Digital Image Watermarking in the Discrete Wavelet Domain and Analysis of the Effects of Compression on Watermarked Images

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Abstract *- Digital Watermarking is a technology used for securing digital content, that is, images, audio, and video sequences. Watermarking is useful in various ways and can be used as an effective deterrent against copyright theft of photographs, maps, paper bank notes, stock certificates and other illustrations. This work is based on digital still image watermarking in the discrete wavelet transform (DWT) domain by image/logo fusion and analyses the effects of compression, particularly, JPEG and JPEG2000 on watermarked images. It was required to achieve imperceptible watermarking that would not degrade image quality and that would be robust against compression. Watermarking and compression are two conflicting ideas in that the former adds extra bits of information while the latter removes bits from an image. However, since watermarked images are compressed prior to transmission or storage, it is important to ensure that the digital watermark is robust against compression.*

Keywords *- Digital Watermarking, Digital still image, Discrete Wavelet Transform, Image/Logo Fusion, and Compression.*

1. INTRODUCTION

Developments in digital communications technology has led to the rapid expansion of the Internet. The Internet has made downloading of digital content, namely pictures, music, video etc. very easy. Digital facilities are currently being used to copy and distribute digital data without degrading the quality, such that, it is very difficult to differentiate between the copy and the original. Digital content, however, is susceptible to piracy because of the ease of modification. The need therefore, to develop security systems to combat this problem cannot be overemphasized. One of the solutions is digital watermarking.

Digital watermarking is a technology used for securing digital images, audio and video sequences by adding pieces of information called digital watermarks that can be detected or extracted to make an assertion about the data(www.arnab.org). The watermarks remain intact under transmission/ transformation, allowing for protection of ownership rights in digital form. Digital watermarking can be blind or non-blind and perceptible or imperceptible.

This work involves watermarking of a digital image in the discrete wavelet transform domain and the type of watermarking is non-blind and imperceptible. It also analyses the effects of compression, specifically JPEG and JPEG2000 on a watermarked image to determine the robustness of the embedded watermark. The rest of the paper is organized as follows: Section 2 discusses digital watermarking techniques for still images; section 3 discusses JPEG and JPEG2000 image coding; Section 4 shows the digital watermarking algorithms designed for embedding and extraction of the watermark; Section 5 shows the results obtained for the watermarking algorithms, the effects of JPEG and JPEG2000 compression on the watermarked images and highlights the relevance of Digital watermarking based on the Industry survey that was done as part of this work. Finally, section 6 summarises the study.

2. DIGITAL WATERMARKING TECHNIQUES

Digital watermarking techniques are divided into two main categories based on the domain used for watermarking, that is, spatial and frequency domain. Generally watermarking involves insertion, detection and removal of the watermark, which calls for insertion and extraction algorithms. The watermark is meant to prove ownership and thus can be a small logo, name, image or pseudorandom noise pattern. Figure1 illustrates the basic procedure of watermark insertion and retrieval.

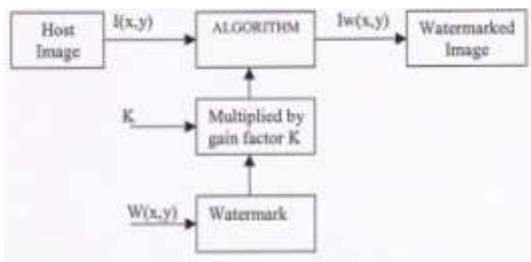

Figure1A)Watermark embedding Procedure

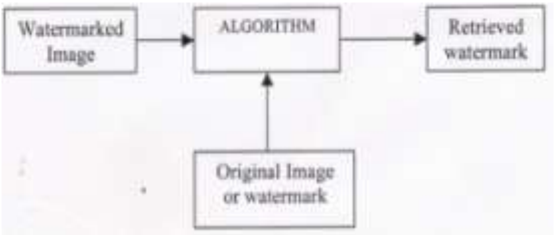

Figure1B)Watermark Retrieval

2.1 Spatial Domain techniques

A) Least Significant Bit (LSB) Technique

It involves embedding the watermark either in the most significant or least significant bits of an image (www.owlnet.rice.edu). For colour images, a pixel has 3 bytes (24 bits). For every pixel of 3 bytes, 3 bits of watermarking information can be hidden in the LSB. For a gray scale image where a pixel has 8 bits, the image is sliced up into bit planes (see Figure 2). The top left hand corner is the least significant bit plane. Since there isn't much information in the 3 least significant bit plane (top row), this enables replacement of these bit planes by watermarking information.

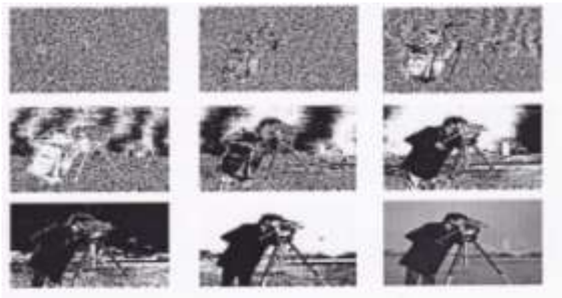

Figure 2 Image of Camera man sliced into 8 bit planes (Cox, 2002)

B) Correlation based Technique

A watermark is embedded into an image by adding a pseudorandom noise pattern consisting of integers -1, 0, 1, to the luminance values of the image pixels. A pseudorandom noise pattern W(x,y) is added to the image I(x,y) to obtain a watermarked image $I_w(x,y)$ as follows:

$$I_w(x,y) = I(x,y) + k*W(x,y); \tag{1}$$

where k is the gain.

Increasing k increases the robustness of the watermark but reduces the quality of the watermarked image. Pre-filtering the image with an edge enhancement filter before correlation increases its robustness and maintains image quality. The edge enhancement filter is given by the matrix

$$F_{edge} = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 10 & -1 \\ -1 & -1 & -1 \end{bmatrix} \tag{2}$$

2.2 Frequency Domain Techniques

The image is transformed from spatial to frequency (spectral) domain before watermarking, that is, the Discrete Cosine Transform (DCT), Discrete Fourier Transform (DFT) or Discrete Wavelet Transform (DWT) domain.

A) DCT Domain Techniques

The image is broken into blocks of size 8x8 pixels and the DCT is applied to form 64 basis functions with increasing horizontal and vertical spatial frequency. The transformed image is then divided into different frequency bands and the watermarking is embedded in the middle frequency bands. Two methods are used to add the watermark. The first involves comparing middle band DCT coefficients to encode a single bit into the DCT block based on the recommended JPEG quantization table. If the coefficients being compared are not equal, the DCT block will encode a "1" otherwise it will encode a "0". The second involves adding a pseudorandom noise pattern (PN) after multiplication by a gain factor k to the middle frequency components. The modulation is as shown in equation 3.

$$I_{W_{x,y}}(u,v) = \begin{cases} I_{x,y}(u,v) + k * W_{x,y}(u,v), & u,v \in F_M \\ I_{x,y}(u,v), & u,v \notin F_M \end{cases} \tag{3}$$

where $I_{wx,y}$ is the watermarked image, $I_{x,y}$ is the original image, $W_{x,y}$ is the watermark and k is the gain.

Inverse transformation is performed to arrive at the final watermarked image I_w.

B) DFT Domain Techniques

The phase is commonly used for watermarking because it makes the watermark robust and has high noise immunity. When the amplitude is used for watermarking, the DFT amplitude coefficients can be modulated as follows;

$$|I_w(u,v)| = |I(u,v)|.(1+k)|W(u,v)| \tag{4}$$

where, $I_w(u,v)$ are the coefficients of the watermarked image, I(u,v) are the coefficients of the original image, k is the gain and W(u,v) are the watermark coefficients.

C) DWT Domain Techniques

Watermarking in the wavelet domain enables the exploitation of the characteristics of the human visual system (Meerwald, at www.cosy.sbg.ac.at)such that watermarks are hidden with more energy. The DWT separates an image into lower resolution approximation image (LL) as well as high resolution bands which are; horizontal (HL), vertical (LH) and diagonal (HH) as shown in Figure 3.

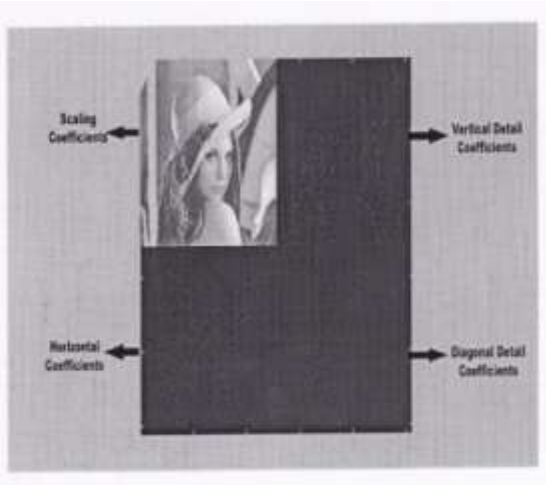

Figure3 1-D Wavelet Decomposition of Lena (www.owlnet.rice.edu)

Due to the human eye being less sensitive to noise in the high resolution DWT bands, watermarking can be applied to these bands. In addition, watermarking in these bands enables the increase in robustness of the watermark without affecting image quality. Watermarking is realised by embedding Code Division Multiple Access (CDMA) spread sequence in the high resolution bands using the following expression:

$$Iw_{u,v} = \left| \begin{array}{ll} Wi+\alpha|Wi|Xi, & u,v \in HL,LH \\ Wi & u,v \in LL,HH \end{array} \right. \qquad (5)$$

where, W_i→the coefficient of the transformed image, X_i→the bit of the watermark to be embedded, α→the scaling factor

The majority of the watermark is stored in the larger coefficients to make the embedding process adaptive.

To detect the watermark, the same CDMA sequence is generated and the correlation with transformed bands is determined. If correlation exceeds a predefined threshold, the watermark is detected.

D) Block Mean Technique

The image is divided into blocks. For each block, the mean is obtained and subtracted from each pixel in the block. The pixel values are normalized within each block to a range of -127 to 127. (Boland, 1995) An appropriate transform is applied (DCT, DFT or DWT) is applied and selected coefficients are modulated using bidirectional coding which involves either incrementing the mean to encode a one and decrement to encode a zero. The inverse transform is then applied and the processed block is replaced in the image.

To detect the watermark the above process is performed on both the original and the watermarked image and the value of the coefficients compared.

Transforming an image to the frequency domain before watermarking is a better approach because watermarking in the spatial domain exposes the watermark to removal by compression, scaling, cropping and geometric transformations.

3. IMAGE COMPRESSION

Digital images like any other information need to be shared. This entails transmission on various media or storage on digital storage devices. Bandwidth and storage space are limited resources, as such images have to be compressed. For watermarked images it is important that the watermark is robust against compression otherwise the purpose of securing the image is defeated. JPEG and JPEG2000 codecs are used to compress the watermarked images for this work. Therefore the underlying principles of these codecs are covered here.

3.1 Basics of Compression

Compression reduces the number of bits required to represent image information by reducing redundancy and irrelevancy. Redundancy reduction discards duplicate information while irrelevancy reduction omits information that cannot be noticed by a human observer. Three types of redundancies are exploited in compression namely; spectral, spatial and temporal redundancies. Compression can be lossy or lossless. Lossless compression results in no image degradation after reconstruction while in lossy compression the reconstructed image is an approximation of the original image and can yield distortions.

3.2 Joint Photographic Expert Group (JPEG) Compression

The JPEG standard is used for coding still images and video that is made up of successive images known as motion JPEG. It is a block based compression standard that uses the Discrete Cosine Transform and is lossy due to the process involved in coding. Figure 4 shows the stages in JPEG compression.

3.2.1 Stages in JPEG Compression

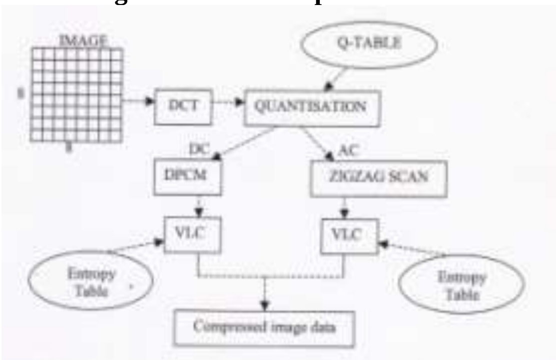

Figure 4 JPEG Compressor

Transformation: The image is divided into blocks of 8x8 pixels and the forward DCT is applied on each block resulting in 64 coefficients per block (http://www.ece.purdue.edu)(http://www.stanford.edu). The forward DCT is defined as:

$$DCT(i,j) = \frac{1}{\sqrt{2N}} C(i)C(j) \sum_{x=0}^{N-1}\sum_{y=0}^{N-1} pixel(x,y).Cos\left[\frac{(2x+1)j\pi}{2N}\right] Cos\left[\frac{(2y+1)j\pi}{2N}\right] \quad (6)$$

$$C(x) = \frac{1}{\sqrt{2}} \; if \; x \; is \; 0, else \; 1 \; if \; x > 0 \quad (7)$$

i,j =0,1,2… 7 and N=8

Quantisation: Involves the use of quantisation matrix, which allows different weighting to be done according to perceptual importance and by rounding off to the nearest integer, a process that results in many zero valued coefficients. This enables efficient coding but is lossy. To control the elements of the quantisation matrix, a quality factor in the ranges 1 to 100% is used.

Encoding: The 64 coefficients per block comprise of 1 DC coefficient and 63 AC coefficients. DC coefficients are coded using Differential Pulse Code Modulation (DPCM). Coding is done by first categorizing differences by magnitude, then variable length coding using Huffman code and appending bits for the binary representation of the amplitude. AC coefficients undergo a zig-zag scan to facilitate entropy coding. A codeword is assigned to each non zero coefficient with the help of the AC code table.

Decompression is just the reverse of the compression process and has three main stages namely decoding, de-quantisation and inverse DCT.

3.3 JPEG2000 Compression

JPEG2000 is a filter based standard for compressing still images using the Discrete Wavelet Transform. The wavelet transformation performs low pass and high pass filtering on a signal and decimates it to obtain two or more sub bands. To obtain multi-levels of the wavelet transform, the above process has to be repeated. Figure 5 shows this process.

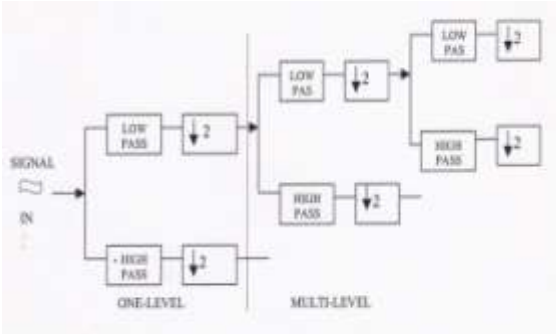

Figure 5 Signal Decomposition by Low Pass and High Pass Filtering

The down arrow indicates down sampling (decimation) and the down sampling factor (2) corresponds to the number of filters.

Applying the wavelet transform on an image compacts its energy into relatively small number of coefficients and splits it into four sub bands; low (LL), middle (LH, HL) and high (HH) frequencies. The coefficients in the sub bands are known as scaling, vertical, horizontal and diagonal coefficients respectively. The low frequency sub band or scaling coefficients have the most energy while the high frequency sub band or diagonal coefficients have the least energy. Figure 6 shows a two level decomposition of Lena's image.

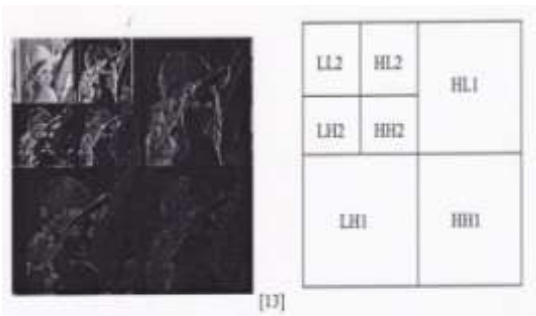

Figure 6 Two level Decomposition of Lena(Meerwald, at www.cosy.sbg.ac.at)

The Daubechies 9/7 wavelet filter is the most commonly used filter for wavelet transformation. (IEEE, 2001)

3.3.1 JPEG2000 CODEC

The compression process in the JPEG2000 coder is a three part process involving; Pre-processing, Core-processing and bit stream formation.

Pre-processing: Is a three- step process that is done prior to performing the DWT and involves image tiling, dc level shifting and component transformation. The image is partitioned into rectangular blocks called tiles which are processed independently. Samples of the image tiles are converted to two's complement through a step called dc level shifting. Component transformations are then applied to improve compression.

Core Processing: This is the main processing which involves performing the forward DWT on the tile components by means of low pass and high pass filtering and categorizing the resulting coefficients into different sub bands. Low pass samples are the low-resolution components while high pass samples are the high resolution components. The DWT coefficients are then quantized (reduced in Precision). Quantisation is lossy and the resulting coefficients are integers.

Bit Stream Formulation: Each sub band of the quantised wavelet decomposition is divided into rectangular blocks of size 64x64 called Code Blocks. These serve as inputs to the entropy coder and are coded a bit plane at a time. The coding employed here is Arithmetic coding. Entropy coding enables formation of separate bit stream for each code block.

The decoding process is simply the reverse of encoding as illustrated in Figure7

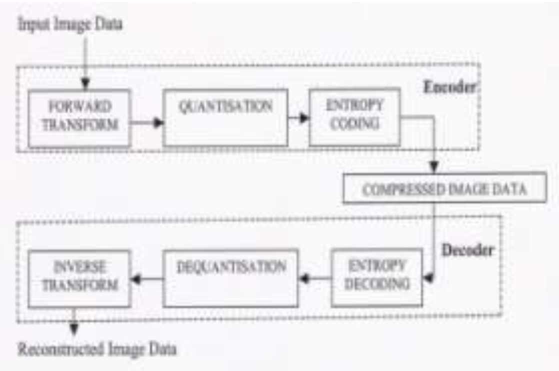

Figure 7 JPEG2000 CODEC

3.4 Quality/Distortion Measures

Distortion measures between the input and the output of a processing system can be either subjective or objective. In compression peak signal to noise ratio (PSNR) measures are used to estimate the quality of the reconstructed image compared with the original image. Compression ratio is also used as a measure of compression performance. Distortion is the mean square error (MSE) which is the averaged term-by-term difference between the input and output. The following mathematical expressions are used to arrive at distortion and quality measures.

$$MSE = \frac{1}{NM} * \sum_{i} \sum_{j} [F_r(i,j) - F(i,j)]^2 \quad (8)$$

where: F(i,j) is the original image
Fr(i,j) is the reconstructed image
i = 1,2,3…N (rows) and
j = 1,2,3…M (columns)

$$PSNR = 10log_{10}\left(\frac{256^2}{MSE}\right) \ decibels \quad (9)$$

Computations are done on the luminance signal only, thus pixel values range between black (0) and white (255). Images with high PSNR may not necessarily look better than those with low values hence the relevance and importance of the subjective measure.

For this work, the point of focus is how compression affects watermarked images to determine whether watermarks are present after compression. Another point of focus is to assess which of the two compression standards performs best on watermarked images.

4. DIGITAL WATERMARKING ALGORITHMS DESIGNED

The main objective was to perform digital watermarking of a still image by image/logo fusion, which is non-blind and imperceptible. This entails that the Watermark is in form of an image or logo and carries meaningful data. The advantages of using such a watermark are: a human observer can easily compare the extracted watermark with the original, thus eliminating the occurrence of false positive or negative detection that is prevalent in correlation. In addition, the existence of a visual image or logo in the watermarked image is better proof of ownership than a statistical correlative value.

The algorithms were developed using three methods, that is; linear addition, least significant bit replacement and correlation based method.

4.1 Linear Additive Method

Watermarking was performed by addition of a watermark in the form of an image to a scaled version of the original image. Both the host image and watermark were the same size and had to be transformed to the frequency domain using the DWT transform before addition. Linear addition was performed as follows:

$$I_w(m,n) = [I(m,n) * \alpha] + W(m,n) \quad (10)$$

where; I_w(m,n) are the coefficients of the watermarked image, I(m,n) and W(m,n) are the coefficients of the original image and watermark respectively. A is an amplification (scaling) factor.

All subbands were used to add the watermark. Placing the watermark in the most important low frequency band enhances the robustness of the watermark and entails that tempering of the watermark will mean tempering with the actual image. Thus an attacker's attempt to destroy the watermark destroys the image as well. Figure 8 shows the stages in Linear Additive Digital Watermarking and extraction process.

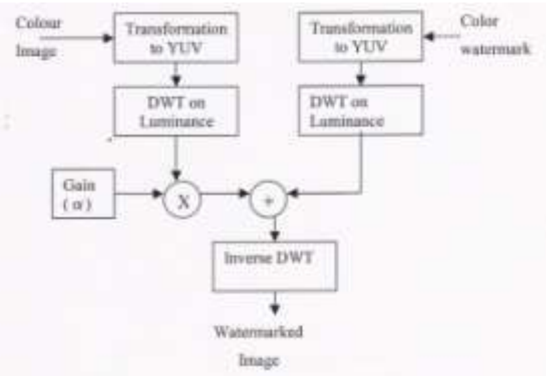

Figure 8A)Stages in Linear Additive Digital Watermarking

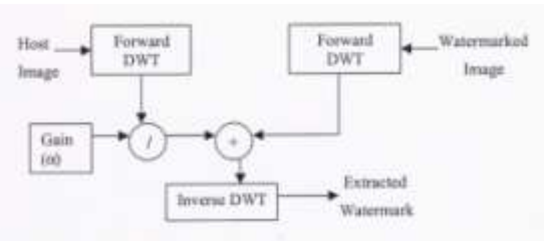

Figure 8B) Stages in Extraction of Linear additive method

4.2 Least Significant Bit Method

Watermarking was achieved by replacing the least significant bit (LSB) of the largest coefficients of the host image with the most significant bits (MSBs) of the largest coefficients of the watermark. To improve watermarked image quality, the number of coefficients of the watermark were varied. The host image and the watermark were the same size and had to be changed to black and white (8 bits per pixel) before transformation to the wavelet domain. For each coefficient, the three LSBs of the host image were discarded by setting to zero to facilitate MSB replacement. A bit shift was performed on the watermark so that the MSBs take the position of the LSBs and vice versa. The MSBs of the watermark were then added to the LSBs that were set to zero.

Extraction of the watermark was achieved by use of two vectors, one with the indices of where the hidden bits are located in the watermarked image and the other with indices of where the hidden bits go in the extracted watermark. Stages in the LSB method are shown in Figure 9.

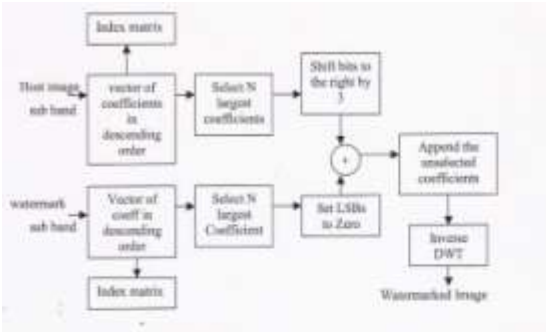

Figure 9 Stages in LSB method

4.3 Correlation Based Method

A watermark that is smaller in size compared to the host image, of bitmap file format and comprising the name 'ANNA', that serves as a unique identity for proving ownership of the image was used.

The watermark was first converted to a logical matrix of ones and zeros and then transformed to a vector having a pattern of ones and zeros. Based on the 1-0 pattern of the watermark vector, watermarking was performed by adding a pseudorandom noise patter (PN) to the horizontal and vertical sub bands of the host image, if and only when the values of the watermark vector element was a zero and leaving the sub bands unaffected when the element was a one. The strength of the watermarking was varied by multiplying the PN with a gain K. The PN was generated by a random number generator based on a pre- defined seed (key) and was of the same size as the sub bands.

Watermark extraction was achieved by correlating the PN with the horizontal and vertical sub bands of the watermark image. A new vector of ones the same size as the watermark vector was generated and correlation performed based on the length of the watermark vector and following the PN addition procedure. Thus, the ones in the new vector changed to zeros each time the PN was detected resulting in a retrieved vector identical to the watermark vector. The retrieved vector was converted back to the logical matrix and then displayed as the extracted watermark. A threshold was used for detection, which is the mean of all correlation values. The process of watermarking by correlation based method is shown in Figure 10.

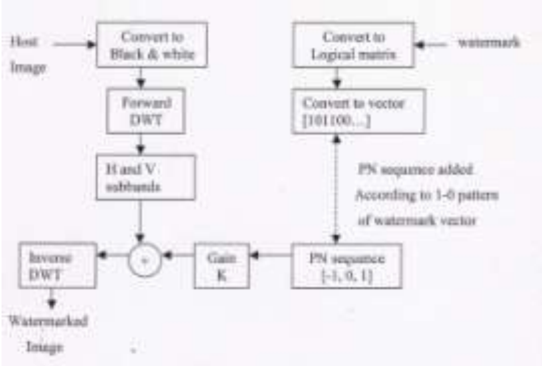

Figure10 Watermarking by correlation based method

4.4 Compression Method

Having achieved watermarking, the other objective was to test for robustness of the watermarking against compression. To fully appreciate the effects of compression on watermarking, it is more meaningful to compare two different standards and analyse their performance. For compression, the following approach was taken:

- The Lurawave smart compress software was used to compress watermarked images using JPEG and JPEG2000 compression standards. The images were saved at a range of compression rates to cover the spectrum of compression ratios. Five image files compressed at different rates were obtained per standard.
- The performance of the two standards were assessed by comparing the quality of the compressed outputs and the peak signal to noise ratio (PSNR)
- For all compressed outputs, the extraction algorithms were applied to retrieve the watermark. Subjective quality assessments and PSNR measures of the extracted watermarks were taken to compare the performance of the two standards.

It is worth noting that these approaches are not just confined to watermarking of still images, they can also be adopted for watermarking of video images, probably with a few modifications.

5. WATERMARKING AND COMPRESSION RESULTS

The primary objective was to watermark a digital image in the wavelet domain by image or logo fusion and satisfy the following requirements:

(i) The watermarked image should not be visibly degraded by the watermark.
(ii) The watermark should be imperceptible to the human observer.
(iii) The watermark should be robust against compression.

5.1 Linear Additive Algorithm

The original (host) image used was that of lady Tiffany and the watermark was an image of peppers, shown in Figure 11. Watermarking was achieved by fusing the peppers inside Tiffany by linear addition.

Figure 11Host Image and watermark

5.1.1 Quality and Imperceptibility Assessment

Watermarking: The quality of the watermarked image and the imperceptibility were governed by a scaling factor α. For α<30, the watermark could be perceived by the human visual power. When α was increased to 30, the watermark was completely imperceptible.

Linear addition yielded a watermarked image of Tiffany of the same quality as the original image and the watermark was imperceptible to the human observer at scaling factors greater than or equal to 30. Figures12A and 12B show results obtained at scaling factors of 5 and 30 respectively.

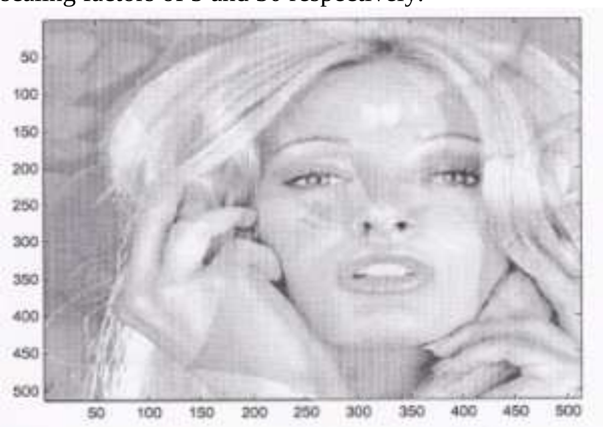

Figure 12A) Watermarked Image – α=5

Figure 12B) Watermarked Image – α=30

Extraction: The quality of the extracted watermark was very good at α=5, although covered by a shade of grey and the edges of the host image being perceived. This is shown in Figure 13A). When α was increased to 30, the quality was poor, however, the peppers could still be perceived by the human visual system as shown in Figure 13B). The watermark could still be useful for proof of ownership.

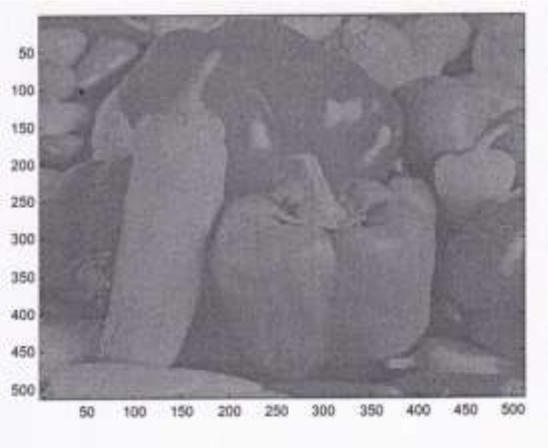

Figure 13A) Extracted Watermark – α=5

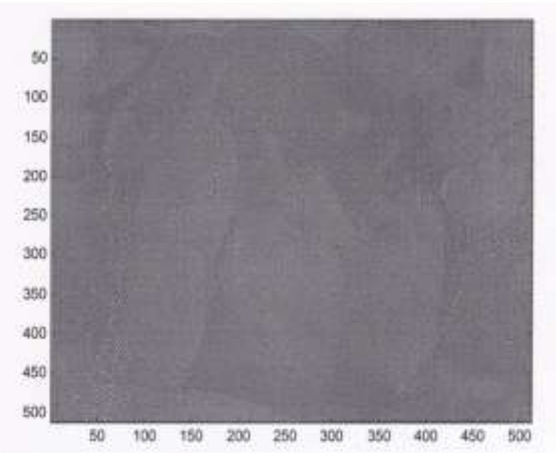

Figure13B) Extracted Watermark – α=30

5.1.2 Objective Measures

Objective measures of the watermarked image and the extracted watermark were obtained by calculating the peak signal to noise ratio (PSNR) using Mat lab code. At α=5, the PSNR of the watermarked image was low while that of the extracted watermark was high. For α=30, the PSNR value o the watermarked image increased while that of the watermark was low. Table 1summarises the results.

Table 1PSNR measures at different scaling factors.

IMAGE TYPE	PSNR (dB)	
	α=5	α= 30
Watermarked image (Tiffany)	11.07	27.23
Extracted watermark (peppers)	22.16	7.11

For low values of α, the error (noise) in the watermarked image was high, while for high values of α, the error reduced. This is due to the fact that small values of α decrease the strength of the host image while increasing that of the watermark and when high values of α are used, the opposite is achieved. This ties in well with the subjective (quality) measure.

5.2 Least Significant Bit Substitution

The same image for the host and watermark as in the Linear Additive approach were used. The least significant bits (LSBs) of the host image were replaced by the most significant bits (MSBs) of the watermark.

5.2.1 Quality Assessment and Imperceptibility

The quality of the watermark depended on the number of elements of the watermark that were embedded in the host image, as well as the number of LSBs replaced by the MSBs of the watermark. Two cases were considered as follows:

Case 1: Number of elements = 130 x 130 coefficients. First, 3 LSBs were used for watermark embedding and the results obtained after watermarking and extraction are shown in Figure 14.

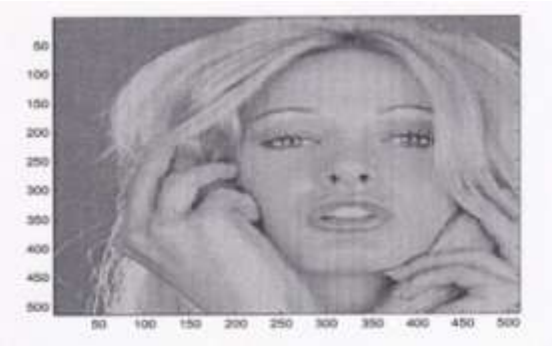

Figure 14A) Watermarked Image – Coefficients = 130 x 130 (3 LSBs)

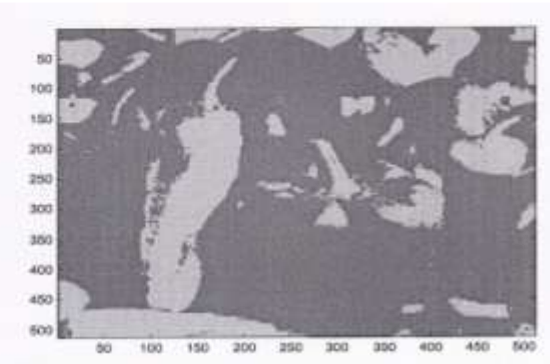

Figure 14B) Extracted Watermark – Coefficients = 130 x 130 (3 MSBs)

The quality of the watermarked output was good although the edges were not very smooth. The extracted watermark was slightly poor as the image was dominated by dark patches which hid some of the details. However, it was very easy for the human observer to tell what the image represented hence, the extracted watermark was sufficient for proof of ownership. Imperceptibility was achieved since the embedded watermark could not be perceived from the watermarked output.

When the LSBs were increased to 6 while maintaining the same number of elements, the quality of the watermarked output was degraded while that of the watermark remained the same as before. Although the watermarked output was imperceptible, the degraded watermarked output would create suspicion to an attacker who may easily guess that the image was watermarked and look for ways to remove the watermark. Results obtained for LSB = MSB = 6 are shown in Figure 15.

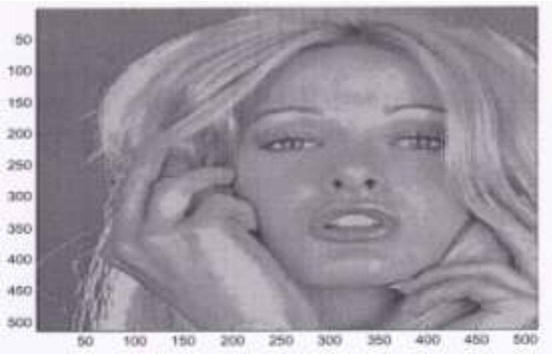

Figure 15A) Watermarked image – Coefficients = 130 x 130 (LSB = 6)

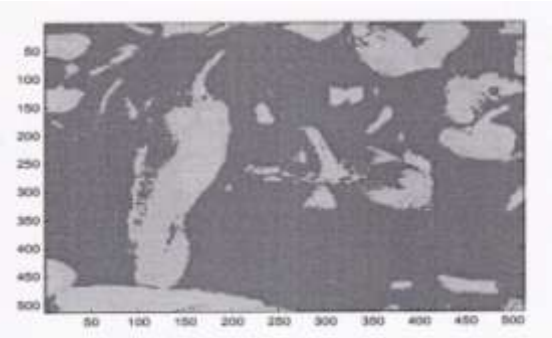

Figure 15B) Extracted Watermark – Coefficients = 130 x130 (MSB = 6)

Case 2: Number of Elements = 256 x 256 (all coefficients). When all the coefficients and 3 LSBs were used for watermarking, the quality of the extracted watermark improved tremendously. However, that of the watermarked image of Tiffany was slightly degraded and the edges were not smooth. When the LSBs were increased to 6, the quality of the watermarked image of Tiffany was further degraded and could not serve any useful purpose. The extracted output however was very good. Results are shown Figure 16.

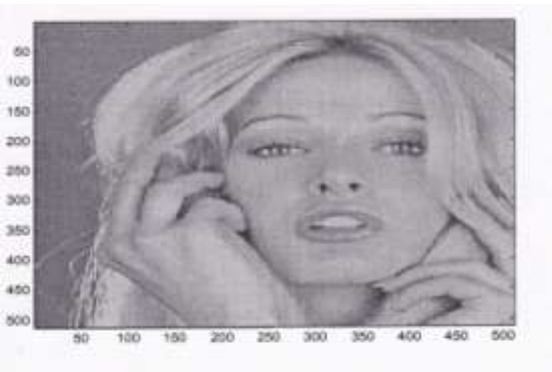

Figure 16A) Watermarked Image – 256 x 256 coefficients (3 LSBs)

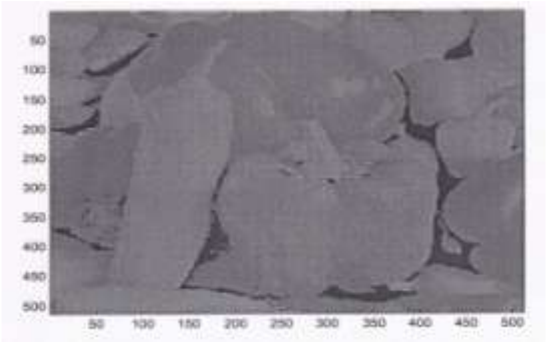

Figure 16 B) Extracted Watermark – 256 x 256 coefficients(3 MSBs)

Figure 16C) Watermarked Image(6 LSBs) and Extracted Watermark (6 MSBs) – 256 x 256 coefficients

A compromise had to be reached on the number of coefficients of the watermark and bits used for watermarking. 130 x 130 coefficients with a replacement of 3 LSBs was most appropriate.

5.2.2 Objective Measures

The PSNR values indicate the amount of distortion in the images. The higher the value, the less the error or distortion and the better the quality of the image. The lower the value of PSNR, the more the image was distorted, hence the more degraded the image appeared. Table 2 displays the results.

Table 2 PSNR values of LSB watermarking

Image Type	PSNR (dB)			
	Elements = 16900		Elements = 65536	
	3 LSBs	6 LSBs	3 LSBs	6 LSBs
Watermarked Image	30.23	26.39	30.17	24.86
Extracted Watermark	16.81	17.86	19.11	21.51

The PSNR of the watermarked image was high when fewer coefficients (16 900) and 3 LSBs of the watermark were used for watermarking, while PSNR of the watermark was high when more coefficients (65 536) and 6 LSBs were used. This is in agreement with the results of the quality measures obtained.

5.3 Correlation Based Watermarking

A different watermark was used comprising of a small logo with the name ‘ANNA’ shown in Figure 17. This represented the name of the owner of the image and was stored as a bit map file.

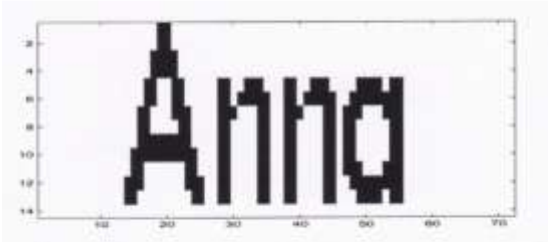

Figure 17 Watermark used in correlation based method

5.3.1 Quality and Imperceptibility Assessment

The quality of the watermarked image was governed by the gain applied to the watermark. Increasing the gain makes the watermark strong and vice versa. Again of 0.5 gave the best quality of the watermarked image, which was identical to the original image of Tiffany. When the gain was increased to values greater than 2, the quality of the image began to deteriorate. Figures 18 A) and B) shows the results obtained at gains of 0.5 and 10 respectively.

Figure 18A) Watermarked Image – Gain = 0.5

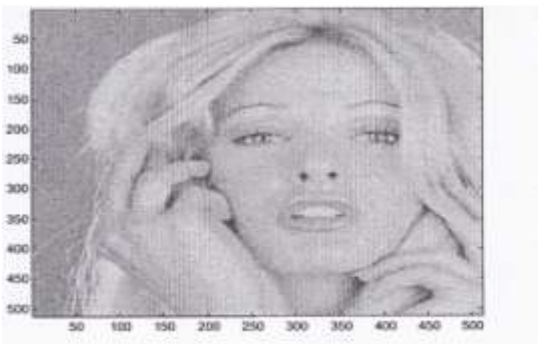

Figure 18B) Watermarked Image – Gain = 10

Imperceptibility of the embedded watermark was achieved at low gains. At high gains, the watermarked image appeared to have been affected by noise. The extracted watermark is shown in

Figure 19.

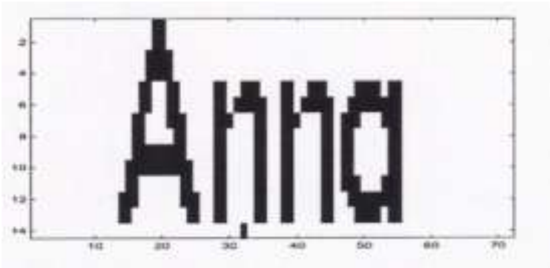

Figure 19A)Extracted watermark – Gain = 0.5

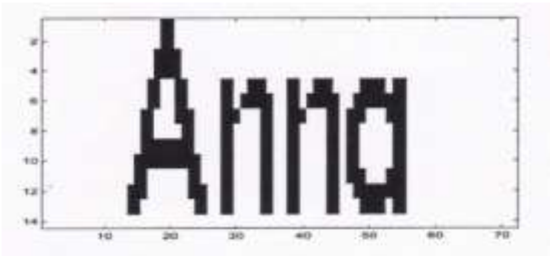

Figure 19B) Extracted watermark – Gain = 10

The quality of the extracted watermark is excellent at both low and high gains.

5.3.2 Objective Measures

PSNR was calculated for both the watermarked image and extracted watermark as shown in Table 3.

Table 3 PSNR values of Correlation based watermarking

Image type	PSNR (dB)	
	Gain = 0.5	Gain = 10
Watermarked image	37.31	25.27
Extracted watermark	102.35	∞

When the gain was increased, the extracted watermark was the exact replica of the embedded watermark, hence the infinite value obtained for PSNR. The PSNR was also very high at the low gain of 0.5, which indicated that there was very minimal distortion in the extracted watermark. The error in the watermarked image increased as the watermark was made stronger (at gain = 10)

5.4 Effects of JPEG and JPEG2000 Compression

The other objective of this study was to determine whether the watermarking achieved was robust against compression. The performance of JPEG and JPEG2000 on watermarked images was also compared. Two watermarked images obtained from the LSB and correlation based methods were used. It was not possible to save the watermarked output from the linear additive method to a file that was supported by the Lurawave software used for compression.

5.4.1 Results for the Least Significant Bit Method

When both JPEG and JPEG2000 were applied on the watermarked image of Tiffany, the embedded watermark could be retrieved at both low and high compression rates with slight variations in quality. The watermark could still be identified as an image of peppers. The results obtained for JPEG and JPEG2000 at different compression rates are shown in Figure 20.

Rate – 1:5 Rate – 1:29 Rate – 1:67

Figure 20A) LSB based retrieved watermark after JPEG compression

Rate – 1:5 Rate – 1:29 Rate – 1:67

Figure 20B) LSB based retrieved watermark after JPEG2000 compression

The LSB method is commonly used in the spatial domain and yields watermarking that does not survive compression. However, applying it in the wavelet domain results in watermarking that is robust against compression. Table 4 summarises results for JPEG and JPEG2000 compression on watermarked images using 3 LSBs and 130 x 130 coefficients. This includes the PSNR measures of the retrieved watermarks after compression, which is used to compare the performance of the two standards.

Table 4 JPEG and JPEG2000 compression results – LSB

Q-JPEG	RATE	PSNR OF RETRIEVED WATERMARK (dB)	
		JPEG	JPEG2000
90	1:5	29.00	29.01
30	1:22	28.98	29.00
20	1:29	28.97	28.98
10	1:43	28.95	28.96
1	1:67	28.93	28.94

The results show minimal differences in PSNR values between the watermarks retrieved prior to compression and those retrieved after compression, where the former had a value of 30.23dB. Hence, the quality of the watermark was not adversely affected by compression.

5.4.2 Results for Correlation Based Method

The watermarked output used for compression was that for the gain at 0.5 since it had superior quality. The correlation based method resulted in watermarking that was robust at rates less than 1:18. At higher compression rates, the name 'ANNA' was completely distorted as shown Figure 21.

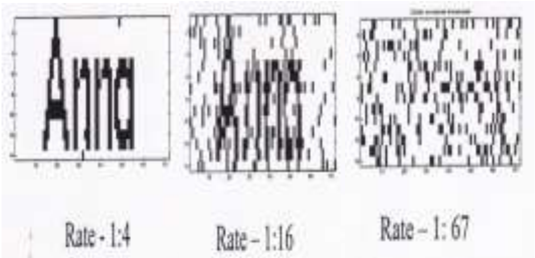

Figure21A) Correlation based retrieved watermark after JPEG compression

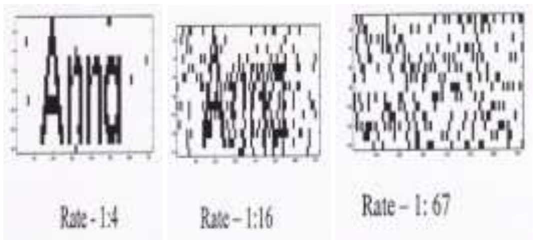

Figure 21B) Correlation base retrieved watermark after JPEG2000 compression

Table 5 summarises results of the retrieved watermarks after JPEG and JPEG2000 compression.

Table 5 JPEG and JPEG2000 compression results – Correlation based

Q-JPEG	RATE	PSNR OF RETRIEVED WATERMARK (dB)	
		JPEG	JPEG2000
90	1:4	97.58	97.81
50	1:16	80.14	81.47
20	1:27	77.58	78.95
10	1:41	73.77	74.71
1	1:67	70.01	72.02

5.5 Performance of JPEG and JPEG2000

Below are the PSNR profiles derived from the PSNR values of the watermarks retrieved after compression that compare the performance of the two standards on watermarked images.

The profiles for the LSB method indicate that JPEG2000 out performs JPEG compression. However, for both standards, the embedded watermark was retrieved and could be easily perceived by the human visual system. The profiles for the correlation based method are almost at par, with JPEG2000 performing slightly better than JPEG as shown in Figure 22.

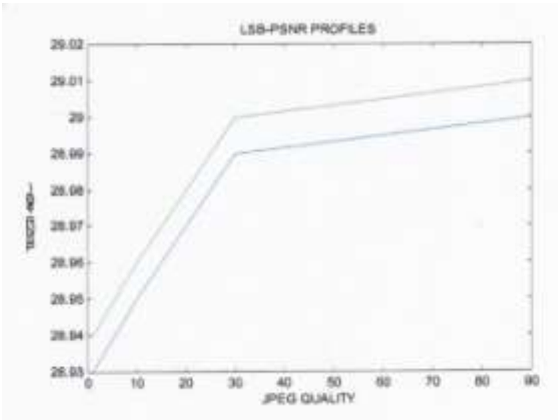

Figure22A)PSNR Profiles for LSB Watermarking

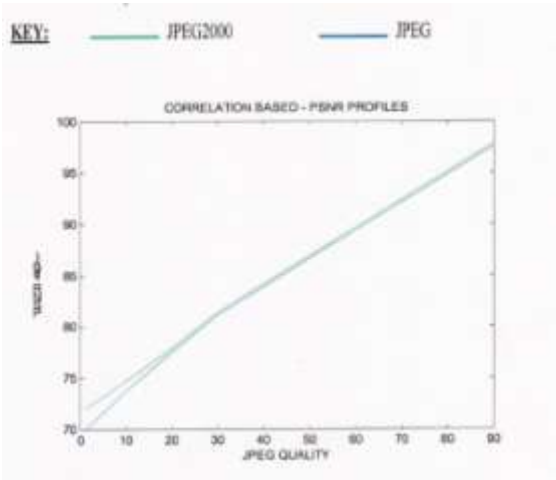

Figure 22B)PSNR Profiles for Correlation Based Watermarking

The results obtained clearly indicate that digital watermarking by image fusion was achieved for both linear additive and LSB approaches. Digital watermarking by logo fusion was achieved with the correlation based approach. In all cases, a good quality output and imperceptibility were achieved by varying parameters such as gain, scaling factor, number of LSBs and coefficients. Robustness against compression was achieved with the LSB method at both low and high compression rates while with the correlation based method, it was achieved at low rates.

5.6 Industry Survey

The industry survey on digital watermarking and the use of JPEG2000 in industry was conducted through a questionnaire and research on the web. Thirty (30) companies were contacted and for reporting purposes, the information and views obtained from six (6) companies are presented.

5.6.1 Digital Watermarking at Signum Technologies

The company provides a range of advanced digital watermarking solutions for data authentication and integrity applications. One of their advanced technologies is *signumveri*-data technology used for law enforcement, e-commerce and medical imaging.

5.6.2 Digital Watermarking at Sarnof Corporation

The corporation is involved with the development of watermarking and data hiding techniques for commercial and government clients and also development of tracking watermark suitable for digital camera. They developed a watermark that can be recovered from a pirated copy of a motion picture that was obtained by recording the movie off the theatre screen with a camcorder and then subsequently compressing the movie for internet distribution. They have developed two main watermarking namely; General purpose video watermark and secure robust forensic watermark.

5.6.3 Digital Watermarking at Kodak

The company implements watermarking aimed at protecting digital pictures to discourage and prevent theft of pictures and also making them more useful to the owners. The forms of watermarking they are implementing are: identification card security, intelligent cameras and image tagging.

5.6.4 Views from Digital Imaging Centre

Digital Imaging Centre deals with video production/editing, video compression and image production for web/print. They are using JPEG, MPEG and MPEG2 due to the benefit of portability (ease of use across applications) that these standards offer. They have challenges using MPEG2 due to the vagueness of the universal DVD standards (in practice) for MPEG2 and thus feel that this needs to be seriously addressed. They have not yet considered the new standards JPEG2000 and motion JPEG2000. To protect their digital content from copy or interception they have been using time-code burn until master purchased, but are willing to use digital watermarking for protecting their images and video.

5.6.5 Views from Image Processing Techniques

Image processing techniques provide products and electronics design service for the professional video and broadcast television markets. They are also involved in professional video system and product design for both high definition and image processing systems. They deal with uncompressed images and video to preserve quality as per customer requirement. This is giving them challenges in terms of storage space and data transfer rates since high bandwidth is required for uncompressed images and video. They are not using compression standards and do not require watermarking, however, they are keeping an eye on JPEG2000 to see if any in the television broadcasting arena would be interested in switching from MPEG.

5.6.6 Views from Re-Vision Effects Incorporation

Re-Vision effects produce software for 2-D and 3-D video and image processing. This does not require use of compression standards and digital watermarking. However, they are of the view that JPEG2000 as well as MPEG4 are not being used by many companies due to the issue of licensing fees.

6. CONCLUSION

The aim of this work was to perform digital image watermarking in the discrete wavelet transform domain. The watermarking scheme developed was expected to fulfill the following requirements of watermarking: that the watermarked image was not visibly degraded by the watermark, the watermark was imperceptible to the human observer and finally, the watermark was robust against compression.

All the three algorithms developed, that is, linear additive, least significant bit and correlation based satisfied the first two requirements. The linear additive approach could not be tested for robustness due to failure to save the watermarked output to a compressible file format. Thus only the LSB and correlation based approaches were considered. The watermark embedded using LSB method was robust against compression at both high and low rates while that embedded by correlation based approach was only robust at compression rates less than 1:18.

The industry survey not only underscored the relevance of digital watermarking, but also its importance by bringing to the fore the different areas of application namely; law enforcement, e-commerce, medical imaging and forensics

This work only focused on digital watermarking of grey scale still images in the wavelet domain. Future work can be done in the following aspects: digital watermarking of colour images, digital watermarking in Regions of Interest (ROI) and digital watermarking of video sequences.

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