On the embedding limits of the discrete cosine transform

Article *in* Multimedia Tools and Applications · April 2015

DOI: 10.1007/s11042-015-2557-x

Tamer Rabie
University of Sharjah

I. Kamel
University of Sharjah

Noname manuscript No.
(will be inserted by the editor)

On the Embedding Limits of the Discrete Cosine Transform

Tamer Rabie · Ibrahim Kamel

Received: date / Accepted: date

Abstract This work investigates the embedding capacity limits of high-capacity data hiding in color images based on an auto-selectable-area discrete cosine transform (ASA-DCT) frequency domain data hiding scheme, and explores the relationship between hiding capacity and image quality. It also compares the embedding capacities of various steganography schemes which have been recently published in the literature. Experimental results confirm that our proposed scheme successfully enhances hiding capacity while maintaining acceptable image quality and concludes that the capacity for our DCT hiding scheme can achieve extremely high bit rates which is much higher than other DCT approaches, as well as other spatial and frequency domain schemes.

Keywords

Data Hiding; Color Image Hiding; Steganography; Frequency-domain Image Embedding; Discrete cosine transform; DCT.

T. Rabie
Associate Professor of Computer Engineering
Department of Electrical and Computer Engineering
University of Sharjah, U.A.E.
Phone: +97165053943
E-mail: trabie@sharjah.ac.ae

I. Kamel
Professor & Chair
Department of Electrical and Computer Engineering
University of Sharjah, U.A.E.
E-mail: kamel@sharjah.ac.ae

1 INTRODUCTION

The proliferation and exchange of multimedia data over the internet and wireless networks has brought with it new prospects for covert communication. Data hiding techniques, commonly known as steganography when dealing with hiding secret messages into a cover medium to form a "stego" medium [21], or watermarking when copyright protection of multimedia data is involved [30], have received a great deal of attention in the past decade [4,26,14,19,20].

Techniques for data hiding inside digital images have been generally confined to three popular approach, namely the spatial [3,7], compression [9,6] and frequency [8,22–24] domains of the cover images, with variants that try to improve four different aspects; perceptibility, capacity, security, and robustness [10].

Perceptibility deals with the amount of "distortion" in the cover medium due to embedding information and if this information will lead to a visibly (visually or audibly) unacceptable level of the cover medium. Capacity refers to the amount of information that can be hidden in the cover medium relative to the change in perceptibility. For images, capacity is measured in bits per pixel (bpp). Security refers to an eavesdropper's inability to detect and inturn extract or change the hidden information, and robustness to the amount of modification the stego medium can withstand before an adversary can destroy the hidden information. Embedding capacity for steganographic information security systems has been a major area of research during the past few years [15,2,17,24] due to the fact that embedding capacities have remained relatively small, where researchers had to trade-off between higher capacity and reduced robustness and perceptual quality or higher perceptual quality and more robustness with lower capacities.

Other aspects of importance in the data hiding field are losslessness and reversibility. A lossless steganography scheme is able to extactly retrieve the hidden data without any modification in its bit pattern, while reversibility is concerned with the ability to reconstruct the host cover medium after extraction of the hidden information with bit-by-bit exactness. Steganography and watermarking schemes satisfying this reversibility requirement are called reversible schemes. Reversibility is much more common in watermarking than in steganography. Reversible techniques for watermarking have drawn more and more interest in recent years, especially for some critical applications such as digital watermarking systems in the area of medical and military imaging and remote sensing where the watermarked media is required to be in exact form after watermark extraction [18,16].

The image hiding scheme described in this paper is lossless but irreversible. The main advantages of lossy-irreversible steganography schemes is increased hiding capacities. For the purpose of our work where both the hidden information and the host cover medium are color image data, we maintain losslessness of the hidden image while relaxing the reversibility constraint since we are mainly concerned with steganography applications and not watermarking. Nevertheless we show that extremely high capacities can be achieved for reasonable perceptibility taking into account the typically subjective nature of the measure of visual fidelity, which is our own visual perception.

The main driving force behind data hiding in images is the fact that most images have inter-pixel relations that vary between high correlation and almost no correlation. The idea is to identify the redundancy in the pixel information of the cover image where the correlation is the least and use it to embed the information that we seek to hide.

Spatial and time domain methods are mainly broken into the following techniques: least significant bit (LSB) methods; Color palette methods [2,29]; Minimax algebra decomposition; and Spatial delay (echoing in audio signals) methods. Transform domain methods include: Unitary transforms (discrete Fourier transform, discrete cosine transform); Wavelet transform methods; and Mellin-Fourier transform methods. Compression-based techniques include: Singular value decomposition; Use of edge and shape characteristics in images; and Fractal encoding in image data.

In the spatial domain approach, the secret message is embedded directly into the pixels of a cover image. The manipulation of the LSB of an image pixel value and the rearrangement of image colors to create LSB or parity bit patterns, which correspond to the message being hidden [12], are the most commonly used strategies in this approach.

An algorithm by Lee and Chen specifically designed for high capacity embedding is given in [15]. Their scheme modifies the LSB of pixels in an image and then attenuates the result to control the perceptibility. In Chang et al.'s scheme [7], a dynamic programming strategy is used to find the optimal LSB substitution in order to hide images. In addition to LSB-based hiding strategies, several schemes that use different strategies to hide secret messages in the spatial domains of cover images also have been proposed [15,27]. For example, Chung et al. offered the singular value decomposition (SVD)-based hiding scheme [11], Tsai et al. used the bit plane of each block truncation coding (BTC) block to embed secret messages [28], and Chang et al. used the GA algorithm and absolute moment BTC to embed secret messages into color images [6].

In the frequency domain [13,8,22,18,16,23,24], the cover host image must first be transformed using a frequency-oriented mechanism such as the discrete Fourier transform (FFT), the discrete cosine transform (DCT), the discrete wavelet transform (DWT) or similar transformations, after which the secret messages can be combined with the coefficients in the frequency spectrum of the cover image to achieve embedding.

In [22] the author introduced a novel image hiding framework that makes use of the Fourier magnitude of the Luminance cover host image to maintain color composition of the stego image while allowing a relatively large size hidden image (to a maximum of half the size of the color cover host image in both dimensions [24]) to be robustly embedded and extracted with acceptable perceptibility of the stego image and minor degradation in the extracted hidden data.

In Chang et al.'s scheme [5], the medium-frequency coefficients of DCT-transformed cover images are used to embed a secret message. The JPEG quantization table is also modified to further protect the embedded secret message. Similarly, Iwata et al. use the boundaries between zero and non-zero DCT coefficients to hide secret data [13]. In 2007, Chang et al. extended Iwata et al.'s idea and presented a lossless steganographic scheme for hiding secret data in each block of quantized DCT coefficients in JPEG images [8]. In Chang et al.'s scheme, the two successive zero coefficients of the medium-frequency components in each block are used to hide secret data. They further modified the quantization table to maintain the quality of the stego-image while concealing a higher payload compared with Iwata et al. scheme. Thus, their scheme achieves reversibility and acceptable image quality of the stego-image simultaneously. However, their scheme can only embed secret bits into the zero coefficients located in the successive zero coefficients in the medium area; non-zero coefficients in the medium area cannot be used.

In 2009, Lin and Shiu combined Chang et al.'s [8] scheme and then designed a 2-layers data hiding scheme for DCT-based images. Lin and Shiu's [16] scheme outperforms Chang et al.'s scheme [8] in hiding capacity but the size of the hidden secret data was still less than 70000 bits on average (equivalent to approximately embedding a 94 × 94 pixel gray-level image size inside a 512×512 gray-level cover image) because it retains the reversibility function.

Our work in this paper investigates the embedding capacity limits of high-capacity data hiding in color images based on an auto-selectable-area discrete cosine transform (ASA-DCT) frequency domain data hiding scheme and explores the relationship between hiding capacity and image quality. A comparison with the embedding capacities of various steganography schemes that have been recently published in the literature [15, 2, 24, 31, 17] is also demonstrated. It will be shown that our scheme takes the embedding capacity of the DCT to its limits where an extremely high embedding capacity of approximately 20 bpp can be achieved with reasonable perceptibility.

The rest of this paper is organized as follows. In section 2, we briefly review the theory of the DCT transform and its wide use in compression of JPEG images. Our proposed high-capacity data hiding scheme is discussed in section 3, and section 4 presents our comparison results and demonstrates the highest-capacity limits that can be achieved based on our DCT approach. Finally, concluding remarks appear in section 5.

2 The 2D Discrete Cosine Transform

The one-dimensional Discrete Cosine Transform (1D-DCT) is often used in signal and image processing, especially for lossy data compression, because it has a strong "energy compaction" property: most of the signal information tends to be concentrated in a few low-frequency components of the DCT [1, 25]. The 2-dimensional DCT (2D-DCT) is a widely used image transformation and is extended from the 1D-DCT to compress JPEG images. Figure 1 shows the JPEG compression process, which consists of first transforming an (R,G,B) color image to a (Y,Cb,Cr) image where Y is the Luminance component and (Cb,Cr) are the two chrominance compnents. The transformed image is then subdivided into non-overlapping blocks of 8×8 pixels. The 2D-DCT is then performed on each block using equation 1. This generates 64 coefficients in the DCT domain which are then quantised to reduce their magnitude. The coefficients are then reordered into a one-dimensional array in a zigzag manner before further entropy encoding. The compression is achieved in two stages; the first is during quantisation and the second during the entropy coding process. JPEG decoding is the reverse process of coding. An example 8×8 DCT basis functions (Left) and the zigzag reordering (Right) are shown in figure 2.

The forward 2D-DCT equation which calculates the coefficients $F(u,v)$, for an $N \times N$ block from gray-scale image $f(x,y)$ is:

$$F(u,v) = \frac{2}{N} C(u)C(v) \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x,y) \times \left[\cos\left(\frac{\pi u(2x+1)}{2N}\right)\cos\left(\frac{\pi v(2y+1)}{2N}\right)\right] \quad (1)$$

and the inverse equation to retrieve the gray-scale $N \times N$ block for image $f(x,y)$ from 2D-DCT-coefficients $F(u,v)$ is obtained, as in equation 2, by multiplying the coefficients by the DCT basis functions:

$$f(x,y) = \frac{2}{N} \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} C(u)C(v)F(u,v) \times \left[\cos\left(\frac{\pi u(2x+1)}{2N}\right)\cos\left(\frac{\pi v(2y+1)}{2N}\right)\right] \quad (2)$$

where the basis functions are the cosines multiplied by the constant scale factors $C(u)C(v)$, where

$$C(u) = \begin{cases} \frac{1}{\sqrt{2}} & if\, u = 0 \\ 1 & otherwise \end{cases} \quad (3)$$

and similarly for $C(v)$.

Referring to the left part of figure 2, each basis function from the 8×8 block is multiplied by its coefficient and then this product is added to the previous value to form the final image $f(x,y)$.

3 High-Capacity Auto-Selectable-Area DCT Scheme

The strong "energy compaction" property of the 2D-DCT suggests that we can make use of the high-frequency areas in the DCT domain to hide information, given that most of the signal information tends to be concentrated in a few low-frequency components of the DCT. It should be noted that the upper-left corner of the 2D-DCT represents the lower frequency coefficients with increasingly higher frequency components towards the lower-right corner. The fact that DCT coefficients of the

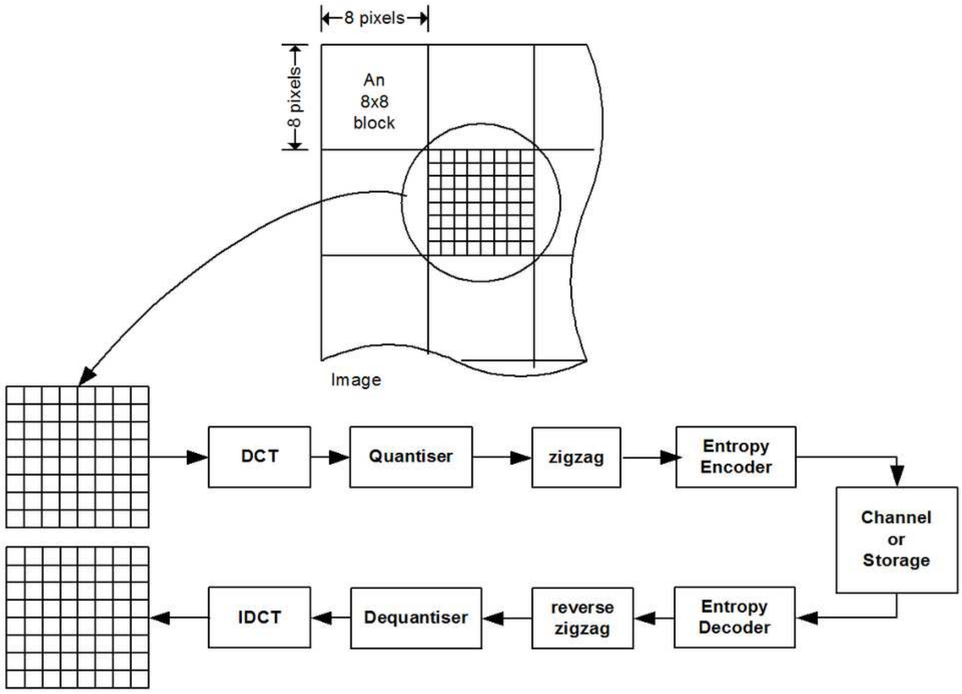

Fig. 1 Block diagram showing steps of JPEG image compression and decompression.

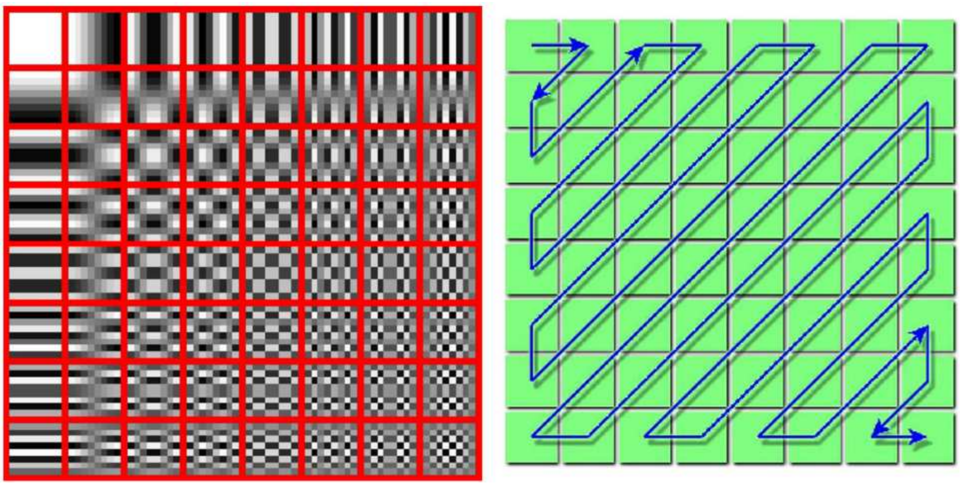

Fig. 2 Left: 8×8 2D-DCT basis functions. Right: zigzag reordering before encoding.

lower-frequency areas can represent the image information to a high degree of accuracy allows us to embed the hidden image into the high-frequency areas of the DCT with minimal effect on the perceptibility of the cover host image. In this work we seek to find the maximum possible size that can be embedded into the DCT of the cover host image which will not reduce the perceptibility below the limit of 20 decibels (dB) for the peak-signal-to-noise-ratio (PSNR).

The auto-selectable-area discrete cosine transform (ASA-DCT) embedding approach we follow to demonstrate the hiding capacity limits of DCT-based steganography is influenced by the JPEG compression standard. A smart-based technique is implemented where the cover host image is first divided into non-overlapping equal-sized $m \times m$ blocks[1] and the 2D-DCT is applied to each block using equation 1. Next, a maximum contiguous square area of variable size $n \times n; n < m$ in the high-frequency region (lower-right corner) of the individual DCT blocks of the cover host image is automatically estimated by the embedding function and this region of the DCT block is then replaced by a region of the same $n \times n$ block size from the hidden image after first re-scaling this hidden block's gray-level values to

[1] For JPEG standard the block size $m \times m$ is 8×8

the range $[0 \cdots k]$. This re-scaling step is necessary to allow the hidden image information to blend into the natural range of values of the DCT coefficients. The maximum scale value k is empirically estimated and is found to be in the range $k = [10 \cdots 20]$ for typical natural RGB color images. This is repeated for all DCT blocks of the DCT of the cover host image.

The technique used to automatically estimate the largest contingous square area of variable size $n \times n$ in the high-frequency region of the individual DCT blocks of the cover host image is depicted in figure 3. The idea is to use a quantization step to help the embedding function to automatically estimate the maximum area in the lower-right (high-frequency) corner of the DCT of the current block in the cover image. The hidden image is then directly embedded by replacing the zero DCT coefficients in this square area by the $k-$scaled values in the current block of the hidden image information.

Quantization of each individual $m \times m$ cover image DCT block is computed by dividing the elements of this block by the elements of a quatization matrix of the same size. The quatization matrix values used are shown in figure 3 and are simply one of the many standard quatization matrices used for JPEG compression. The purpose of this quantization step is to keep intact the important DCT coefficients which can be used to reconstruct the original cover host image while masking out the coefficients which provide less important (redundant) information which can be removed to compress the image (as in the lossy JPEG standard) or replaced by the hidden information as is the case with steganography.

The block size we use is not limited to 8×8 as in the JPEG method, but this block size is allowed to vary to the maximum cover image size (512×512 for our experiments) in multiples of the smallest size 8×8 (i.e. $16 \times 16, 32 \times 32, \cdots, 256 \times 256, 512 \times 512$). In cases where the the block size used is larger than 8×8, the standard 8×8 quantization matrix indicated in figure 3 is still used after first interpolating its values to the larger $m \times m$ block size. It should be noted that the larger the block size we used the less the JPEG-like blocky artifacts appeared in the final stego image.

The Inverse 2D-DCT given by equation 2 is then applied to the modified DCT coefficients containing the hidden color image information to produce the color stego image. This is stored in the highest quality (lossless) JPEG image format to maintain the hidden information from being modified. Extraction is performed in the reverse order where the 2D-DCT of the stego image is taken and, knowing the hidden block size $n \times n$ apriori, the same $n \times n$ sized lower-right region of the DCT coefficient blocks are extracted and rescaled to the original intensity range ($0 \cdots 255$ per color channel). For extra security, an encryption step may be introduced before embedding the hidden image during the hiding stage, and a decryption key must then be known apriori to be able to correctly extract the exact hidden information.

4 Experimental Comparisons

The algorithm by Lee & Chen specifically designed for high capacity embedding is given in [15]. Their scheme modifies the least significant bits (LSBs) of pixels in an image and then attenuates the result to control the perceptibility. They were able to embed and extract a maximum capacity of 4.06 bpp from a gray-scale image which can be extrapolated to 12.18 bpp for an (R,G,B) color image (equivalent to 364×364 hidden color image size embedded in a 512×512 color cover image size). The perceptibility for this method was at a PSNR of 34.03 dB.

The maximum capacity that was reached in the work of Brisbane *et. al.* [2] was an average 6 bpp for an (R,G,B) color cover image, with a perceptibility given by a PSNR of 40 dB. This is equivalent to 2 bpp per color channel (i.e. 256×256 hidden color image embedded in 512×512 color cover image size).

The maximum possible capacity reachable using the FFT Magnitude of the Luminance channel approach described in our previous work in [24] was 6 bpp for hiding an (R,G,B) color image in an (R,G,B) color cover host image, with a maximum perceptibility given by a small PSNR of 19.51 dB. This is equivalent to 256×256 hidden color image embedded in 512×512 color cover image size. In comparison the DCT high-capacity steganography scheme described in this work takes the embedding capacity of the DCT to its limits and shows that an extremely high embedding capacity of approximately 20 bpp can be achieved with reasonable perceptibility.

Other DCT-based information hiding techniques include the work by Yang *et. al.* [31] and Lin & Shiu [17]. In [31] they present a high capacity reversible watermarking scheme and use the bit-shift operation of companding technique over integer DCT coefficients of image blocks. The maximum data hiding capacity they reached was 173123 bits for a gray-scale image which can be extrapolated to 1.96 bpp for an (R,G,B) color image at PSNR of 28.16 dB which is equivalent to hiding a color image of size 147×147 inside a 512×512 color host image. While in [17] the maximum achievable hiding capacity was 90112 bit which is equivalent to a hidden image of size 106×106 gray pixels inside a 512×512 gray cover host image which translates to

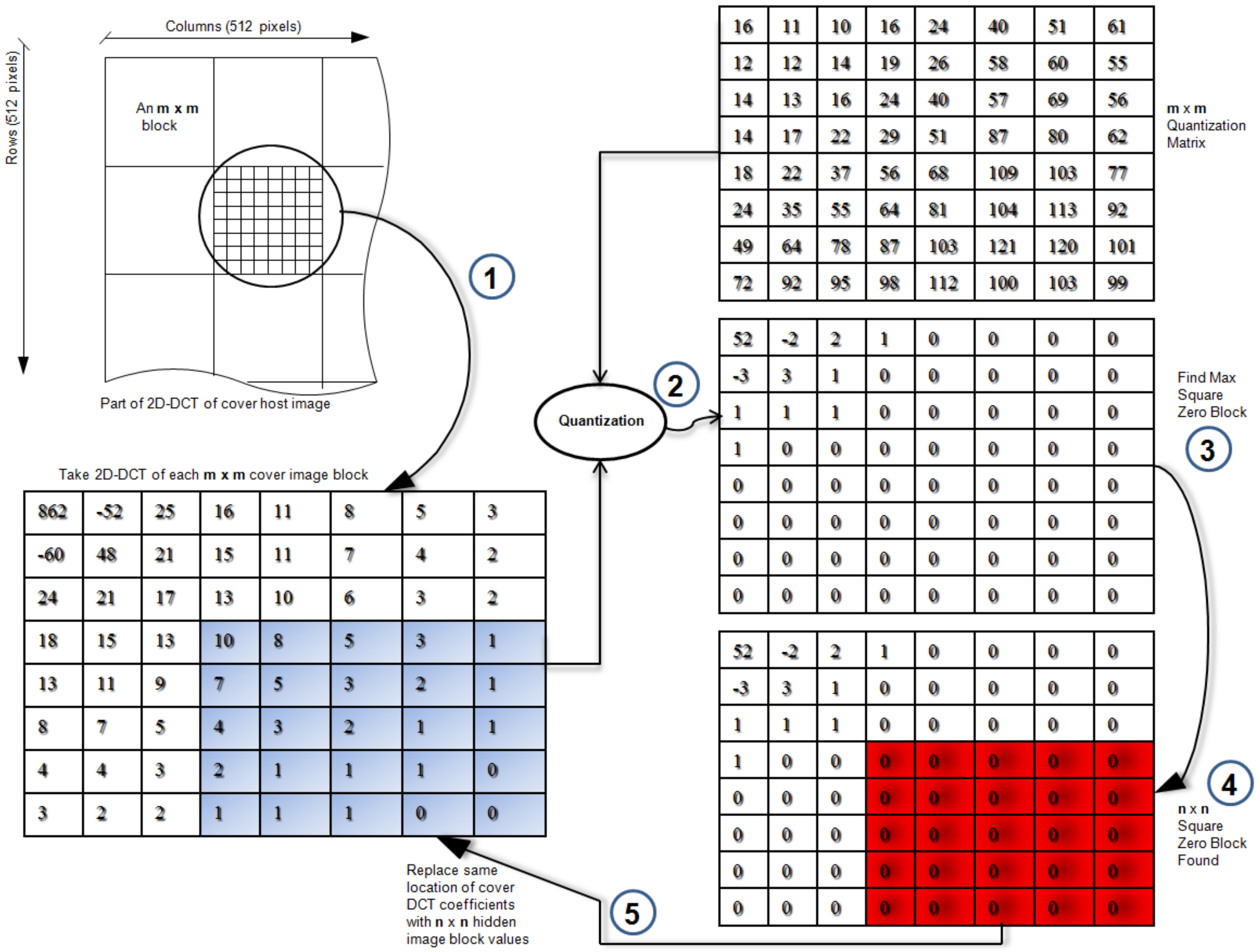

Fig. 3 Example showing quantization of each individual $m \times m$ ($m = 8$) cover image DCT block by dividing the elements of each DCT block of the cover image by the elements of a quatization matrix of the same size and then auto-selecting the largest square zero region which was found to be of size $n \times n$ (for this example $n = 5$ shown as the shaded area in red).

about 0.34 bpp per channel which can be extrapolated to 1.02 bpp for a three-color image at PSNR of 28.22 dB.

Using our auto-selectable-area embedding scheme, described in section 3 above, we were able to embed and losslessly extract 6.125 bpp per color channel of a three channel (R,G,B) color cover image for a maximum of 18.375 bpp embedding capacity with a perceptibility measured at PSNR of 25.8 dB. This corresponds to embedding a color image of size 448×448 inside a color cover image of size 512×512 with an 87.5% embedding capacity. When taking our scheme to the limits and forcing the embedding capacity in the DCT of the cover image to a size increase of 32×32 above the auto-selected area which takes the embedded color hidden image size to 480×480, the average PSNR was still 23.2 dB for a total embedding capacity of 7.03 bpp per color channel which is equivalent to 21.1 bpp in the three color channels of an (R,G,B) color cover image. Table 1 shows a comparison of the different capacity limits with corresponding maximum PSNR values.

Table 1 Comparative results expressed as maximum Capacity/PSNR values for the various methods. Highest Capacities and PSNR values are emphasized in a bold font.

Method	Capacity	PSNR
Lee & Chen (2000) [15]	12.18 bpp	34.03 dB
Yang *et. al.* (2004) [31]	1.96 bpp	28.16 dB
Brisbane *et. al.* (2005) [2]	6 bpp	**40 dB**
Lin & Shiu (2010) [17]	1.02 bpp	28.22 dB
Rabie (FFT) (2013) [24]	6 bpp	19.51 dB
Our ASA-DCT Method (Auto)	**18.375 bpp**	25.8 dB
Our ASA-DCT Method (Forced)	**21.1 bpp**	23.2 dB

Figure 4 shows a stego image portion from a Tiger Face image used as a cover host to embed the different sizes of the Red Rose image indicated on each image using our technique. The figure clearly shows that the hiding capacity of the DCT continues to produce acceptable perceptibility when working below 90% (approximately 20 bpp) embedding capacity where PSNR values remain above 25 dB.

5 CONCLUSIONS

The authors have presented an auto-selectable-area discrete cosine transform (ASA-DCT) high-capacity image embedding framework that exceeds the hiding capacity of other spatial and frequency domain data hiding schemes while maintaining very acceptable perceptibility of the stego image. The idea is to use a quantization step to help the embedding function to automatically estimate the maximum area in the lower-right (high-frequency) corner of the DCT of the current block in the cover image. The hidden image block is then directly embedded in this square area replacing the cover host image's DCT coefficients in the same block. It was shown that our scheme takes the embedding capacity of the DCT to its limits where an extremely high embedding capacity of approximately 21.1 bpp can be achieved with reasonable perceptibility. One potentially attractive application of our high-capacity steganography scheme is video privacy protection where an important video sequence may be embedded frame-by-frame in the individual frames of another less important video thus securing its privacy.

ACKNOWLEDGMENT

This work was funded by the College of Graduate Studies and Research at the University of Sharjah under project number 140440 for 2014.

References

1. Ahmed, N., Natarajan, T., Rao, K.: Discrete cosine transform. IEEE Trans. Computers **23**(1), 90–93 (1974)
2. Brisbane, G., aini, R.S.N., Ogunbona, P.: High-capacity steganography using a shared colour palette. IEE Proc., Vis. Image Signal Process. **152**(6), 787–792 (2005)
3. Celik, M.U., Sharma, G., Tekalp, A.M., Saber, E.: Lossless generalized-lsb data embedding. IEEE Trans. Image Processing **14**(2), 253–266 (2005)
4. Chan, C.K., Cheng, L.: Hiding data in images by simple LSB substitution. Pattern Recognition **37**, 469–474 (2004)
5. Chang, C.C., Chen, T.S., Chung, L.Z.: A steganographic method based upon jpeg and quantization table modification. Information Sciences **141**, 123–138 (2002)
6. Chang, C.C., Chen, Y.H., Lin, C.C.: A data embedding scheme for color images based on genetic algorithm and absolute moment block truncation coding. Soft Computing **13**, 21–331 (2008)
7. Chang, C.C., Hsiao, J.Y., Chan, C.S.: Finding optimal least-significant-bit substitution in image hiding by dynamic programming strategy. Pattern Recognition **36**(7), 1595–1683 (2003)
8. Chang, C.C., Lin, C.C., Tseng, C.S., Tai, W.L.: Reversible hiding in dct-based compressed images. Information Sciences **177**, 2768–2786 (2007)
9. Chang, C.C., Tai, W.L., Lin, C.C.: A reversible data hiding scheme based on side match vector quantization. IEEE Trans. Circuits and Systems for Video Technology **16**(10), 1301–1308 (2006)
10. Chen, B., Wornell, G.: Quantization index modulation: A class of provably good methods for digital watermarking and information embedding. IEEE Trans. Information Theory **47**(4), 1423–1443 (2001)
11. Chung, K.L., Shen, C.H., Chang, L.C.: A novel svd- and vq-based image hiding scheme. Pattern Recognition Letters **22**(9), 1051–1058 (2001)
12. Curran, K., Bailey, K.: An evaluation of image based steganography methods. International Journal of Digital Evidence **2**(2), 1–40 (2003)
13. Iwata, M., Miyake, K., Shiozaki, A.: Digital steganography utilizing features of jpeg images. IEICE Trans. Fundamentals **E87-A**(4), 929–936 (2004)
14. Jain, A., Uludag, U., Hsu, R.: Hiding a face in a fingerprint image. In: Proc. of the International Conference on Pattern Recognition (ICPR). Quebec City, Canada (2002)
15. Lee, Y., Chen, L.: High capacity image steganographic model. IEE Proc., Vis. Image Signal Process. **147**(3), 288–294 (2000)
16. Lin, C.C., Shiu, P.F.: Dct-based reversible data hiding scheme. In: Proc. of the 3rd International Conference on Ubiquitous Information Management and Communication (ICUIMC09), pp. 327–335 (2009)
17. Lin, C.C., Shiu, P.F.: High capacity data hiding scheme for dct-based images. Journal of Information Hiding and Multimedia Signal Processing **1**(3), 220–240 (2010)
18. Lin, C.Y., Chang, C.C., Wang, Y.Z.: Reversible steganographic method with high payload for jpeg images. IEICE Trans. Information and Systems **91-D**(3), 836–845 (2008)
19. Marvel, L.M., Charles G. Boncelet, J., Retter, C.T.: Spread spectrum image steganography. IEEE Trans. Image Processing **8**(8), 1075–1083 (1999)
20. Nozaki, K., Niimi, M., Eason, R.O., Kawaguchi, E.: A large capacity steganography using color bmp images. In: ACCV '98: Proceedings of the Third Asian Conference on Computer Vision-Volume I, pp. 112–119. Springer-Verlag, London, UK (1998)
21. Provos, N., Honeyman, P.: Hide and seek: An introduction to steganography. In: IEEE Security & Privacy Magazine, pp. 32–44. IEEE Computer Society (2003)
22. Rabie, T.: Frequency-domain data hiding based on the matryoshka principle. Special Issue on Advances in Video Processing and Security Analysis for Multimedia Communications, International Journal of Advanced Media and Communication **1**(3), 298–312 (2007)
23. Rabie, T.: Digital image steganography: An fft approach. In: 4th International Conference on Networked Digital Technologies (NDT), pp. 217–230. Springer Verlag (2012)
24. Rabie, T.: High-capacity steganography. In: 6th International Congress on Image and Signal Processing (CISP), vol. 2, pp. 858–863 (2013)

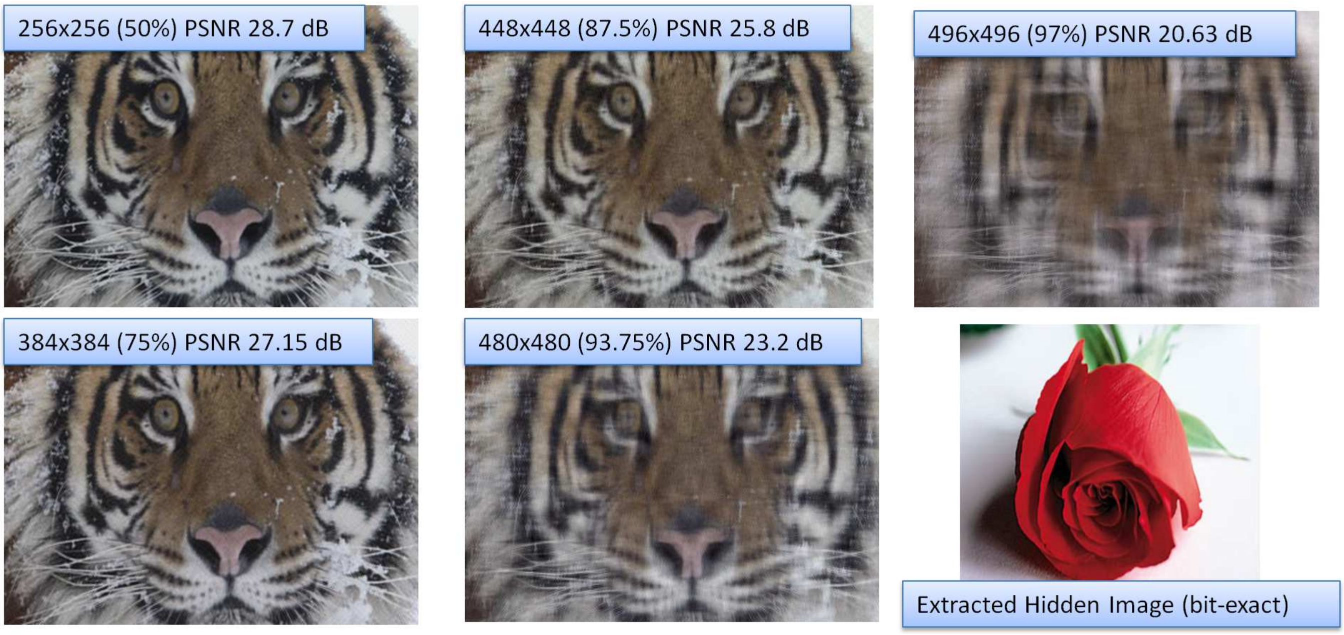

Fig. 4 Stego image portion from a 512×512 "Tiger Face" image used as a cover host to embed the different sizes of the "Red Rose" image indicated on each image using our DCT scheme.

25. Rao, K., Yip, P.: Discrete Cosine Transform: Algorithms, Advantages, Applications. Academic Press, ISBN 0-12-580203-X, Boston (1990)
26. Solanki, K., Jacobsen, N., Madhow, U., Manjunath, B.S., Chandrasekaran, S.: Robust image-adaptive data hiding using erasure and error correction. IEEE Trans. Image Processing **13**(12), 1627–1639 (2004)
27. Tian, J.: Reversible data embedding using a difference expansion. IEEE Trans. Circuits and Systems for Video Technology **13**(8), 890–896 (2003)
28. Tsai, P., Hu, Y.C., Chang, C.C.: An image hiding technique using block truncation coding. In: Proc. of Pacific Rim Workshop on Digital Steganography, pp. 54–64 (2002)
29. Wang, X., Yao, Z., Li, C.T.: A palette-based image steganographic method using colour quantisation. In: Proc. of the IEEE International Conference on Image Processing (ICIP), pp. II – 1090–3 (2005)
30. Wu, M., Liu, B.: Data hiding in image and video:part I - fundamental issues and solutions. IEEE Trans. Image Processing **12**(6), 685–695 (2003)
31. Yang, B., Schmucker, M., Funk, W., Busch, C., Sun, S.: Integer dct-based reversible watermarking for images using companding technique. Proc. SPIE 5306, Security, Steganography, and Watermarking of Multimedia Contents **6**(405) (2004)