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Reversible watermarking mechanisms - a new paradigm in image security

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Abstract: This paper, discuss the features and concepts pertaining to the three popular visible reversible watermarking algorithms and analyze them to evaluate with metrics such as MSE and PSNR values based on implementation i.e. a) Wavelet based watermarking technique b) Tian's difference expansion technique c) LSB-prediction error expansion technique. It is recommended to adopt new reversible data-embedding technique called *Least Significant Bit prediction-error expansion* which exploits the correlation inherent in the neighborhood of a pixel and provides an effective method for data embedding than the difference-expansion wavelet based schemes. Reversibility aspect ensures image verification, security , lossless embedding and also extraction of images during the damage of source images itself (*i.e*., image recovery process).
Keywords: Watermark, data embedding, data security.

Introduction

Multimedia data has become much easier to access due to the rapid growth of the Internet. While this is usually considered an improvement in everyday lifestyle, it also makes unauthorized copying and distributing of images, data much easier, therefore presenting a challenge in the field of copyright protection.

Many solutions are there to solve this problem *e.g*., digital signatures. But these solutions need additional bandwidth (Miller *et al*., 2000; Lebrun *et al*., 2001). Due to limitations of the traditional copyright protection system, a new technique came into existence. This technique is known as digital watermarking. Fig.1 shows the motivations behind digital watermarking that increases the security of watermarks and digital contents (Tseng *et al*., 2002; Diljith *et al*., 2007).

Digital watermarking (Cox *et al*., 2001; Ghouti *et al*., 2006) is a method of embedding useful information into a cover image (i.e. image, video or audio) for the purpose of copy control, content authentication, distribution tracking, broadcasting monitoring etc (Fridrich *et al*., 2002). There are plenty of methods which ensures the embedding and extraction of images resulting in a reversible process (Rafael *et al*., 2004; Kamstra & Heijmans, 2005). Watermarking is often used whenever the cover is available to the parties and for whom the existence of the hidden data matters and may have an interest in removing it for confidential transactions.

Also referred to as simply watermark, a pattern of bits inserted into a digital image, audio, video or text file that identifies the file's copyright information (author, rights, etc.). Researchers try to invent techniques that increase the security, capacity, and Imperceptibility of watermarked images. The watermark must be robust enough to resist common image processing attacks and not be easily removable; only the owner of the image is able to extract the watermark. This paper assesses a new image watermarking technique that can embed more number of watermark bits in the cover image without affecting the imperceptibility.

Figure 1 Motivations behind digital watermarking

Fig. 2. Wavelet basis

Algorithms

Wavelet based Watermarking Algorithm

A *wavelet* is a mathematical function (Keinert, 2004) used to divide a given function or continuous-time signal into different frequency components and study each component with a resolution that matches its scale. A *wavelet transform* is the representation of a function by wavelets. The wavelets are scaled and translated copies (known as "daughter wavelets") of a finite-length or fast-decaying oscillating waveform (known as the "mother wavelet"). Wavelet transforms have advantages over traditional Fourier transforms for representing functions that have discontinuities and sharp peaks, and for accurately deconstructing and reconstructing finite, non-periodic and/or non-stationary signals (Martin *et al*., 2001).

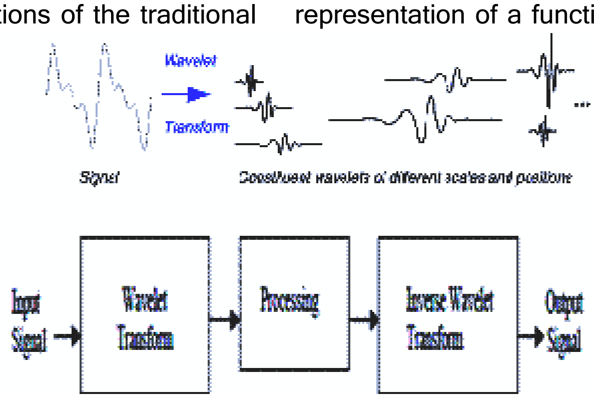


Fig.3. Wavelet scales and signal processing application using wavelet transform

Wavelet basis: The fundamental idea behind wavelets is to analyze according to scale (Petitcolas *et al.*, 1999). Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. However, in wavelet analysis, the *scale* that we use to look at data plays a special role. Wavelet algorithms process data at different *scales* or *resolutions.* If we look at a signal with a large window, we would notice gross features. Similarly, if we look at a signal with a small window, we would notice small features. The result in wavelet analysis is to see both the forest *and* the trees.

Wavelet function: The wavelet only has a time domain representation as the wavelet function ψ(t). For instance, Mexican hat wavelets can be defined by a wavelet function (Fig. 2, 3).

A wavelet is a waveform of effectively limited duration that has an average value of zero. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelet of the original signal.

- Wavelet transform decomposes a signal into a set of basis functions (Fridrich *et al.*, 2002).
- These basis functions are called *wavelets.*
- Wavelets are obtained from a single prototype wavelet *y(t)* called mother *wavelet* by *dilations* and *shifting.*

where *a* is the scaling parameter and *b* is the shifting parameter.

$\Psi_{a,b}(t)=(1/\sqrt{a})\psi(t-b/a)$

An advantage of wavelet transforms (Strela *et al.*, 1999) is that the windows *vary.* In order to isolate signal discontinuities, one would like to have some very short basis functions. Fig. 3 shows the coverage in the time-frequency plane with one wavelet function, the Daubechies wavelet (Fig. 4). Wavelet transforms have an infinite set of possible basis functions. Thus, wavelet analysis provides immediate access to information that can be obscured by other time-frequency methods such as Fourier analysis.

Multi-Resolution analysis using filter banks: Filters are one of the most widely used signal processing functions. Wavelets can be realized by iteration of filters with rescaling. The resolution of the signal, which is a measure of the amount of detail information in the signal, is determined by the filtering operations, and the scale is determined by up sampling and down sampling (sub sampling) operations. The Discrete Wavelet Transform is computed by successive low pass and high pass filtering (Fig. 6, 7). The signal is denoted by the sequence x[n] decomposing in to approximations and details i.e. the low pass filter is denoted by G_0 while the high pass filter is denoted by H_0.

The filtering (Strela *et al.*, 1999) and decimation process is continued until the desired level is reached. The maximum number of levels depends on the length of the signal. The DWT of the original signal is then obtained by concatenating all the coefficients, a[n] and d[n], starting from the last level of decomposition.

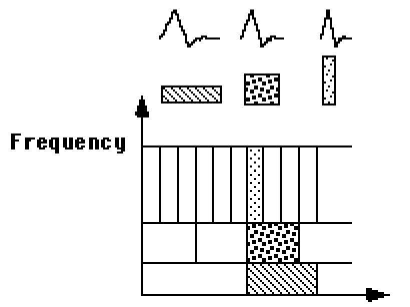


Fig. 4. Wavelet expression & Daubechies wavelet basis functions: coverage of the time-frequency plane.

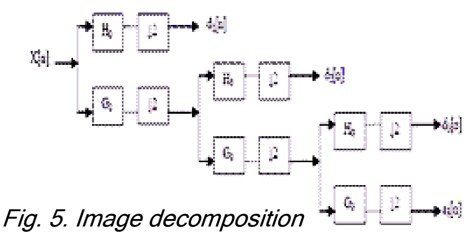
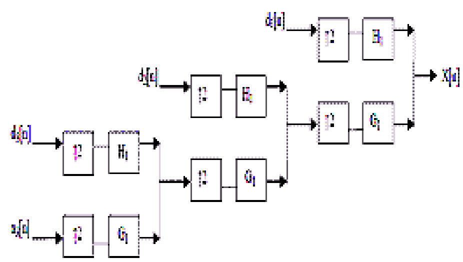


Fig. 5. Image decomposition and re-construction



Tian's difference expansion method.

A reversible watermarking algorithm with very high data hiding capacity (Van der Veen *et al.*, 2003) has been developed for color images. The Tian's algorithm allows the watermarking process to be reversed, which restores the exact original image. The algorithm hides several bits in the difference expansion of vectors of adjacent pixels (Tian, 2002). The required general reversible integer transform and the necessary conditions to avoid underflow and overflow are derived for any vector of arbitrary length. Also, the potential payload size that can be embedded into a host image is discussed, and a feedback system for controlling this size is developed. In addition, to maximize the amount of data that can be hidden into an image, the embedding algorithm can be applied recursively across the color components. Simulation results using spatial triplets, spatial quads, cross-color triplets, and cross-color quads are presented and compared with the existing reversible watermarking algorithms (Petit Colas *et al.*, 1999).

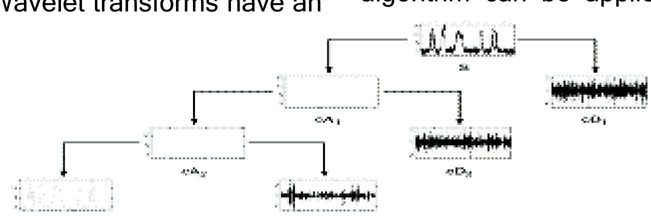


Fig.6.Discrete wavelet transformation / de-noising/compression

These results indicate that the spatial quad-based algorithm allows for hiding the largest payload at the

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highest Peak -signal-to-noise ratio (PSNR) (Van der Veen *et al.*, 2003).

Here, we extend Tian's algorithm using difference expansion of vectors, instead of pairs, to increase the hiding ability and the computation efficiency of the algorithm. This approach allows the algorithm to embed several bits in every vector in a single pass through the image data.

Generalized difference expansion: Vector: the vector u= (u_0 ,u_1 ,.........., u_{N-1}) is formed from pixel values chosen from different locations within the same color component according to a predetermined order (Diljith *et al.*, 2007). This order may serve as a security key. The simplest way to form this vector is to consider every set of a adjacent pixel values as shown in Fig. 7 as a vector. The width and the height of the host image, respectively, then $1 \le a \le h$, $l \le b \le w$, and $a+b\neq 2$ (Tian, 2002).

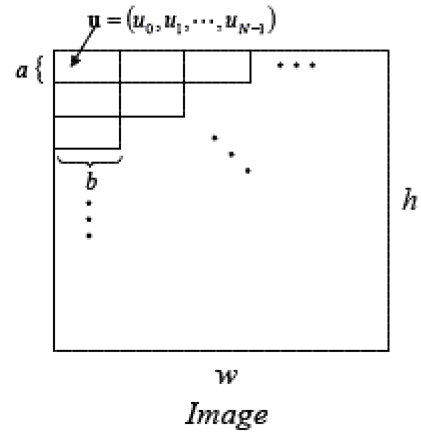

Fig. 7. Vector configuration in an image

For simplicity, we require that each color component be treated independently and, hence, have its own set of vectors. Also, we require that vectors do not overlap each other i.e., each pixel exists in only one vector. These requirements may be removed at the expense of complicating the watermarking algorithm due to the extra caution required to determine the processing order of the overlapped vectors (Lin et *al.*, 2005).

Reversible Integer Transform: The forward difference expansion transform, for the vector is defined as:

$$v_0 = \left\lfloor \frac{\sum_{i=0}^{N-1} a_i u_i}{\sum_{i=0}^{N-1} a_i} \right\rfloor$$
$$v_1 = u_1 - u_0$$
$$\vdots$$
$$v_{N-1} = u_{N-1} - u_0 .$$

u= ($u_{0,}$ $_{u1,}$..... u_{N-1})

Where [.] is the least nearest integer, and is constant integer. Obviously, v_0 is the weighted average of the entities of the vector u, while $v_{1,}$ $_{V2}$, ...,v_{N-1} are the differences between u_1 ,$u_{2,}$ .... , u_{N-1} and u_0 respectively .The inverse difference expansion transform, for the transformed vector (Lin *et al.*, 2005) , v=(v_0 ,v_1 ,........, v_{N-1}) as defined as (Fig.8):

$$u_0 = v_0 - \left\lfloor \frac{\sum_{i=1}^{N-1} a_i v_i}{\sum_{i=0}^{N-1} a_i} \right\rfloor$$
$$u_1 = v_1 + u_0$$
$$\vdots$$
$$u_{N-1} = v_{N-1} + u_0 .$$

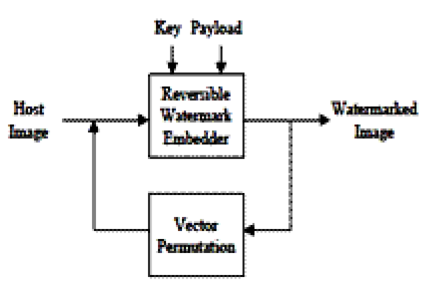

Fig.8. Recursive embedding of the reversible watermark

The DE embedding technique involves pairing the pixels of the host image and transforming them into a low-pass image **L** containing the integer averages and a high-pass image **H** containing the pixel differences **h**. If a and b be the intensity values of a pixel-pair, then 'l' and '**h**' are defined as

l = [(a + b) /2] (1)

h = a – b (2)

a= l + [h+1)/2] (3)

b =l – [h/2] (4)

This transformation is invertible, so that the gray levels **a** and **b** can be computed from **l** and **h.** Appending it to the LSB of the difference, thus creating a new LSB embeds an information bit. The watermarked difference is $h_w = 2h + i$ (5)

Apart from the DE embedding technique, Tian's algorithm also uses an embedding technique called LSB replacement. In the LSB-replacement embedding technique, the LSB of the difference is replaced with an information bit. This is a lossy embedding technique since the true LSB is overwritten in the embedding process. However, in Tian's scheme, the true LSBs of the differences that are embedded by LSB-replacement are saved and embedded with the payload, to ensure lossless reconstruction.

Least significant bit prediction eror expansion method.

The most straightforward method of watermark embedding would be to embed the watermark into the least significant bits of the cover object. Given the extraordinarily high channel capacity of using the entire cover for transmission in this method, a smaller object may be embedded multiple times. Even if most of these are lost due to attacks, a single surviving watermark would be considered a success. LSB substitution however despite its simplicity brings a host of drawbacks. Although it may survive transformations such as cropping, any addition of noise or lossy compression is likely to defeat the watermark.

An even better attack would be to simply set the LSB bits of each pixel to one fully defeating the watermark with negligible impact on the cover object. Furthermore, once the algorithm is discovered, an intermediate party could easily modify the embedded watermark (Kamstra & Heijmans, 2005) but clicks over better PSNR values when compared with other methods.

Image: 11001010 00110101 00011010 00000000 ...

Watermark: 1 1 1 0 ...

Watermarked Image:

11001011 00110101 00011011 00000000 ...

This reversibility enables the recovery of the original host content upon verification of the authenticity of the received content. The algorithm exploits the correlation inherent among the neighboring pixels

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in an image region using a predictor. The prediction-error at each location is calculated and, depending on the amount of information to be embedded , locations are selected for embedding. Data embedding is done by expanding the prediction-error values. LSB Algorithm exploits the redundancy in the image to achieve very high data embedding rates while keeping the resulting distortion low

Implementation

Test Images

In this paper three algorithms are implemented based on our proposal to investigate the performance of the algorithms with reference to the *Peak Signal-to-Noise Ratio* (PSNR) values computed. Here 21 samples of Benchmark and other commonly used images both (color and grey-scale) were considered to ascertain the quality of watermarking process including reversibility nature among the three (Lebrun & Vetterli, 2001) (Cox *et al.*, 2001) (Fig. 9a, 9b). The performance of the proposed watermarking methods in this paper can be tested against (JPEG) signal distortions, image cropping, sharpening, and blurring attacks.

Capacity versus distortion- performance

The different points are obtained on the peak of the bar chart mentioned afore which are Calculated in order to establish the variation of the PSNR (Van der Veen *et al.*, 2003) (Tseng *et al.*, 2002) values with reference to the images and the chosen algorithm. The computation of PSNR for all the three algorithms i.e between host and watermarked images is used to measured the distortion between the two images (Table 1). The methods proposed in this paper is based on 21 images sets.

The PSNR block computes the peak signal-to-noise ratio, in decibels (dB), between two images. This ratio is often used as a quality measurement between the original and a compressed image. The higher the PSNR, the better the quality of the watermarked/compressed image (Ghouti *et al.*, 2006; Diljith *et al.*, 2007).

To compute the PSNR, the block calculates the mean-squared error parameter using the following equations:

Mean Square Error (mse) – Calculated between the in put and output Images.

mse= $\sum$ ([I_1(m,n) -I_2(m,n)] ^{2} /Prod. Of rows, col.s m,n OR mse = sum ((sum((abs (watt – orig)).* abs (watt – orig)))) / m * n; PSNR = abs (20 * log 10 (255 / sqrt (mse))). In the above equation, m, n are the rows and columns in the input images, respectively.

Algorithm for wavelet based watermarking method

Step1: Read two test images named image1 and 2.

Step2: Apply discrete wavelet transform on both test images.

Step3: Consider the approximation for image 1(image to be watermarked).

Step4: Consider the diagonal/horizontal parameter for image 2(watermark).

Step5: Sum up Approximation of image1 and details of image2 to get watermarked images.

Step6: To obtain the watermark and original image we subject the watermarked image to inverse discrete wavelet transform components.

Step7: Apply a low pass filter on the Approximation components to get cover image1 and apply low pass filter on Details to get the watermark (i.e image2) .

Table 1. PSNR - Values from image sets

SET-1			PSNR
Algorithm	Input Image1	Input Image2	Value(dB)
Wavelet	Baboon.png	Monarch.png	20.416dB
Tian's	Baboon.png	Monarch.png	26.770dB
LSB	Baboon.png	Monarch.png	29.696dB
SET-2			
Wavelet	Lenna.png	Barabra.png	20.92dB
Tian's	Lenna.png	Barabra.png	20.91dB
LSB	Lenna.png	Barabra.png	30.09dB
SET-3			
Wavelet	Watch.png	Venus.jpg	12.100dB
Tian's	Watch.png	Venus.jpg	11.222dB
LSB	Watch.png	Venus.jpg	19.261dB
SET-4			
Wavelet	Boy.jpg	Girl.jpg	15.167dB
Tian's	Boy.jpg	Girl.jpg	18.176dB
LSB	Boy.jpg	Girl.jpg	22.23dB
SET-5			
Wavelet	Baby.jpg	Barbara.png	23.693dB
Tian's	Baby.jpg	Barbara.png	24.918dB
LSB	Baby.jpg	Barbara.png	30.094dB
SET-6			
Wavelet	Waterlil.jpg	Tulips.jpg	16.933dB
Tian's	Waterlil.jpg	Tulips.jpg	21.174dB
LSB	Waterlil.jpg	Tulips.jpg	30.193dB
SET-7			
Wavelet	Boy.jpg	Lenna.png	19.572dB
Tian's		Lenna.png	19.728dB
LSB	Boy.jpg	Lenna.png	27.521dB
SET-8			
Wavelet	Winter.jpg	Redmndrt.jpg	17.082dB
Tian's	Winter.jpg	Redmndrt.jpg	27.490dB
LSB	Winter.jpg	Redmndrt.jpg	27.601dB
SET-9			
Wavelets	Blue_hill.jpg	Boeing747.jpg	18.999dB
Tian's	Blue_hill.jpg	Boeing747.jpg	26.4902dB
LSB	Blue_hill.jpg	Boeing747.jpg	29.8766dB
SET-10			
Wavelets	Peppersbig.png	Pepersclr.png	19.8892dB
Tian's	Peppersbig.png	Pepersclr.png	23.5248dB
LSB	Peppersbig.png	Pepersclr.png	23.9566dB
SET-11			
Wavelet	Loopsync.jpg	Redmndsrt.jpg	20.9188dB
Tian's	Loopsync.jpg	Redmndsrt.jpg	27.3200dB
LSB	Loopsync.jpg	Redmndsrt.jpg	27.3744dB
SET - 12			
Wavelets	Arielandscp.jpg	Matlogo.png	19.8014dB
Tian's	Arielandscp.jpg	Matblogo.png	25.0049dB
LSB	Arielandscp.jpg	Matlogo.png	29.9621dB
SET-13			
Wavelet	Gandhimarc.jpg	Baby1.jpg	21.420dB
Tian's	Gandhimarc.jpg	Baby1.jpg	19.0563dB
LSB	Gandhimarc.jpg	Baby1.jpg	30.5019dB
SET-14			
Wavelet	Green_tree.jpg	Babies.jpg	22.1449dB
Tian's	Green_tree.jpg	Babies.jpg	29.7299dB
LSB	Green_tree.jpg	Babies.jpg	34.0230dB

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SET-15			
Wavelet	Redmoondsrt.jpg	Charlesbab.jpg	19.232dB
Tian's	Redmoondsrt.jpg	Charlesbab.jpg	22.901dB
LSB	Redmoondsrt.jpg	Charlesbab.jpg	29.899dB
SET-16			
Wavelet	Lenna.png	Baboon.png	18.3516dB
Tian's	Lenna.png	Baboon.png	18.9176dB
LSB	Lenna.png	Baboon.png	27.7402dB
SET-17			
Wavelet	Monarch.png	Fruits.png	16.9914dB
Tian's	Monarch.png	Fruits.png	20.3226dB
LSB	Monarch.png	Fruits.png	29.7612dB
SET- 8			
Wavelet	Earthfrmspac.jpg	CharlesBab.jpg	7.5902dB
Tian's	Earthfrmspac.jpg	CharlesBab.jpg	17.4263dB
LSB	Earthfrmspac.jpg	CharlesBab.jpg	27.8397dB
SET-19			
Wavelet	Peppers.png	Lenna.png	18.2927dB
Tian's	Peppers.png	Lenna.png	20.3680dB
LSB	Peppers.png	Lenna.png	25.5196dB
SET-20			
Wavelet	Watch.png	Tulip.jpg	16.1846dB
Tian's	Watch.png	Tulip.jpg	21.2555dB
LSB	Watch.png	Tulip.jpg	30.1931dB
SET-21			
Wavelet	Monarch.png	Tulip.jpg	18.7592dB
Tian's	Monarch.png	Tulip.jpg	20.7015dB
LSB	Monarch.png	Tulip.jpg	30.1927dB

Algorithm for Tian's difference expansion method

Step1: Take the input images, original (cover image) and image to be embedded

Step2: Divide the images into R, G, and B components

Step3: Apply the Difference Expansion Equations to the image to be embedded

Step 4: Based on rgb vectors compute the values of image to be embedded

Step5: Add this image to the original image (cover image)

Step6: Now we get the watermarked image

Step7: Apply Tian's Inverse Difference Expansion to the watermarked image to get embedded image

Step 8: Subtract embedded image from watermarked image to get the original image

Algorithm for Least Significance Bit -Prediction Error method

Step 1: Consider the two input images.

Step 2: Convert the two images into gray color.

Step 3: Divide the original image1 by two.

Step 4: Find out the LSB of original image 1 and the divided image .

Step 5: Add the two LSB images and sort the divided image in descending order.

Step 6: Now add the LSB predicted image and original image 2.

Step 7: And the result is Watermarked image.

Step 8: In decoding process add the LSB predicted image to the divided image and get image1

Step 9: Now subtract the original image1 from the Watermarked image we get Hidden image2 .

Test -Image sets and experimental results

Findings / Analysis based on Implementation of above the three popular Algorithms (Table 1).

Findings

* The images with different Image formats showcases Lower PSNR values i.e. 20dB or above.
* The images with same image formats has produced higher PSNR values i.e. nearer to 30dB.
* The Benchmark Images has revealed better PSNR values comparativly .
* The LSB- Prediction Error Expansion Algorithm has Produced best psnr values among the three methods.

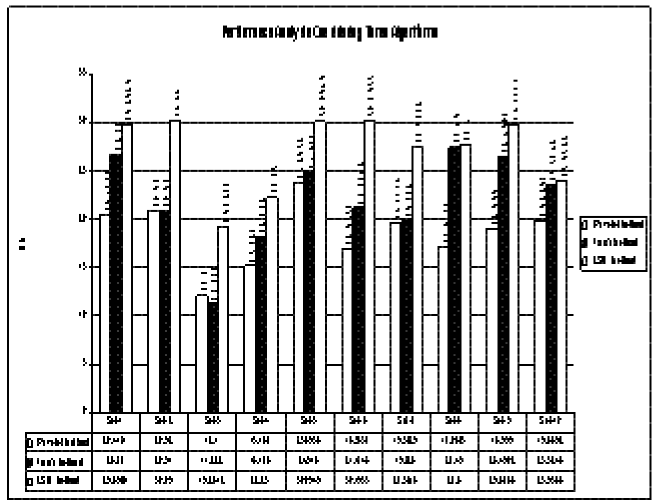

Fig. 9a. Performance comparison of algorithms based on computed PSNR values.

Conclusion

Having implemented the three popular classical and new methods of Reversible Image watermarking, the algorithms has shown different embedding capacities. It is analyzed and concluded that out of three algorithms the LSB method has emerged as a better technique which is bit value based embedding with higher PSNR value . During the analysis and testing of various samples it is found that the *wavelet-based multiwavelet technique [the first method]* is best suited for compression attacks and robust using down sampling operation by a power of two.

But it has shown very low PSNR value due to multi resolution nature and the results are depending on the Quality of the input cover image and the embedding image. Computational complexity of DWT is more compared to the Tian's difference-expansion technique [the second method] which is a high-capacity reversible method for data/image embedding.

However, this method suffers from undesirable distortion at low embedding capacities and has lack of capacity control due to the need for embedding a location map. Thus, it computes plenty of coefficients due to color componentization, but exhibits better PSNR value that the wavelet method.

At last we had implemented LSB Reversible watermarking method which has become a highly desirable subset of fragile watermarking for sensitive digital imagery in application domains such as military and medical areas because of the ability to embed data with zero loss of host information. This reversibility enables the recovery of the original host content upon verification of the authenticity of the received content. . The prediction-error at each location is calculated and, depending on the amount of information to be embedded , locations are selected for embedding. Data embedding is done by expanding the prediction-error values.

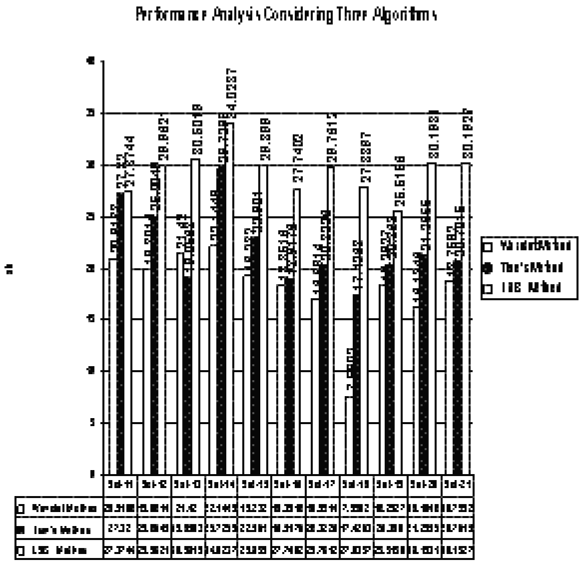

Fig. 9b. Performance comparison of algorithms based on computed PSNR values.

Thus, LSB algorithm reversibility aspect ensures Image Verification , Image Security and also Extraction of images during the damage of source images itself(i.e image recovery) as compared to other available methods.

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