ISSN No. 0976-5697

Volume 3, No. 3, May-June 2012

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

Insight into New Color Image Watermarking With DWT-DCT and only DCT with Comparative Analysis in YIQ Color Space

Baisa L. Gunjal*
Amrutvahini College of Engineering,
Sangamner, District: A'nagar, MS, India.
hello_baisa@yahoo.com

Suresh N. Mali
Singhgad Institute of Technology and Science,
Narhe, Pune, Maharashtra, India.
snmali@rediffmail.com

Abstract: The aim of this paper is to present our new technique for Color image watermarking using combine DWT-DCT domain as well as only DCT domain in YIQ Color space. Also our aim is to provide the comparative analysis of combine DWT-DCT domain as well as only DCT domain. Q component was used in YIQ Color space and in DWT domain all middle and high frequency regions i.e. LH, HL and HH regions are tested. In DWT-DCT domain, we got maximum PSNR 67.56, 67.66, 67.57 for HL, LH and HH regions respectively for Jet Plane Image and maximum NC was 0.97 in HH region. But in only-DCT domain, we got PSNR up to 54.12 only. We recommend the DWT-DCT domain than only DCT domain for better results. At the same time, we provide strongly robust and multilayer secured color image watermarking scheme with DWT-DCT domain in YIQ color space

Keywords: Color Space, Conversion, Decomposition, DWT-DCT, Combination, Transparency.

I. INTRODUCTION

It has become a daily need to create copy, transmit and distribute digital data as a part of widespread use of multimedia technology in internet era. Hence copyright protection has become essential to avoid unauthorized replication problem. Image Watermarking has become one of the widely used means to protect the copyright of digital images. Robustness, Perceptual transparency, capacity and Blind watermarking are four essential factors to determine quality of watermarking scheme [4][5]. In spatial domain, watermark is embedded by directly modifying pixel values of cover image. Least Significant Bit insertion is example of spatial domain watermarking. These algorithms are simple in implementation. But problems with such algorithms are: Low watermark information hiding capacity, Less PSNR, Less Correlation between original and extracted watermark and less security, hence anybody can detect such algorithms.

The Frequency domain the watermarks inserted into transformed coefficients of image giving more information hiding capacity and more robustness against watermarking attacks because information can be spread out to entire image [6]. Digital Color Image Watermarking can be implemented using different color spaces like YUV color space, RGB color space or YIQ color.

II.SURVEY

Spatial domain methods including LSB based methods and LSB with pseudo random generator are traditional methods and are not secured [12]. In transform domain methods, watermarking using CWT, only DWT, only DCT or combined approach of DWT-DCT are proposed. Following are some existing methods for in color image watermarking. In [10], Integer Wavelet Transform with Bit Plane complexity Segmentation is used with more data hiding capacity. This method used RGB color space for watermark embedding. In [2] DWT based watermarking algorithm of color images is proposed. The RGB color space is converted into YIQ color space and watermark is embedded in Y and Q components. This method gives correlation up to 0.91 in JPEG Compression attack. In [3], Watermarking Algorithm

Based on Wavelet and Cosine Transform for Color Image is proposed. A binary image as watermark is embedded into green or blue component of color image. In [1], Color Image Watermarking algorithm based on DWT-SVD is proposed in green component of color image. The scrambling watermark is embedded into green component of color image based on DWT-SVD. The scheme is robust and giving PSNR up to 42, 82. In [5], Pyramid Wavelet Watermarking Technique for Digital Color Images is proposed. This algorithm gives better security and better correlation in Noise and compression attacks. Discrete Wavelet Transform provides multi resolution for given image and can efficiently implemented using digital filter, it has become attraction of researchers in image processing area. Here, review of literature survey is done with existing color image watermarking techniques with based on 'Discrete Wavelet Transform. The rest of the paper is organized as follows: In Section III Color Spaces Transforms and scrambling are explained. Section IV explorers proposed methodology with embedding and extraction algorithms. Section V shows experimental results after implementation and Testing and the conclusion is drawn in section VI.

III. COLOR SPACES, TRANSFORMS AND SCRAMBLING

A. RGB Color Spaces:

Some of researches have used RGB color space for watermark embedding. First R, G, B planes are separated using equations 1, 2, 3 and either one of these planes or combination of two can be used for embedding.

$R = \text{Cover\_Image}(:,:,1)$ (1)

$G = \text{Cover\_Image}(:,:,2)$ (2)

$B = \text{Cover\_Image}(:,:,3)$ (3)

But, RGB color space is complex in describing the color pattern and has redundant information between each component [2]. Since Pixel values in RGB color space are highly correlated, RGB color space is converted into YIQ color spaces. Then watermark is embedded in Y,I,Q color spaces or combination of them.

B. YIQ Color Space and conversion between RGB and YIQ Color Spaces:

The National Television Systems Committee (NTSC) defines a color space known as YIQ. This color space is used in televisions in the United States. One of the main advantages of this format is that grayscale information is separated from color data, so the same signal can be used for both color and black and white sets. In the NTSC color space, image data consists of three components: luminance (Y), hue (I), and saturation (Q). The first component, luminance, represents grayscale information, while the last two components make up chrominance (color information). Here, color image is read and R, G, B components of original Cover Image are separated. Then they are converted into YIQ color Space using following equations [2]. After conversion of RGB color spaces into YIQ color spaces, Watermark is embedded.

$Y = 0.299 * R + 0.587 * G + 0.114 * B$ (4)

$I = 0.596 * R - 0.274 * G - 0.322 * B$ (5)

$Q = 0.211 * R - 0.522 * G + 0.311 * B$ (6)

After embedding the watermark using DWT, YIQ color space is converted back into RGB color space using following equations.

$R = Y + 0.956 * I + 0.621 * Q$ (7)

$G = Y - 0.272 * I - 0.647 * Q$ (8)

$B = Y - 1.106 * I + 1.702 * Q$ (9)

C. Convenient Block Size in DCT:

The discrete cosine transform (DCT) represents an image as a sum of sinusoids of varying magnitudes and frequencies. The DCT has special property that most of the visually significant information of the image is concentrated in just a few coefficients of the DCT [3]. It's referred as 'Energy compaction Property'. For this reason, the DCT is often used in image compression applications. For example, the DCT is at the heart of the international standard lossy image compression algorithm known as JPEG (Joint Photographic Experts Group). The DCT for image A with M x N size is given by:

$$DCT_{pq} = \alpha_p \alpha_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A_{mn} \cos\left(\frac{\pi(2m+1)p}{2M}\right) \cos\left(\frac{\pi(2n+1)q}{2N}\right) \quad (10)$$

where,

$0 \le p \le M-1$, and $0 \le q \le N-1$ (11)

$$\alpha_p = \begin{cases} 1/\sqrt{M}, & p = 0 \\ \sqrt{2/M}, & 1 \le p \le M-1 \end{cases} \quad (12)$$

$$\alpha_q = \begin{cases} 1/\sqrt{N}, & q = 0 \\ \sqrt{2/N}, & 1 \le q \le N-1 \end{cases} \quad (13)$$

As DCT is having good energy compaction property, many DCT based Digital image watermarking algorithms are developed.

D. High and Middle Frequency Regions of DWT:

Calculating wavelet coefficients at every possible scale is a fair amount of work, and it generates an awful lot of data. It's better if we choose only a subset of scales and positions so-called dyadic scales and positions, then our analysis will be much more efficient and just as accurate. Such an analysis is provided by discrete wavelet transform (DWT).

Discrete wavelet can be represented as

$$\psi_{j,k}(t) = a_0^{-j/2} \psi\,(a_0^{-j} t - k\, b_0 \quad (14)$$

For dyadic wavelets a_0 =2 and b_0 =1, Hence we have,

$$\psi_{j,k}(t) = 2^{-j/2} \psi\,(2^{-j} t - k) \qquad j, k \in Z \quad (15)$$

When image is passed through series of low pass and high pass filters, DWT decomposes the image into sub bands of different resolutions [6]. Decompositions can be done at different DWT levels.

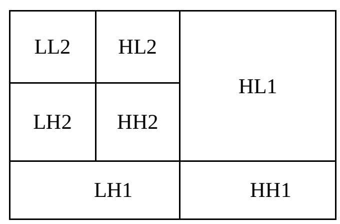


Figure 1: Two Level Image Decomposition

At level 1, DWT decomposes image into four non overlapping multi resolution sub bands: LL1 (Approximate sub band), HL1 (Horizontal sub band), LH1 (Vertical sub band) and HH1 (Diagonal Sub band). Here, LL1 is low frequency component whereas HL1, LH1 and HH1 are high frequency (detail) components [7][8][9]. One level image decomposition is shown in Figure:1. Embedding watermark in low frequency coefficients can increase robustness significantly but maximum energy of most of the natural images is concentrated in approximate (LL1) sub band. Hence modification in this low frequency sub band will cause severe and unacceptable image degradation. The good areas for watermark embedding are high frequency sub bands (HL1, LH1 and HH1), because human naked eyes are not sensitive to these sub bands. Here, we have used HL, LH and HH regions to embed the watermark in DWT-DCT based combination.

E. Image Scrambling:

Magic square, Fass Curve, Gray Code, Arnold Transform etc. are some of the methods those can be used for image scrambling. Image Scrambling can be carried out through many steps to improve security levels. Arnold Transform has special property of Arnold Transform is that image comes to it's original state after certain number of iterations. These 'number of iterations' is called 'Arnold Period' or 'Periodicity of Arnold Transform'. Arnold Transform of image is

$$\begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 2 \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} (mod N) \tag{16}$$

Where, (x, y) = {0,1,.....N} are pixel coordinates from original image. (x_n, y_n) are corresponding results after Arnold Transform. The periodicity of Arnold Transform (P), is dependent on size of given image. From equation: 3 we have,

x_n=x+y (17)

y_n=x+2*y (18)

If (mod (x_n, N) ==1&& mod (y_n, N) ==1) then P=N (19)

The watermark as image is undergone through Arnold Transform to improve security. After few of iterations (less than Arnold periodicity P), the scrambled watermark is obtained which is used for embedding.

IV. PROPOSED METHOD

The technique is developed first using DWT-DCT based Image Watermarking. Then same algorithm is modified using only DCT Domain. In DWT_DCT based method three cases are considered i.e. embedding the watermark logo in LH, HL and HH regions after DWT Decomposition.

A. Embedding Algorithm using DWT-DCT Domain:

Step 1: Read Color Cover Image of 512x512 size. Separate it's R, G, B components using equations: 1, 2, 3 and convert into YIQ color space using equations 4,5,6.

Step 2: Now select Q component and apply one level DWT. Consider LH1 sub band.

Step 3. Read grey scale watermark of 64x64 size.

Step 4: Depending upon Key K1, generate pn sequence for given watermark and calculate sum say SUM, which is summation of all elements in generated pn sequence.

Step5. Determine Arnold Periodicity P for given watermark.

Step 6: If SUM > T, where T is some predefined threshold value, then perform watermark scrambling by Key K2= P+ Count, Otherwise perform watermark scrambling by Key K3= P+ Count, where count is programmer defined counter. Here, we get 'Scrambled Watermark' by Arnold Transform.

Step 7: Generate two pn sequences: pn_sequence_0 and pn_sequence_1, depending upon sum of all elements of mid band used for 4x4 DCT transformation.

Step 8: Perform watermark embedding using following equations:

If Watermark bit is 0, then

$$D' = D + K * pn\_sequence\_0 \tag{18}$$

If Watermark bit is 1, then

$$D' = D + K * pn\_sequence\_1 \tag{19}$$

Where D is matrix of mid band coefficients of DCT Transformed block and D' is Watermarked DCT block.

Step 9: Apply Inverse DCT to get 'New_LH1' component.

Step 10: Apply inverse DWT with 'LL1, HL1,New_LH1, HH1' to get 'New_Q' component.

Step 11: Combine, Y, I and New_Q components and convert to RGB color space using equations: 7,8 and 9.

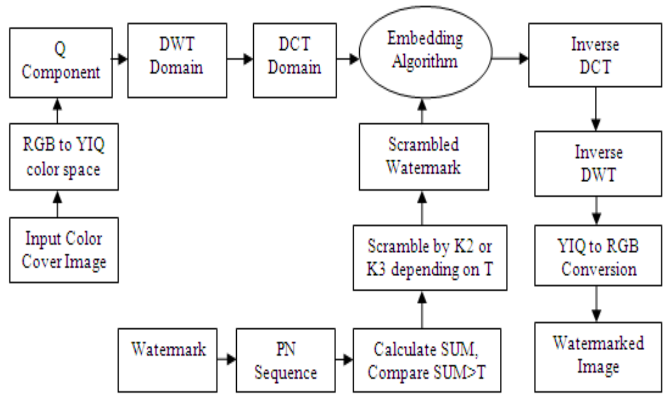


Figure 2: Watermark Embedding Process in DWT-DCT Domain

B. Extraction Algorithm using DWT-DCT Domain:

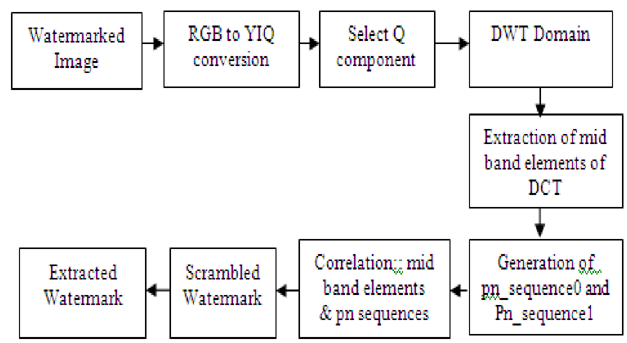


Figure 3 Watermark Extraction Process in DWT-DCT Domain

Step 1: Read Color 'Watermarked_Image' and separate it's R, G and B components using equations 1,2,3. Now convert to YIQ color space using equations 4, 5 and 6.

Step 2: Now select Q component and apply one level DWT to retrieve LH1 sub band.

Step 3: Use 4x4 size for DCT blocks. Generate two pn sequences: pn_sequence_0 and pn_sequence_1, depending upon sum of all elements of mid band used for 4x4 DCT transformation. Use same seed which was used in watermark embedding process. e.g. if rand ('state', 15) is used in embedding process, then, same process is to repeated here.

Step 4: Extract mid band elements from DCT block and find correlation between 'extracted mid band coefficients and pn_sequence_0' as well as 'extracted mid band coefficients and pn_sequence_1'.

Step 5 Determine watermark bits as follows:

If correlation between 'extracted mid band coefficients and pn_sequence_0' is greater than 'extracted mid band coefficients and pn_sequence_1', then record watermark bit as 0 else record watermark bit as 1. Here we get 'Scrambled watermark'.

Step 6: Apply Arnold Scrambling to 'Scrambled watermark' to give final 'extracted watermark'.

C. Embedding Algorithm using DCT Domain:

Step 1: Read Color Cover Image of 512x512 size. Separate it's R, G, B components using equations: 1,2,3 and convert into YIQ color space using equations 4,5,6.
Step 2: Now select Q component. Transform it to 4x4 DCT.
Step 3: Read grey scale watermark of 64x64 size.
Step 4: Depending upon Key K1, generate pn sequence for given watermark and calculate sum say SUM, which is summation of all elements in generated pn sequence.
Step 5. Determine Arnold Periodicity P for given watermark.
Step 6: If SUM > T, where T is some predefined threshold value, then perform watermark scrambling by Key K2= P+ Count, Otherwise perform watermark scrambling by Key K3= P+
Count, where count is programmer defined counter. Here, we get 'Scrambled Watermark' by Arnold Transform.
Step 7: Generate two pn sequences: pn_sequence_0 and pn_sequence_1, depending upon sum of all elements of mid band used for 4x4 DCT transformation.
Step 8: Perform watermark embedding using following equations:
If Watermark bit is 0, then

$$D' = D + K * pn\_sequence\_0 \quad (18)$$

If Watermark bit is 1, then

$$D' = D + K * pn\_sequence\_1 \quad (19)$$

Where D is matrix of mid band coefficients of DCT Transformed block and D' is Watermarked DCT block.
Step 9: Apply Inverse DCT to get 'New_Q' component.
Step 10: Combine, Y, I and New_Q components and convert to RGB color space using equations: 7, 8,and 9

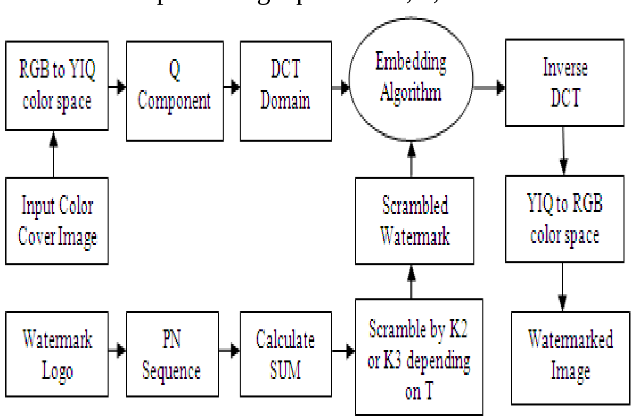


Figure 4: Watermark Embedding Process in DCT Domain

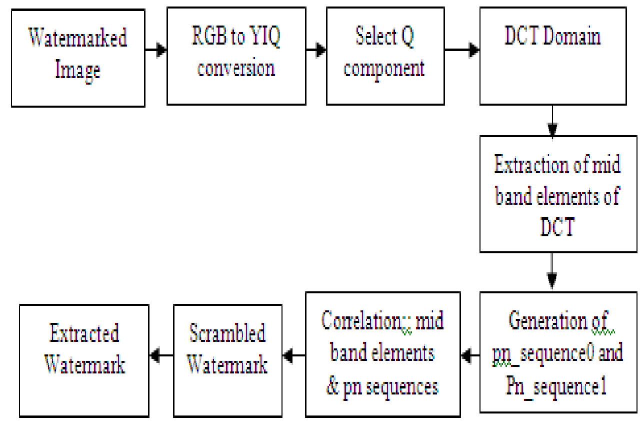


Figure 5 Watermark Extraction Process in DCT Domain

D. Extraction Algorithm using DCT Domain:

Step 1: Read Color 'Watermarked Image' and separate it's R,G and B components using equations 1,2,3. Now convert to YIQ color space using equations 4, 5 and 6.
Step 2: Now select Q component and take it into DCT Domain.
Step 3: Using 4x4 size DCT blocks, generate two pn sequences: pn_sequence_0 and pn_sequence_1, depending upon sum of all elements of mid band used for 4x4 DCT transformation. Use same seed which was used in watermark embedding process. e.g. if rand ('state', 15) is used in embedding process, then, same process is to repeated here.
Step 4: Extract mid band elements from DCT block and find correlation between 'extracted mid band coefficients and pn_sequence_0' as well as 'extracted mid band coefficients and pn_sequence_1'.
Step 5: Determine watermark bits as follows:
If correlation between 'extracted mid band coefficients and pn_sequence_0' is greater than 'extracted mid band coefficients and pn_sequence_1', then record watermark bit as 0 else record watermark bit as 1. Here we get 'Scrambled watermark'.
Step 6: Apply Arnold Scrambling to 'Scrambled watermark' to give final 'extracted watermark'.

V. TESTING AND RESULT DISCUSSION

The implementation of above algorithms is done in Matlab. The results are tested for both algorithms: using DWT_DCT domain and Only DCT domain in YIQ Color space. Q component was used in YIQ Color space and in DWT domain all middle and high frequency regions i.e. LH, HL and HH regions are tested. Here two performance parameters are applied to measure the performance of watermarking scheme: 'Perceptual Transparency' and 'Robustness'. 'Perceptual Transparency' is measured in terms of 'Peak Signal to Noise Ratio'. PSNR for gray scale image with size M x N is given
by:

$$PSNR = lg\left(\frac{M*N*255^2}{\sum_x \sum_y e^2{}_{(x,y)}}\right) \quad (20)$$

Where e(x, y) is the difference between Original Image and Watermarked Image. With size M*N, corresponding to color image, PSNR is expressed as,

$$PSNR = 10 * lg\left(\frac{3*M*N*255^2}{\sum_{c=R,G,B}\sum_x\sum_y(e^2(c,x,y))}\right) \quad (21)$$

Robustness is measured in terms of Normalized Correlation (NC). Here, c indicates the color component which e belongs to. The correlation factor (Normalized Correlation) measures the similarity and difference between original 'watermark and extracted watermark. It's values is ideally 1, but the value more than 0.75 is highly accepted. Normalized Correlation (NC) is given by:

$$NC = \frac{\sum_{i=1}^{N} w_i w_i'}{\sqrt{\sum_{i=1}^{N} w_i}\sqrt{\sum_{i=1}^{N} w_i'}} \quad (22)$$

Where, N is number of pixels in watermark, wi is original watermark, wi' is extracted watermark. As shown in table1, five different images with 512x512 sizes are tested with grey scale watermark logo of 64x64 size. As shown in Table 2, in DWT-DCT domain, we got maximum PSNR 67.56, 67.66, 67.57 for HL, LH and HH regions respectively for Jet Plane Image and maximum NC was 0.97 in HH region. But in only DCT domain, we got PSNR 54.12. Bigger is PSNR, better is quality of image. Thus, in DWT-DCT domain, better quality of watermarked image is achieved. Also, DWT-DCT domain provides more security than only DCT domain.

Table 1: Cover Image 'Lake' and Y, I, Q components, Watermarked image, original and extracted watermark

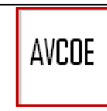
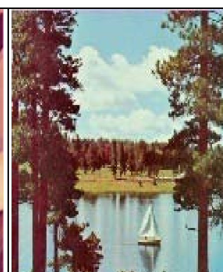
					 Original  Extracted
a) Cover Image	b) Y Component	c) I Component	d) Q Component	e) Watermarked Image	Watermark

Table 2: Comparative performance with Q Channel and Flexing Factor k=1for DWT-DCT and Only DCT domain (HL, LH and HH sub bands)

Watermarked Image in Specific Domain										
Performance Measure	PSNR	NC	PSNR	NC	PSNR	NC	PSNR	NC	PSNR	NC
DWT_DCT (HL in DWT)	63.18	0.74	63.99	0.93	64.62	0.73	67.56	0.91	63.94	0.77
DWT_DCT (LH in DWT)	63.19	0.72	64.01	0.90	64.66	0.79	67.66	0.85	63.98	0.80
DWT_DCT (HH in DWT)	63.19	0.97	64.00	0.97	64.59	0.97	67.57	0.97	63.97	0.97
Only DCT Domain	53.66	0.70	54.07	0.96	53.66	0.81	54.12	0.97	53.70	0.95

VI. CONCLUSION

DCT is at the heart of the international standard lossy image compression algorithm known as JPEG (Joint Photographic Experts Group). DCT is having good energy compaction property and DWT gives perfect reconstruction of decomposed image. Using the combination of both increase security levels of watermarking techniques. It's a challenge for researcher to achieve perceptual transparency and robustness simultaneously, since these two watermarking requirements are conflicting to each other. The presented algorithm using DWT-DCT domain yields PSNR up to 64.66 and NC up to 0.97.The demonstrated results show that DWT-DCT based combination gives better results than only-DCT based techniques and increases security levels also.

VII. ACKNOWLEDGMENT

Thanks to Board of Colleges and University Development (BCUD), University of Pune, Maharashtra, India, for providing 'Research Grant' for the research project "Robust Digital Image Watermarking using Discrete Wavelet Transform" for period 2010-2012. Also thanks to Amrutvahini College of Engineering, Sangamner, A'nagar, MS, India for providing Technical Support during this research work.

VIII. REFERENCES

[1] Cheng-qun Yin, Li Li, An-qiang Lv and Li Qu, " Color Image Watermarking Algorithm Based on DWT-SVD", Proceeding of the IEEE International Conference on Automation and Logistiocs August 18-21, 2007, Jinan, China, PP: 2607-2611

[2] Guangmin Sun, Yao Yu, " DWT Based Watermarking Algorithm of Color Images", Second IEEE Conference on Industrial Electronics and Application",2007, PP 1823-1826.

[3] Wei-Min Yang, Zheng Jin, " A Watermarking Algorithm Based on Wavelet and Cosine Transform for Color Image", First International Workshop on Education Technology and Computer Science", 2009, PP 899,903.

[4] Hong-Mei Yang, Yong-Quang Liang, Xiao-Dong Wang, Shu-Juan Ji, "A DWT-Based Evaluation Method of Imperceptibility of watermark in Watermarked Color Image", Proceeding of the 2007 International Conference on Wavelet Analysis and Pattern Recognition, Beijing, China, 2-4 Nov, 2007.

[5] Awad Kh. Al-smari and Farhan A. Al-Enizi, "A Pyramid-Based Technique for Digital Color Images Copyright Protection", International Conference on Computing, Engineering and Information, 2009, pp 44-47 .

[6] B.L.Gunjal, R.R.Manthalkar, "Discrete Wavelet Transform Based Strongly Robust Watermarking Scheme for Information Hiding in Digital Images", Third International Conference- Emerging Trends in Engineering and Technology,19-21 Nov 2010 , Goa, India, ISBN 978-0-7695-4246-1, Availlable:http://doi.ieeecomputersociety.org/10.1109/ICETET.2010.12.

[7] S. Joo, Y. Suh, J. Shin, H. Kikuchi, and S. J. Cho., "A new robust watermark embedding into wavelet DC components," ETRI Journal, 24, 2002, pp. 401-404.

[8] Voloshynovskiy. S. S. Pereira and T. Pun. 2001. "Attacks on Digital watermarks: classification, Estimation-Based attacks and Benchmarks", Comm, Magazine. 39(8):118-126.

[9] Abu-Errub, A., Al-Haj, A.,"Optimized DWT-based image watermarking", First International Conference on Applications of Digital Information and Web Technologies, IEEE,2008, 4-6.

[10] K. Ramani, E Prasad, S Varadarajan, "Stenography using BPCS to the integer wavelet transform", IJCSNS international journal of Computer science and network security, vol-7, No: 7 July 2007.

[11] B.L. Gunjal, "Implementation of discrete wavelet transform with decomposition and synthesis filter banks for robust digital image watermarking", Conference on Signal and Image Processing Applications, COEP, Pune Maharashtra, India, 19-20 Sept. 2009, ,PP:1-11.

[12] Baisa L. Gunjal, Suresh N. Mali, "Strongly Robust and Highly Secured DWT-SVD Based Color Image Watermarking: Embedding Data in All Y, U, V Color Spaces", in International Journal of Information Technology and Computer Science, Vol:4, No:3, April 2012, PP: 1-7.

[13] Giakoumaki, S. Pavlopoulos, D. Koutsouris: Multiple Image Watermarking Applied to Health Information Management, IEEE Transactions on Information Technology in Biomedicine 2006, PP: 722-732.

[14] Suresh N. Mali, Rajesh M. Jalnekar: Imperceptible and Robust Data Hiding Using Steganography Against Image Manipulation, International Journal of Emerging Technologies and Applications in Engineering,Technology and Sciences, (IJ-ETA-ETS) (2008) 84-91.

[15] Kaushal Solanki, Noah Jacobsen, Upamanyu Madhow, B. S.Manjunath and Sivkumar Chandrasekhar, " Robust Image-Adaptive Data Hiding Using Erasure and Error Correction," IEEE Trans. Image Processing, Vol. 13, No. 12, , Dec. 2004,PP: 1627-1639

Short Bio Data for the Author

Baisa L. Gunjal completed her B.E. Computer from University of Pune and M.Tech in I.T. in Bharati Vidyapeeth, Pune , Maharashtra, india. She is having 13 Years teaching experience in Computer Engineering. She is having 18 international and national journals. and conferences publications. Presently she is working on "Watermarking research project" funded by BCUD, University of Pune. Her areas of interest include Image Processing, Advanced databases and Network Security.

Dr. Suresh N. Mali has completed his PhD from Bharati Vidyapeeth Pune and presently he is working as Principal, Singhgad College of Technology and Science, Narhe, Pune, India. He is author of 3 books and having more than 18 international and national publications. Now, he is working as Member of expert Committee of AICTE, New Delhi to visit at various newly opened institutes on behalf of for western region, working as BOS member for Computer

Engineering at University of Pune, MS, India. He has worked as a Member of Local Inquiry Committee to visit at various institutes on behalf of University of Pune. His research interests are information security, data hiding, signal processing, digital multimedia communications and steganography.