A High Performance Novel Image Compression Technique using Hybrid Transform for Multimedia Applications

P.John Paul,
Professor, Dept of ECE
Gurunanak Engg College
Ibrahimpatnam, R.R (Dist)
Andhra Pradesh. India

P. N. Girija
Professor, Dept of CSE
University of Hyderbad

Summary

In advanced multimedia applications which are normally used in 3G communications, image compression can improve the performance of the systems by reducing time and cost in image storage and transmission without significant reduction of the image quality. This rapid growth of digital imaging applications which includes teleconferencing, high-definition television (HDTV) (e.g. i-phone) has increased the need for effective and standardized image compression techniques. These techniques have become more prominent with the help of System-On-Chip (SOC) technology, which gives low power, less area and high speed requirements. But of course, uncompressed multimedia which is normally called as lossless image compression used in medical imaging requires considerable storage capacity and transmission bandwidth. For all these things to achieve, discrete cosine transform has emerged as the new state-of-the art standard for image compression. This paper proposes novel and high performance architecture for image compression which is based on the frequency domain representation. The digitized image is compressed using Discrete Hartley Transform (DHT), Discrete Walsh Transform (DWT), Discrete Fourier Transform (DFT), and Discrete Radon Transform (DRT) and their combinations with DHT. Discrete Hartley Transform is used as basic transform because of its reversibility, hence other transform kernels can developed from DHT. The proposed architecture is developed using Verilog Hardware Descriptive Language and has been tested for still images. Simulation Results show the hybrid transforms DHT+DCT and DHT+DRT give better results with respect to compression ratios.

Key words:
VLSI, Discrete Cosine Transform, JPEG, Hartley transform, Radon Transform
.

1. Introduction

Both Analog and Digital transmissions and their related developments and technologies are the fundamental components of the present day communication systems like 3G.[1-5] There exist several fundamental transmission analog blocks and their related issues are being quickly converted into the digital form of ones and zeros. In next five to ten years, the broadcasting systems like television as we know it today will no longer exist[6-9]. Publicly this broadcasted digital television system with high bandwidth and other several functionalities are definitely required in the near future. With the help of tremendous improvements in the transmission systems, the television viewers will have a larger number of channels, each with increased resolution and picture quality [1, 2]. This can be done by Digital image (or video) compression with higher bandwidths and lower noise [7, 10-12]. But of course, digital broadcasts will utilize JPEG-2000 (or MPEG-4) image (or video) compression. In addition to changes in high end application of multimedia, it is now quite evident that the age of communications has reached to a specific point where the no of users will increase along with their expectations and this leads to invention of smart phones like i-phone providing full visual communication as opposed to the conventional land line telephones. However, the bandwidth play important role in transmission of the digital images and videos [12, 13, 15]. The limitations imposed by our existing communication systems makes high definition (HD) quality image (or video) transmission quite difficult. However, growing application which completely relies on digital compression technology is the present day wireless and wired Internet. The World Wide Web (WWW) has connected all the users across the globe and enabled them to convey information in so many forms: text, images, video, sound, etc. Image and video compression have been played important role in the WWW to serve the information needs of our increasingly multimedia-focused world [14]. This paper is organized as follows. Section 2 describes overview of image compression both lossy and lossless compressions techniques. Section 3 explains the proposed scheme which reduces the compression ratio. Simulation results are explained in section 4 and finally conclusions are made in section 5.

Manuscript received April 5, 2011
Manuscript revised April 20, 2011

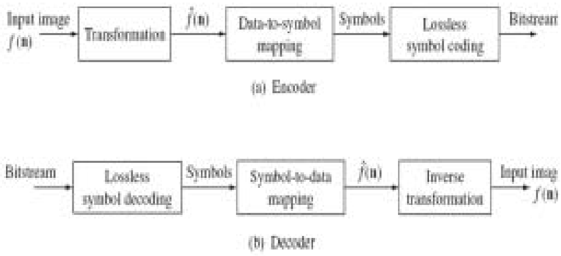
2. Overview of Image Compression

The images which are used multimedia contain lots of unnecessary information, and thus they are normally compressed to remove redundancy and to minimize the storage capacity and also transmission bandwidth [16-17]. Sometimes the process of redundancy removing is reversible, i.e. the exact reconstruction of the original image can be achieved which is merely impossible, it is called lossless image compression; otherwise, it is called lossy image compression. It is the fact in modern technology and all defense and scientific applications that make lossy compression unacceptable for many high performance applications namely telemetric applications, non-destructive evaluation, and medical imaging, which will still require lossless image compression. The techniques employed in lossless image compression are all fundamentally depends on entropy coding theory and Shannon's noiseless coding theorem, which guarantees that as long as the average number of bits per source symbol at the output of the encoder exceeds the entropy (i.e. average information per symbol) of the data source by an arbitrarily small amount, the data can be decoded without error [6, 7, 8]. Still images may be modeling broadly into two categories, one of them is Image based modeling and second one is image-based rendering (IBR) techniques. These two techniques have received much attention as a powerful alternative to traditional techniques which normally used in medical imaging techniques for image analysis [18-20]. These two techniques use images rather than geometric structure of image as primitives for rendering novel views. Hence, overall points which are related to IBR have suggested characterizing a technique based on how image centric it is. This has resulted in the image-geometry continuum of image-based representations [9, 10].

Broadly, image compression may be lossy or lossless. Lossless compression is preferred for archival purposes and often for medical imaging, technical drawings, etc. This is because lossy compression methods, especially when used at low bit rates, introduce compression artifacts. Lossy methods are especially suitable for natural images such as photographs in applications where minor (sometimes imperceptible) loss of fidelity is acceptable to achieve a substantial reduction in bit rate. The lossy compression that produces imperceptible differences may be called visually lossless.

2.1 Lossless Image Compression Techniques

The block diagram of a lossless coding system is shown in Fig. 2.1. The encoder (Fig. 2.1(a)) takes as input an image and generates as output a compressed bitstream. The decoder (Fig. 2.1(b)) takes as input the compressed bitstream and recovers the original uncompressed image. In general, the encoder and decoder can be each viewed as consisting of three main stages. In this section, only the main elements of the encoder will be discussed since the decoder performs the inverse operations of the encoder. As shown in Fig. 2.1(a), the operations of a lossless image encoder can be grouped into two stages:



(i) Transformation: This stage applies a reversible (one-to-one) transformation to the input image data. The purpose of this stage is to convert the input image data f(n) into a form $\hat{f}$(n) that can be compressed more efficiently. For this purpose, the selected transformation can aid in reducing the data correlation (interdependency, redundancy), alter the data statistical distribution, and/or pack a large amount of information into few data samples or subband regions.

(ii) Data to Symbol Mapping: This stage converts the image data $\hat{f}$(n) into entities called symbols that can be efficiently coded by the final stage. The conversion into symbols can be done through partitioning and/or run-length coding (RLC), for example. The image data can be partitioned into blocks by grouping neighboring data samples together; in this case, each data block is a symbol. Grouping several data units together allows the exploitation of any correlation that might be present between the image data, and may result in higher compression ratios at the expense of increasing the coding complexity.

There are several coding techniques which are useful for lossless image compression and discussed very briefly below.

(i). Huffman Encoding: One of the most famous algorithms in image compression is Huffman Encoding. This algorithm [9], has been developed by D.A. Huffman, was based on the fact that in an input stream certain tokens occur more often than others. Based on this knowledge, the algorithm builds up a weighted binary tree according to their rate of occurrence. Basically, each element of this tree is assigned a new code word, where at the length of the code word is determined by its position in the tree. Therefore, the token, which is most frequent and becomes the root of the tree, is assigned the shortest code. Each less common element is assigned a longer code word

(ii). Arithmetic Coding: Image Compression techniques performs a wide variety of algorithms and have quite different stages of complexity, but share some common steps. Figure 2.2 shows a diagram with typical processes used for data compression. These processes depend on the data type, and the blocks in Fig. 2.3 may be in a different order or combined. Numerical processing, like predictive coding and linear transforms, is normally used for waveform signals, like images and audio.

(iii) Burrows-Wheeler compression: A new algorithm for loss less image compression and it is relatively faster than other algorithms proposed in the past, first presented by Burrows and Wheeler in 1994 [1]. In contrast to most other compression algorithms it treats the incoming text as a block, or sequence of blocks, with transformations on each block.

2.2 Lossy Image Compression Techniques

Lossy compression techniques are one where compressing data and then decompressing it retrieves data that may well be different from the original, but is close enough to be useful in some way. Lossy compression is most commonly used to compress still images, especially in applications such as streaming media and internet telephony. Some of the lossy compression techniques are discussed below.

(i). Vector quantization (VQ) is a lossy image/data compression method based on the principle of block algorithm coding. It is a "fixed to fixed" length algorithm. In the past days, the design issues of a vector quantizer (VQ) [22] is considered to be a very challenging research problem due to the need for multi-dimensional or multi tasking integration. In late 1980s, Linde, Buzo, and Gray (LBG) proposed a VQ design algorithm based on a training sequence. The need of a training sequence bypasses the need for multi-dimensional integration [21]. A VQ that is designed using this algorithm are referred to in the literature as an LBG-VQ.

(ii). Fractal parameters or conditional codes which can be effectively used in image compression using fractal dimension, as well as others described below, have the same impending characteristics to provide efficient methods of describing imaginary in a highly compact fashion for both intra- and inter frame applications [23]. Fractal algorithms have been developed for both noisy and noise free coding methods. Images of natural scenes are likely candidates because of the fractal structure of the scene content, but results are reported to be applicable to a variety of binary, monochrome, and color scene.

(iii). Discrete Cosine Transform (DCT): DCT helps separate the image into parts (or spectral sub-bands) of differing importance (with respect to the image's visual quality). The DCT is similar to the Discrete Fourier Transform (DFT): it transforms a signal or image from the spatial domain to the frequency domain. With an input image, A, the coefficients for the output image B, is as shown in Figure 2:

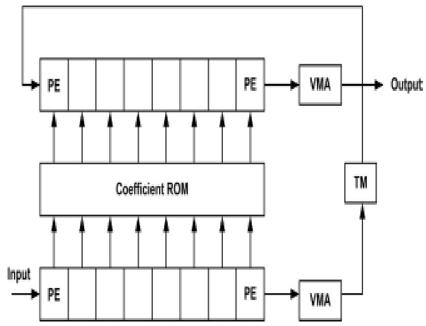
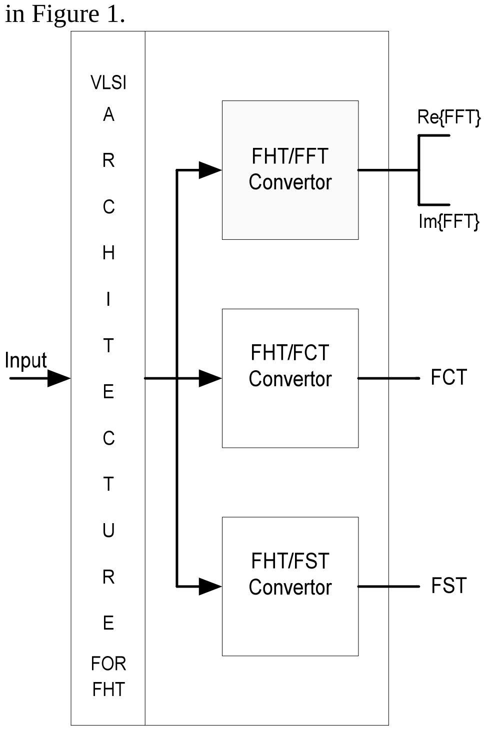


Fig 2. Implementation of DCT

(iv). Programmable Architecture: In contrast to function oriented approaches with limited functionality, programmable architectures enable the processing of different tasks under software control. The particular advantage of Programmable architectures is the increased flexibility. Changes of architectural requirements, e.g., due to changes of algorithms or an extension of the aimed application field, can be handled by software changes. Thus a generally cost-intensive redesign of the hardware can be avoided. Moreover, since programmable architectures cover a wider range of applications, they can be used for low-volume applications, where the design of function specific VLSI chips is not an economical solution. On the other hand, programmable architectures require a higher expense for design and manufacturing, since additional hardware for program control is required. Moreover, programmable architectures require software development for the envisaged application. Although several vendors provide development tools, including high level language compilers, the expense for software development may not be neglected and has to be considered for deciding which type of architecture, function oriented or programmable, has to be used for a specific application. Image processing, especially video coding applications; often require a real-time processing of the image data. To achieve this goal, parallelization strategies have to be employed. A variety of programmable and dedicated VLSI architectures for video coding applications have been presented in the past [9-12]. for real-time video compression, are presented. These examples clarify the wide range of architectural alternatives for the VLSI implementation of processors for video coding applications.

3. Hybrid Transform

In the following sections the hybrid transforms are discussed. The coefficients of Hartley transform are expressed in terms of other transforms and the combined coefficients are used for image compression. The different transforms FFT, FCT, FST, and FHT are studied for similarities and the conversions has been proposed [24-27]. A single chip converged VLSI architecture for hybrid transforms for image compression has been developed as shown in Figure 1.



3.1 DFT/FFT Definition

The Discrete Fourier Transform (DFT) of a sampled signal x(n), n=0 ……N-1 is given by

$$X(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\exp\left(\frac{-j2\pi nk}{N}\right) \qquad (1)$$

for $k = 0,1,2,\cdots\cdots\cdots(N-1)$

The inverse Fourier Transform is defined as

$$x(n) = \sum_{k=0}^{N-1} X(k)\exp\left(\frac{j2\pi nk}{N}\right) \qquad (2)$$

FFT is fast algorithm used to evaluate the DFT

3.2 Hartley Transform

The Discrete Hartley Transform (DHT) of a real signal x(n) is defined as follows

$$H(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\,cas\left(\frac{2\pi nk}{N}\right) \qquad (3)$$

for $k = 0,1,2,\cdots\cdots\cdots(N-1)$.

The complex multiplications in the DFT formula are replaced with real multiplications in the DHT. This reduces the computation time. As shown in [7], we achieve the inverse DHT by

$$x(n) = \sum_{k=0}^{N-1} H(k)\,cas\left(\frac{2\pi nk}{N}\right) \qquad (4)$$

where $cas\theta = \cos\theta + \sin\theta$

3.3 DFT and FHT Hybrid Transform

After studying the similarities of FHT and DFT we can propose the architecture for DFT from FHT as follows.

$$\operatorname{Re}(X(k)) = \frac{H(k) + H(N-k)}{2} \qquad (5)$$

$$\operatorname{Im}(X(k)) = \frac{H(k) - H(N-k)}{2} \qquad (6)$$

3.4 FHT and FFT Hybrid Transform

The relation between the FHT coefficients and DFT coefficients is obtained as follows

$$H(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)cas\left(\frac{2\pi nk}{N}\right) \qquad (7)$$

$$H(k) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)\left\{\cos\left(\frac{2\pi nk}{N}\right) + \sin\left(\frac{2\pi nk}{N}\right)\right\} \qquad (8)$$

$$H(k) = \frac{1}{2}\{X(-k) - jX(k)\} \qquad (9)$$

3.5 DCT and DST Definition

The Discrete Cosine and Discrete Sine Transform are defined as

$$X_D(k) = \frac{\sqrt{2}}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) A_k B_k \cos\left(\frac{\pi nk}{N}\right) + \frac{\sqrt{2}}{\sqrt{N}} \sum_{n=1}^{N-1} x(n) \sin\left(\frac{\pi nk}{N}\right) \quad (10)$$

3.6 Hartley and DCT/DST Hybrid Transform

The similarities of FHT and FCT/FST can be related as follows

$$X_D(k) = \sqrt{2N} A_k B_k H(k/2) \qquad (11)$$

3.7 DCT and FHT Hybrid Transform

To implement the FHT from FCT the following equation is used

$$H(k/2) = \frac{X_D(k)}{\sqrt{2N} A_k B_k} \qquad \textbf{(12)}$$

4. Simulation and Synthesis Results

The similarities among each transform are studied and the hybrid transforms are developed. Each transform is simulated using Active HDL 8.1 and then synthesized using Synopsys tools. The Delay and Area of each Transform are obtained and for each Hybrid transform from FHT which is considered to be the main transform for rest of the transforms. But compression ratio have been found out for each transform and Hybrid transform using MATLAB® simulation because as Verilog can not give the numerical numbers with regarding to compression ratio. All these results are tabulated in the following sections for comparison and to approve the novelty of the above mentioned architecture.

The delays are measured using Synopsys tools and tabulated in the following tables 1, 2 and 3 In all these tables CR represents Compression Ratio

Table 1: Compression Ratios of individual transforms

Transform	CR (%)
Discrete Cosine Transform (DCT)	72
Discrete Sine Transform (DST)	61
Discrete Fourier Transform (DFT)	45
Discrete Hartley Transform (DHT)	75
Discrete Radon Transform (DRT)	78
Discrete Walsh Transform (DWT)	69

Table 2 shows the compression ratio of hybrid transform and it can be observed that DCT+DHT give better efficiency compared to other hybrid transform. For this analysis only a still image is considered. This table also shows that DRT+DHT can also be used for compression of still images.

Table 2. Compression Ratio of Hybrid Transform

Transform	Compression Ratio (%)
DCT+DHT	81
DST+DHT	65
DFT+DHT	54
DRT+DHT	73
DWT+DHT	70

It is also important to verify all these algorithms for various text inputs. For this experiment, we have considered still image (400KB), text (20KB) and video (2MB) as data inputs for this experiment. The results are tabulated in the following table 3. From this table, it can be observed that the for still image compression DCT+DHT can be used and for video DRT+DHT can be used. Of course for compression of a text data, any of these methods will do well.

Table 3: Hybrid Transform for various data inputs

Transform	Type of the Image	Compression Ratio (%)
DCT+DHT	**Still Image**	**81**
	Text	56
	Video	34
DST+DHT	Still Image	45
	Text	22
	Video	31
DFT+DHT	Still Image	30
	Text	13
	Video	23
DRT+DHT	Still Image	72
	Text	61
	Video	**73**
DWT+DHT	Still Image	56
	Text	42
	Video	63

Delays and area of the proposed algorithm can be calculated using Synopsys tool and tabulated in the following table 4. In this table area is calculated with respect to number of gates. Hence, the number in area column represents gates that are used for transform.

Table 4: Delays and area of the individual and Hybrid transform

Transform	Delay	Area
DHT	14.81ns	761
DFT	34.12ns	656

DCT	23.15ns	688
DRT	22.56ns	535
DST	31.65ns	890
DHT+DFT	45.35ns	1341
DHT+DCT	32.76ns	1123
DHT+DST	49.19ns	1457
DHT+DRT	37.17ns	1290
DHT+DWT	41.90ns	1670

5. Conclusions

Hybrid Transform is calculated from other transforms by deriving the transformation coefficients in terms of Hartley Transform. For all these combined transform Hartley transform is used because of its less complexity. Even in the Hybrid Transform, the coefficients which are generated from DCT gives the best results. Because, DCT performs only real operations and as same as DHT therefore for still images hybrid transform DCT+DHT is used and for video processing DRT+DHT is used. Hence, the proposed hybrid transform can be used for multimedia applications. Synthesis results are shown for all kinds of hybrid transform and results are encouraging.

References

[1] Tzong-Jer Chen; Keh-Shih Chuang "A pseudo lossless image compression method" in 3rd International congress on Image and Signal Processing (CISP), 2010, Vol: 2, Page(s): 610 – 615, 2010

[2] Yang Guang; Sun Jing; Tian Di; "Research on the screen image compression method of scientific instruments" in IEEE 3rd International Conference on Computer Science and Information Technology (ICCSIT), Vol: 2 , Page(s): 401 – 405, 2010

[3] Nishikawa, Y.; Kawahito, S.; Furuta, M.; Tamura, T.; "A High-Speed CMOS Image Sensor with On-chip Parallel Image Compression Circuits" in IEEE Custom Integrated Circuits Conference, 2007. CICC '07. Page(s): 833 – 836, 2007.

[4] Xiangjian He; Wang, H.; Wu, O.; Hintz, T.; Hur, N. "Fractal Image Compression on Spiral Architecture" in International Conference on Computer Graphics, Imaging and Visualization, Page(s): 76 – 83, 2006.

[5] Chien-Wen Chen; Tsung-Ching Lin; Shi-Huang Chen; Trieu-Kien Truong; "Near Lossless Wavelet-Based Compression Scheme for Satellite Images " in WRI World Congress on Computer Science and Information Engineering, Vol: 6 , Page(s): 528 - 532 , 2009.

[6] Yuehua Wan; Shiming Ji; Qiaoling Yuan; Yi Xie; "Multivariate Statistical Modeling for Medical Image Compression Using Wavelet Transforms" In 5th IEEE International Conference on Cognitive Informatics, Vol: 1, Page(s): 214 – 217, 2006

[7] Cottour, A.; Alfalou, A.; Hamam, H.; "Optical video image compression: a multiplexing method based on the spectral fusion of information" in 3rd International Conference on Information and Communication Technologies: From Theory to Applications, (ICTTA 2008). Page(s): 1 - 6 , 2008

[8] Dong Liu; Xiaoyan Sun; Feng Wu; Shipeng Li; Ya-Qin Zhang; "Image Compression With Edge-Based Inpainting" in IEEE Transactions on Circuits and Systems for Video Technology, Vol: 17, Issue: 10 Page(s): 1273 – 1287, 2007

[9] P. John Paul; P.N. Girija; "A Novel VLSI Architecture for Image Compression" in IEEE International Symposium on Multimedia 2006, Page(s): 794 – 795, 2006

[10] Xiwen Zhao; Zhihai He; "Lossless image compression using super-spatial prediction of structural components" in IEEE conference Picture Coding Symposium" Pages: 1-4, 2009.

[11] Yang Shuyuan; Peng DongLiang; Wang Min; "SAR Image Compression Based on Bandelet Network" in Forth International Conference on Natural Computation, (ICNC '08) Vol: 4, Page(s): 559 – 563, 2008.

[12] Thakur, N.V.; Kakde, O.G.; "Fractal Color Image Compression on a Pseudo Spiral Architecture" in IEEE Conference on Cybernetics and Intelligent Systems, Page(s): 1 – 6, 2006

[13] Koli, N.A.; Ali, M.S.; "Color Image Data Compression in Multimedia" in International Conference on Electrical and Computer Engineering, 2006. ICECE '06. Page(s): 456 – 461, 2006.

[14] Xiao-Yan Xu; Chen, P.; Juan Dai; "Hybrid encoding analysis of fractal image compression method based on wavelet transform" in International Conference on Machine Learning and Cybernetics, Page(s): 2886 – 2889, 2007

[15] Wang Yu-zeng; Geng Shi-chao; Fan Yu-jun; Feng Zhi-quan; "Research the Compression and Transmission Technology of Medical Image Base on the Remote Consultation" in the 2nd International Conference on Bioinformatics and Biomedical Engineering, 2008. ICBBE (2008). Page(s): 2142 – 2145, 2008.

[16] Yan Wang; Shoushun Chen; Bermak, A.; "FPGA Implementation of Image Compression using DPCM and FBAR" in International Conference on Integrated Circuits, (ISIC '07). Page(s): 329 – 332, 2007

[17] Kiho Choi; Sunyoung Lee; Jang, E.S.; "Zero coefficient-aware IDCT algorithm for fast video decoding" in IEEE Transactions on Consumer Electronics, Vol:56 and Issue 3, Page(s): 1822 – 1829, 2007

[18] Shortt, A.E.; Naughton, T.J.; Javidi, B.; "Histogram Approaches for Lossy Compression of Digital Holograms of Three-Dimensional Objects" in IEEE Transactions on Image Processing, Vol:16, issue:6, Page(s): 1548 – 1556, 2007

[19] Nan Zhang; Yan Lu; Feng Wu; Xiaolin Wu; Baocai Yin; "Efficient Multiple-Description Image Coding Using Directional Lifting-Based Transform" In IEEE Transactions on Circuits and Systems for Video Technology, Volume: 18 ,Issue: 5 Page(s): 646 – 656, 2008

[20] Chunyu Lin; Yao Zhao; Ce Zhu; "Two-Stage Diversity-Based Multiple Description Image Coding" In IEEE Signal Processing Letters, Volume: 15, Page(s): 837 – 840, 2008

[21] Mantao Xu; Xiaolin Wu; Franti, P.; "Context quantization by kernel Fisher discriminant" In IEEE Transactions on Image Processing, Volume: 15 , Issue: 1, Page(s): 169 – 177, 2006

[22] Dong-O Kim; Rae-Hong Park; "New Image Quality Metric Using the Harris Response" in IEEE Transactions on Signal

Processing Letters Volume: 16 , Issue: 7, Page(s): 616 - 619 , 2009
[23] Klima, M.; Pata, P.; Fliegel, K.; Hanzlik, P.; "Image Quality Evaluation in Security Imaging Systems" In IEEE Conference on Aerospace and Electronic Systems Magazine, Volume: 22 , Issue: 1 Page(s): 22 – 25, 2007.
[24] Shui, P.-L.; Zhou, Z.-F.; Li, J.-X.; "Image denoising algorithm via best wavelet packet base using Wiener cost function" In IET Transactions on Image Processing, Volume: 1 , Issue: 3, Page(s): 311 – 318, 2007
[25] Ryan, O.; "Runlength-Based Processing Methods for Low Bit-depth Images" In IEEE Transactions on Image Processing Volume: 18 , Issue: 9, Page(s): 2048 – 2058, 2009
[26] Villegas, O.O.V.; Elias, R.P.; Villela, P.R.; Sanchez, V.G.C.; Salazar, A.M.; "Edging out the competition: Lossy image coding with wavelets and contourlets" in IEEE Potentials, Volume: 27 , Issue: 2, Page(s): 39 – 44, 2008

Dr. John Paul graduated (B.E., Electronics and Communication Engineering) from Nagarjuna University in the year 1986 with 1st Class. He had completed his post graduation in the year 1994 (M.E., Digital Systems) with first class from Osmania University. He also did his research in Computer Science (VLSI architecture for image compression) and achieved doctorate in the year 2008 from Hyderabad Central University.He has published several papers in national and international conferences and journals. Also authored books in electronics published by New Age International, New Delhi, Galgotia publications, New Delhi, and guiding students for Ph.D. in the areas of parallel computing, G3 mobile technologies and SS7 of signaling. He worked as professor, dean and Principal of several engineering colleges for 25 years.

Dr. P.N.Girija has obtained her PhD in physics from Sri Venkateswara University A.P India. Presently she is professor in department of computer and information sciences, university of Hyderabad. She was a visiting professor in Carnegie Mellon University. She has many national and international publications in the areas of Human Computer Interaction and Speech processing. She has completed many sactioned projects from DST department of space UGC and AICTE. Her areas of interst are speech synthesis, Speech recognition, Spoken dialog systems human computer interactions and intelligent agents.