J $ 5 H L E P D Q D Q G 6 / L Q ³ 0 X O W L S O H 'H V F U ' H O L Y H U \ ´ , (((- Y R O Q R S S ±70, 2005.

[104] C. -M. Fu, W. -L. Hwang, and C. -/ + X D Q J ³ & R P E L Q H G (U U R U & R and Error Correction in Rate-Distortion Analysis for Multiple Sub-stream 7 U D Q V P L V V L R Q V ´ , (((7 U D Q V D F W L R Q V R Q , P D J H 3 U R F H 1035, 2007.

[105] 6 $ L J Q D Q G .) D] H O ³ 7 H P S R U D O D Q G 6 S D W L D O (U For Hierarchical MPEG- 9 L G H R & R G H ,,(((International Conference on Communications (ICC '95), vol. 3, pp. 1778 ±1783, 1995.

[106] : . Z R N D Q G + -directional Interpolation For Spatial Error & R Q F H D O P H Q W ´ , (((7 U D Q V D F W L R Q V R Q & R Q V X P H U (O H 460, 1993.

[107] - : 3 D U N - : . L P D Q G 6 8 / H H ³ ' & 7 -Based & R H I I L F L H Error Concealment Technique And Its Application To The MPEG-2 Bit Stream (U U R U ´ , (((7 U D Q V D F W L R Q V R Q & L U F X L W V D Q G 6 \ V W H P V 6, pp. 845 ±854, 1997.

[108] + * K D U D Y L D Q G 6 * D R ³ 6 S D W L D O L Q W H U S R O F R Q F H D O P H Q W ´ , Q 3 U R F , (((, Q W H U Q D W L R Q D O & R Q I H U Signal Processing, pp. 1153 ±1156, 2008.

[109] < * D R - L Q : D Q J < / L X ; < D Q Spatial Error - L D : D & R Q F H D O P H Q W 7 H F K Q L T X H 8 V L Q J 9 H U J H 3 R L Q W V ´ , (((Acoustics, Speech and Signal Processing, vol. 1, pp. 725 ±728, 2007.

[110] = : D Q J < < X D Q G ' = K D Q J ³ % H V W 1 H L J K E R U Information Loss Restoration Technique For Block- % D V H G , P D J H & R G L Q J 6 \ V V IEEE Transactions on Image Processing, vol. 7, no. 7, pp.1056-1061, 1998.

[111] $. D X S . 0 H L V L Q J H U D Q G 7 $ D F K ³) U H T X H Extrapolation With Applications To Error Concealment In Image & R P P X Q L F D W L R Q AEU-International Journal on Electronics Communications, vol. 59, no. 3, pp. 147 ± 156, 2005.

[112] , 9 % D M L F ³ $ G D S W L Y H 0 $ 3 (U U R U & R Q F H D O P H Q W Wavelet- & R G H G , P D J H V ´ , (((7 U D Q V D F W L R Q V R Q , P D J H 3 U R F H V V L Q J vol. 5, no. 5, pp. 1226 ±1235, 2006.

[113] M. Al- 0 X D O O D 1 & D Q D J D U D M D M D K D Q G ' 5 % X O O ³ 7 H P 8 V L Q J 0 R W L R Q) L H O G , Q W H U S R O D W L R Q ´ (O H F W U R Q L F V 1999.

[114] 0 . L P + / H H D Q G 6 6 X R Q cealment For H.264 Using U R U & R 6 H T X H Q W L D O ' L U H F W L R Q D O , Q W H U S R O D W L R Q ´ , (((7 U D vol. 54, no. 4, pp. 1811-1818, 2008.

[115] W. M. Lam, A. R. Reibman and B. Liu, "Recovery of Lost or Erroneously Received Motion Vectors," International Conference on Acoustic, Speech and Signal Processing, vol. 5, pp. 417–420 1993.

[116] X. Qian, G. Liu and H. Wang, "Texture Based S... Algorithm For Error Concealment," IEEE Conference..., 739–742, 2007.

[117] T. H. Wu, G-L. Wu, C-Y. Chen and S. Y. Chien, "Enhanced Concealment Algorithm With Edge-Sensitive Processing Order," Symposium on Circuits and Systems, pp. 3466-3469, 2008.

[118] D. Agrafiotis, D. R. Bull, and C. N. Canagarajah, "Enhanced Concealment With Mode Selection," IEEE Transactions on ... Video Technology, vol. 16, no. 8, pp. 960–973, 2006.

[119] M.-H. Jo, H.-N. Kim, and W.-J. Song, "Hybrid Error Concealment ... Block Content," IET Image Process, vol. ..., no. ..., pp. ...

[120] Y. Xu and Y. Zhou, "Adaptive Temporal Error ... H.264/AVC Video Decoder," IEEE Transactions on Con..., no. 4, pp. 1846-1851, 2008.

[121] M-J. Chen, C-S. Chen, M-C. Chi, "Temporal Error Concealment ... Recursive Block-Matching Principle," IEEE Transactions On ... For Video Technology, vol. 15, no. 11, pp. 1385-1393, 2005.

[122] Y-L. Huang, and H-Y. Lien, "Temporal Error Concealment For MPEG Coded Video Using A Self-Organizing MAP," IEEE Transactions On Con..., vol. 52, no. 2, pp. 676-681, 2006.

[123] W. Zeng and B. Liu, "Structure-Based Error Concealment With Novel Applications In Block-Based Low-Bit-Rate Coding," IEEE Transactions on Circuits and Systems For Video Technology, vol. 9, no. 4, pp. 648–665,1999.

[124] J. Rombaut, A. Pizurica and W. Philips, "Pass... Wavelet-Coded I-Frames With An Inhomogeneous Gauss–Markov Random Field Model," IEEE Transactions On Image Processing..., 2009.

[125] Z. Rongfu, Z. Yuanhua and ..., "Content-Adaptive Spatial Error Concealment For Video Communication," IEEE Transactions on ... Electronics, vol. 50, no. 1, pp. 335-341, 2004.

[126] X. Qian, G. Liu and H. Wang, "Recovering Connect... Adaptive Error Concealment Order Determination...," IEEE Transactions on Multimedia, vol. 11, no. 4, pp. 683-695, 2009.

[127] S. Belfiore, M. Grangetto, E. Magli and G. Olmo, "An ... Algorithm for Streaming Video," IEEE International ... Processing, vol. 3, pp. 649-652, 2003.

[128] C.-S. Park, H.-M. Nam, S.-W. Jung, S.-J. Baek, and S.-   .R ³3UDFoWLFDO (U   &RQFHDOPHQW 6WUDWHJ\ IRU 9LGHR 6WUHDPLQJ $GRSW   Transactions on Consumer Electronics, vol. 55, no. 3, pp. 1606-1613, 2009.

[129 @ 0 +RQJ / 3 .RQGL + 6FKZDE DQG $ . .DWVDJJHO   Algorithms for Com SUHVVHG 9LGHR ´ 6LJQDO 3URFHVVLQJ ,PDJ   14, no. 6-8, pp. 437-492, 1999.

[130] L.-W. Kang, J.-   /HRX ³$ K\ULG HUURU FRQFHDOPHQW   YLGHR WUDQVPLVVLRQ EDVHG RQ EHVW QHLJKERUKRR   Visual Communication and Image Representation, vol. 16, no. 3, pp. 288-310, 2005.

[131] H.-C. Shyu, J.-   /HRX ³'HWHFWLRQ $QG &RQFHDOPHQW RI   MPEG-2 Images- $ *HQHWLF $OJRULWKP $SSURDFK ´ ,(((7UDQV   Systems For Video Technology, vol. 9, no. 6, pp. 937-948, 1999.

[132] M.-C. Hwang, J.-H. Kim, D.-T. Duong, and S.-   .R ³+\ULG 7HPSRUDO (Concealment Methods For Block-% DVHG &RPSUHVVHG 9LGHR 7UDQV   Transactions on Broadcasting, vol. 54, no. 2, pp. 198-207, 2008.

[133] C.-W. Hsiao, and W.-   7VDL ³+\ULG 0XOWLSOH 'HVFULSWL   +   ´ ,(((7UDQVDFWLRQV RQ &LUFXLWV DQG 6\VWHPV   no. 1, pp. 76-87, 2010.

[134] W.-Y. Kung, C.-S. Kim, and C.-&   .XR ³6SDWLDO DQG 7HPSRUDO (UURU   &RQFHDOPHQW 7HFKQLTXHV)RU 9LGHR 7UDQVPLVVLRQ   Transactions on Circuits and Systems For Video Technology, vol. 16, no. 7, pp. 789-803, 2006.

[135 @ ' 3HUVVRQ DQG 7 (ULNVVRQ DQG Least Squares-Based Packet RGHO   9LGHR (UURU &RQFHDOPHQW ´ ,(((7UDQVDFWLRQV RQ ,   pp. 1048-1054, 2009.

[136] K.-L. Chung, T.-H. Huang, and P.-+   /LDR ³(IILFLHQW +\ULG   &RQFHDOPHQW $OJRULWKP %DVHG RQ $GDSWLYH (VWLF   Communications Image Rep., vol. 18, no. 4, pp. 331-340, 2007.

[137 @ ' 3HUVVRQ 7 (ULNVVRQ DQG 3 +HGHOLQ ³3DFN   :LWK *DXVVLDQ 0L[WXUH 0RGHOV ´ ,(((7UDQVDFWLRQV   no. 2, pp. 145 ±154, 2008.

[138] J. Wiseman, "An Introduction to MPEG Video Compression", http://www.john-wiseman.com/technical/MPEG_tutorial.htm, 2011.

[139] A. Michelson, "Studies in Optics",   ref ! http://colorusage.arc.nasa.gov/ Luminance_cont.php   ref ! , 1927.

[140] Z. Wang, A. C. Bovik, H. R. Sheikh Quality (3 6 L P
D V V H V V P H Q W) U R P H U U R U Y L V L E L GE. W'rans.WIRnagev W U X F W
Process., vol. 13, no. 4, pp. 600 ±612, 2004.

[141] Heath, L. Thomas, ³A History of Greek Mathematics ´Oxford University
Press, vol. 2, pp. 321 ±323, 1921

[142] Information Technology-Digital Compression and Coding of Continuous-
Tone Still Images: Extentions, 1997. JPEG: ITU-T Rec. T.81-ISO/IEC no. 10 918-3.

[143] R. Koenen, Overview of the MPEG-4 standard, Jul. 1997. ISO/IEC
JTC1/SC29/WG11 N1730.