IMAGE IN IMAGE STEGANOGRAPHY USING WAVELET TRANSFORM

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ABSTRACT

This paper describes a stego system in which a gray scale image is embedded in another one.

Wavelet transform of both the cover image and the embedded image is used to sort their subbands energies to guarantee that the embedded image will be inserted in the low frequency components of the cover image with little perceptual distortion.

Embedding by this way increases the robustness of the system but affects the system imperceptibility, so a variable scaling factor (α) is used to attenuate the components of the embedded image before adding them to those of the cover image.

It is found that the stego image with peak signal-to-noise ratio (PSNR) of about 30 dB has good imperceptibility.

The attacker is proposed to be active, so compression is applied to the stego image. According to this, the scaling factor must be increased to compromise between the quality of the stego and the reconstructed images. This increment reduces the imperceptibility of the stego image and here the trade off between the imperceptibility and the robustness occurs.

The attack is proposed to be stego known, so that to increase the security of the system, a stego key is generated from the embedded image itself and is transmitted separately, making the system type secret key steganography.

The size of the embedded image obtained in the work is one quarter the size of the cover image that may be considered good comparing with the available systems.

الخلاصة

في هذا البحث يتم وصف نظام إخفاء صوري و الذي يتم من خلاله إخفاء صورة رمادية المقياس في صورة أخرى رمادية المقياس أيضا.

استخدم تحويل المويجة لكل من الصورة الغطاء و الصورة المطمورة لكي يتم تصنيف حزم الطاقة الفرعية للتأكد من وضع الصورة المطمورة في مركبة الترددات الواطئة للصورة الغطاء مع تشويه غير محسوس.

هذه الطريقة تزيد من متانة النظام ولكنها تؤثر على اللاقابلية لإدراك الصورة، لهذا السبب استخدم عامل تغيير لتضعيف قيمة مركبات الصورة المطمورة قبل إضافتها الى مركبات الصورة الغطاء.

لقد وجد إن الصورة الناتجة من الإخفاء تكون ذات نوعية جيدة عندما تكون نسبة الــذروة للإشــارة مقابــل الضوضاء (نذ/ض) أعلى من 30 ديسيبل.

اقزرح أن يكون المهاجم فعالا لذا تم تطبيق كبس الصورة الناتجة لبيان تأثير الهجوم مما أدى وجوب زيـادة عامل التغيير للموازنة بين الصورة الناتجة والصورة المعاد تشكيلها، وهذه الزيادة الطفيفة تقلل نسبيا اللاقابلية عـى إدراك الصورة الناتجة وهنا تحدث المقايضة بين هذه اللاقابلية على الإدراك وبين المتانة.

اقزرح أن تكون الهجمة مشخصة من قبل المهاجم، لذا لزيادة أمنية النظام، يولد مفتاح الإخفاء من الصـورة الـطمورة نفسها وبهذا يكون النظام من نوع إخفاء بالمفتاح السري.

حجم الصورة المطمورة في هذا العمل هو ربع حجم الصورة الغطاء وهكذا يمكن أن يعد هـذا النظـام ذو اسـتيعابية جيدة.

KEY WORDS
Steganography; information hiding; image hiding.

INTRODUCTION
Moves to restrict the availability of services have motivated people to study methods by which private messages can be embedded in seemingly innocuous cover messages (Stefan and Fabien 2000).

One of the newest methods in security researches is information hiding. An important subdiscipline of information hiding is steganography. While cryptography is about protecting the content of messages, steganography is about concealing their very existence (Stefan and Fabien 2000). Steganography literally means "covered writing" and is the art of hiding the very existence of a message. The possible cover carriers are innocent looking carries (images, audio, video, text or other digitally representative code) which will hold the hidden information. A message is the information hidden and may be plaintext, ciphertext, images or anything that can be embedded into a bit stream. Together the cover carrier and the embedded message create a stego carrier (Jack and Larry 1996), (Areepongsa et al 2000).

Hiding information may require a stegokey, which is additional secret information (Christian 1998). For example, when a secret image is hidden within a cover image, the resulting product is a stego image. A possible formula of the process may be presented as (Neil et al 2001):

Cover medium + embedded message + stegokey = stego medium

Many steganographic methods have been proposed during the past few years. Most try to substitute redundant part of the signal with a secret message; their main disadvantage is the relative weakness against cover modification.

It has been noted early in the development of steganographic systems that embedding information in the frequency domain of a signal can be much more robust than embedding rules operating in the time domain. Most robust steganographic systems known today actually operate in the same sort of transform domain (Stefan and Fabien 2000).

Transform domain methods hide messages in the significant areas of the cover image, which makes them more robust to attacks such as adding noise, compression, filtering and some image processing. However, while they are more robust to various kinds of signal processing, they remain imperceptible which means that the human visual system (HVS) has no sense that there exists a stego-image (Ingemar et al 1996).

In this paper the discrete time wavelet transform (DTWT) is used as the transform technique in the steganography process to increase its robustness by inserting the embedded image in the low frequency component of the cover image in order to reduce the effect of the attacker. The system is subjected to a compression attack to see how it will affect the reconstructed image.

IMAGE EMBEDDING

It is well known that embedding in the low frequency bands is more robust to manipulations. However, changes made to the low frequency component may result in visible artifacts (Abdulaziz and Pang 2000). Modifying the data in a multiresolution framework, such as a wavelet transform appears quite promising for obtaining quality embedding with little perceptual distortion. **Fig. 1** shows the whole embedding process, which will be explained in the following section.

Partition the Cover and the Embedded Images into Subbands

The whole process can be described as follows, denoting the original image by I_0, assuming its size is 2^l x 2^l. After applying the two-dimensional discrete time wavelet transform (2-D DTWT) to it, one can get a matrix I_1 partitioned into four subbands. The 2-D DTWT is applied to each of these bands individually. The result is the coefficient matrix I_1 consisting of 16 subbands, when this process is carried out r times, a coefficient matrix consisting of 2^r x 2^r subbands, each of size 2^{l-r} x 2^{l-r} (Salomon 2000) is obtained.

The main job of applying the wavelet packets to both the cover image and the embedded image in the proposed stegosystem is to partition these images into subbands in which each subband has certain frequency information. Since most of the natural images' energy concentrates in the low frequency band, then in general, the high energy subbands reflect their low frequency contents and vice versa.

The size of the embedded image is chosen to be quarter the size of the cover image to ensure that the entire embedded image be completely inserted in the LL subband of the cover image.

The number of the decomposition levels that are applied to the embedded image is less by one than those applied to the cover image so that the number of coefficients in each subband in both transformed images are equal.

Generation of The Stego-key by Sorting Process

After applying the full tree two-dimensional wavelet packets to both the cover and the embedded images, subbands that contain both the frequency and spatial information are obtained. The energy (Ei) of each subband is then calculated as follows

$$E_i = \sum_{j=1}^{\frac{N}{2^l}} \sum_{k=1}^{\frac{N}{2^l}} S_i^2(j,k) \qquad i = 1,2,....,4^l$$

Where l is the decomposition level.
N x N dimension of the input image
Si order of each subband

The subbands of both the cover and the embedded images are then sorted in a descending manner such that the highest energy is the first and the least energy subband is the last . **Table (1)** illustrates the energies of all subbands resulting from the sorting process of two levels of decomposition applied to 256 x 256 gray level version of Lena standard image.

This sorting process will increase the robustness of the system and improve the security of the proposed stego-system by considering the order of the embedded image subbands as a stego-key.

Table (1) Illustrating the sorting and the scaling processes

Subbands	S_i	Corresponding Energies	Sorted Subbands	Sorted S_i	Corresponding Energies	Scaling Factor α_i
LLLL	S_1	801838270	LLLL	S_1	801838270	0.5
LLLH	S_2	2204826	LLHL	S_3	6751748	0.531
LLHL	S_3	6751748	LLLH	S_2	2204826	0.562
LLHH	S_4	1360912	HLHL	S_{11}	1815081	0.593
LHLL	S_5	199427	LLHH	S_4	1360912	0.625
LHLH	S_6	478589	HLLL	S_9	664613	0.656
LHHL	S_7	143275	HLHH	S_{12}	608941	0.687
LHHH	S_8	418153	LHLH	S_6	478589	0.718
HLLL	S_9	664613	LHHH	S_8	418153	0.750
HLLH	S_{10}	243747	HHHH	S_{16}	301075	0.781
HLHL	S_{11}	1815081	HLLH	S_{10}	243747	0.812
HLHH	S_{12}	608941	LHLL	S_5	199427	0.843
HHLL	S_{13}	80472	HHLH	S_{14}	148554	0.875
HHLH	S_{14}	148554	LHHL	S_7	143275	0.906
HHHL	S_{15}	107074	HHHL	S_{15}	107074	0.937
HHHH	S_{16}	301075	HHLL	S_{13}	80472	0.968

The Scaling Process

In the proposed stego system the embedded image is inserted in the low frequency region of the cover image which is a perceptually significant region to confirm the robustness of the system. This will affect the imperceptibility of the system. To compromise between the two parameters, a variable factor α is chosen which is multiplied by the coefficients of the cover image to attenuate their values. The scaling factor is dependent on the subband energy. In other words, the coefficients of the high-energy subbands are multiplied by factors, which are less than the corresponding factors of the low energy subbands. The scaling factors are calculated by the following equation

$$\alpha_i = \alpha_{min} + \left\{ (i-1)x\frac{\alpha_{min}}{4^\ell} \right\} \qquad i = 1,2,3\ldots4^\ell$$

Where α_{min} is the scaling factor that attenuates the highest energy subbands.
Table (1) gives the scaling factors for two levels decomposition of Lena Image that is shown in **Fig.(2)** with α_{min} chosen to be 0.5.
After this scaling process, one can easily insert the low frequency regions of the embedded image to the low frequency of the cover image to produce a robust stego image. The value of α_{min} must be sent via a secret channel with the stego key to the receiver.

The Re-sorting Process

The resultant stego image is not identical to the cover image due to the sorting process, because the resultant subbands are not arranged in the same order of the cover image subbands. But, from the steganography viewpoint the two images must be identical. For this reason, the need for a re-sorting process arises. In this process the subband, that consists of the cover image subbands added to the attenuated version of the embedded subbands are resorted in the same order of the cover image subbands, such that the stego image will be approximately identical to the cover image.

The Inverse Wavelet Packet Transform

After the resorting process, the sequences of the cover image subbands and the stego image are identical but their frequency contents are not due to the addition of the attenuated embedded image subbands.

Applying the inverse wavelet packet transform to the stego-image subbands followed by a quantization process will produce a stego image with little degradation.

The wavelet filters and the number of the decomposition levels must be the same in the wavelet packets and the inverse wavelet packets. The pixels of the stego image after the inverse transform are not quantized as a gray scale. So that a uniform quantization is applied to this image to preserve the initial dynamic range of the cover image. For 256 subdivisions, uniform quantization can be done as follows

$$f_q(r,c) = \{f(r,c) - f_{min}\}\frac{255}{(f_{max} - f_{min})}$$

Where $f(r,c)$ is the image before quantization and $f_q(r,c)$ is the quantized version of it, f_{max} and f_{min} are the maximum and the minimum values in the original image respectively

Fig. (2) shows the images after each block of **Fig.(1)** for the embedding process. In order to visually recognize the differences between these images, the decomposition levels of the cover and the embedded images are chosen to be two and one respectively (for an example only).

The flow chart of the embedding process is shown in **Fig.(3)**.

IMAGE EXTRACTING

If the original cover image with the stego-image, the stego key and α_{min} are available to the receiver, then the extraction of the embedded image is possible.

The stego-image is transmitted via a public communication channel, while the stego-key and α_{min} are transmitted via a secret channel.

Applying the wavelet packet transform first produces the subbands of the cover image and the stego image. The subbands of the stego image contain the cover image subbands added to those of the embedded image. Then a descending sorting process is applied to the produced subbands. The cover image subbands are then subtracted from the stego image subbands, coefficient by coefficient and the resulted coefficients are multiplied by the reciprocal of the scaling factor to amplify them to their original values to get the coefficients of the embedded image. The stego key that contains the original sequence of the embedded image subbands is used to resort the resultant subbands such that the embedded image can be reconstructed by applying the inverse wavelet packets followed by the quantization process.

The filters and the number of the decomposition levels that are applied to both the stego and the cover images must be identical to those used in the embedding process.

Fig. (4) shows the images after each block of **Fig. (1)** for the extracting process. The flow chart of the extracting process is shown in **Fig. (5)**.

THE ROBUSTNESS OF THE SYSTEM

Since in the proposed stego system the frequency domain has been selected to embed the entire image, it is required to be a robust system. The robustness of the proposed system will be tested against compression attack

The Compression Test

The JPEG (Salomon 2000) compression is used here because it is a standard lossy compression algorithm that uses many parameters allowing users to adjust the amount of the data lost (and thus also the compression ratios) over a wide range.

The compression ratios that are used in this work is 5, 7.5 and 10. These ratios can be obtained by adjusting the factor that multiplies the quantization matrix.

The coding part of the JPEG algorithm is not implemented in this work because it is the lossless part, therefore it is not useful to be used.

The results of this test will be discussed in the following section.

EXPERIMENTAL RESULTS

The test images used in this work are shown in **Fig.(6)** in Image 1 and Image 5. The cover image is the Lena Image with 256 x 256 pixels and the embedded image is the Saturn Image with 128 x 128 pixels as shown in Image 1 and Image 5 respectively.

The proposed stego system uses different decomposition levels and the variable scaling factor α and then selects optimum parameters to compromise between the quality of both the stego and the reconstructed images.

A Daubechies (Burrus et al 1998) filter with four-coefficient (D_4) is used in the wavelet packets and its inverse in both the embedding and the extracting process as a wavelet filter.

Table (2) shows the PSNR's for both the stego and the reconstructed images for three different decomposition levels and with variable scaling factor α. For four decomposition levels applied to the cover image, and three decomposition levels applied to the embedded image, one can notice that the PSNR's of the stego-image increases with decreasing α_{min} which means that the scaling factor does its job properly. The results of the other decomposition levels (five and six) are in the same context but with noticeable improvement. When the number of the decomposition levels increase, the energies of the embedded image's subbands will be distributed equally and there are no subbands in which the energy is concentrated.

Table (2) PSNRs (dB) for the reconstructed images

DL α_{min}	Four Levels		Five Levels		Six Levels	
	Stego	Recon.	Stego	Recon.	Stego	Recon.
0.5	21.13	37.33	21.13	40.71	21.15	43.51
0.4	23.05	35.78	23.06	39.38	23.07	44.12
0.3	25.52	33.44	25.55	36.93	25.57	41.98
0.2	28.99	30.14	29.05	33.42	29.08	38.62
0.1	34.69	24.56	34.95	27.49	35.07	32.82
Optimum Parameters	$\alpha_{opt.}$=0.18 PSNR=29.5 dB		$\alpha_{opt.}$=0.155 PSNR=31.25 dB		$\alpha_{opt.}$=0.12 PSNR=34 dB	

As a result the effect of the quantization process will be decreased and improvement in the results occurs. In this case increasing of the decomposition levels increases the security of the system that is not conflicted with the imperceptibility of the stego system, so that one can select both requirements and there is no need for trade off between them. The optimum scaling factor α_{opt} is the

value of α where the PSNR's of the stego and reconstructed images are equal which is shown n **Fig. (7)** for different decomposition levels. The last row of **Table (2)** lists α_{opt} and the corresponding PSNR's. The corresponding images for these results are shown in **Fig. (6)** in the Images 2, 3, 4, 6, 7 and 8.

The size of the embedded image which is used in this system is one quarter the size of the cover image and this capacity is considered as being good when comparing with the most of the existence systems (Marza 2001),(Avedissian 2000),(Ibrahim 2001).

If the size of the embedded image is increased, part of this image will be inserted in the high frequency of the cover image that may be affected by compression. Obviously, if the size of the image is decreased there is an improvement in the imperceptibility of the stego-image.

The proposed system is assumed to be a secret key stego system. The stego-key is generated from the embedded image itself by considering its sorted subband's sequence as a stego-key. The sequence differs from one image to another because there are no two identical images in nature. The subband's order for different images are changed in different ways, except the first subband that represents the low frequency in both direction and it is expected that its order will not be changed because it still has the largest energy, so that the number of the possible keys that can be generated is $(4^l - 1)!$.

Table (3) shows the results of the compression tests at different decomposition levels,α and compression ratios. These results are plotted in **Fig.(7)**. Comparing with the results obtained without compression (i.e with CR=1), generally, the PSNR's of the reconstructed images decrease due to compression. This reduction in PSNR grows as the compression ratio increases but the results are still acceptable. To compromise between the stego and the reconstructed images,α_{opt} must be relatively increased to reduce the imperceptibility of the stego image as a price to this resistant against the compression attack.

Finally, **Table (4)** shows the optimum parameters with the corresponding compromised PSNR of the stego and the reconstructed images under test. It is clear that α_{opt} is increased for about 0.05 to 0.12 causing a decrease in the PSNR's for about 1.5 to 6 dB. For six decomposition levels the corresponding images of **Table (4)** are shown in **Fig.(8)** in Images 9, 10, 11, 12, 13,and 14.

Table (3) PSNRs (dB) for the reconstructed images for JPEG compression tests

CR / α_{min}	Four Levels			Five Levels			Six Levels		
	5	7.5	10	5	7.5	10	5	7.5	10
0.5	32.99	28.88	25.98	33.55	28.84	26.1	33.96	29.09	26.3
0.4	31.35	27.23	24.43	32.15	27.35	24.53	32.25	27.58	24.51
0.3	29.21	25.23	22.4	29.82	25.19	22.39	30.05	25.33	22.41
0.2	26.05	22.08	18.91	26.76	22.45	19.11	27.06	22.5	19.2
0.1	20.76	16.52	13.83	21.4	16.58	13.92	21.04	16.76	13.97

Table (4) The optimum parameters for JPEG compression tests

CR	FOUR LEVELS		FIVE LEVELS		SIX LEVELS	
	$\alpha_{opt.}$	PSNP	$\alpha_{opt.}$	PSNP	$\alpha_{opt.}$	PSNP
5	0.235	28	0.2240	27.9	0.225	28
7.5	0.308	25.5	0.3025	25.7	0.3	26.2
10	0.362	24	0.3610	24.2	0.36	24.25

CONCLUSIONS

Through the simulation results, one can conclude that:

- The quality of both stego and reconstructed images is considered good with PSNR is above 30 dB.
- Increasing the number of the decomposition levels which increases the security of the system is not conflict with the imperceptibility of the stego image. The PSNR is increased by about 4.5 dB if the decomposition levels are six rather than four.
- As the JPEG compression ratio increased, α must be increased and hence the PSNR of the stego and the reconstructed images is reduced.
- The size of the embedded image is one quarter the size of the cover image, which is considered relatively good when compared with the present stego systems.
- There is still some work to be done. The stego system needs to be subjected to attacks, such as noise addition, filtering, and other processing techniques and see how it will affect the reconstructed image.

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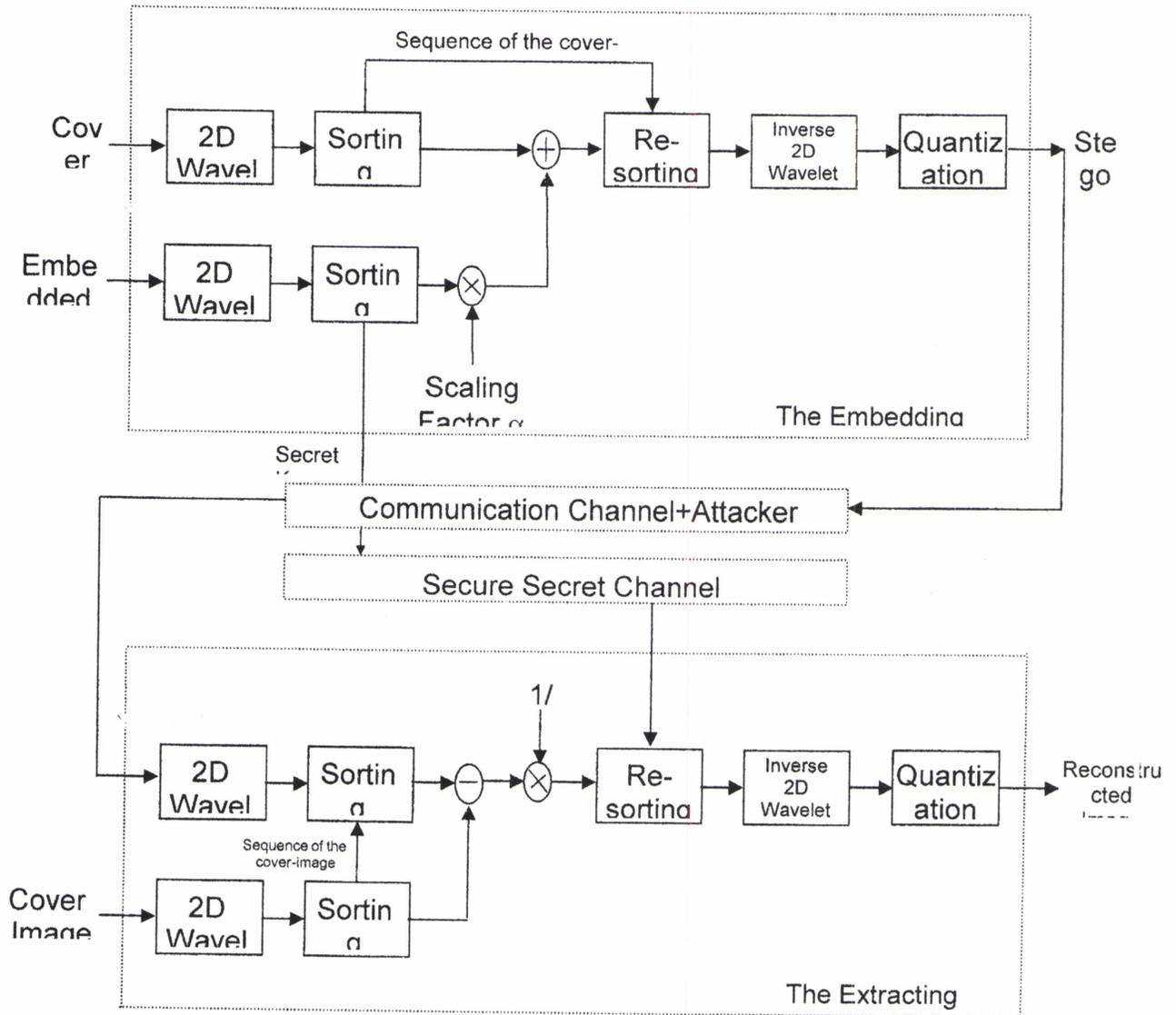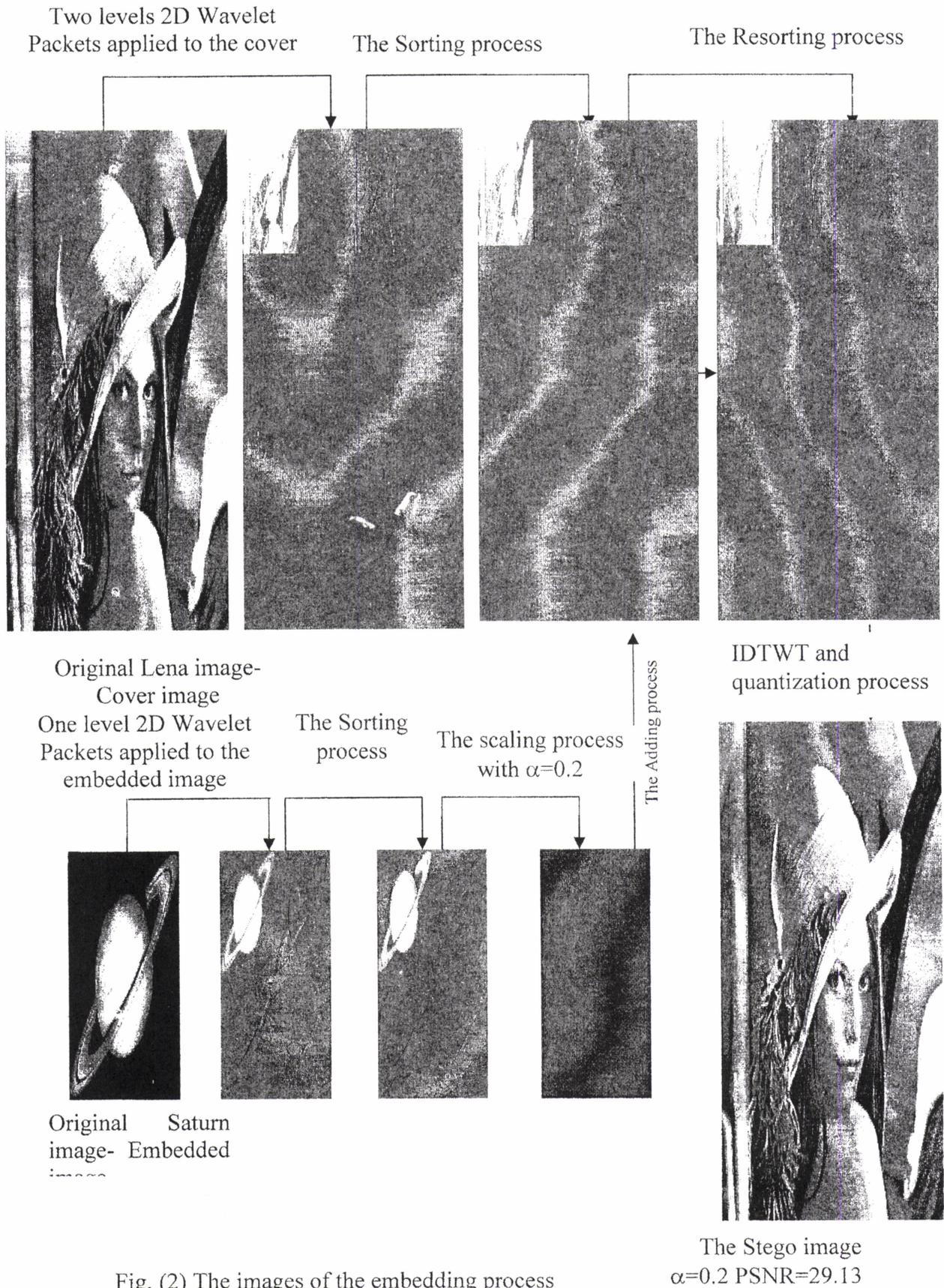
Fig. (1) The Proposed Stego-

Two levels 2D Wavelet
Packets applied to the cover

The Sorting process

The Resorting process

Original Lena image-
Cover image

One level 2D Wavelet
Packets applied to the
embedded image

The Sorting
process

The scaling process
with α=0.2

The Adding process

IDTWT and
quantization process

Original   Saturn
image- Embedded
image

The Stego image
α=0.2 PSNR=29.13

Fig. (2) The images of the embedding process

START

Read cover image file
Read embedded image file

$C(h_1,w_1)$=Cover image file data

$E(h_2,w_2)$=Embedded image file data

Apply DTWT

C_T=DTWT($C(h_1,w_1)$)
E_T=DTWT($E(h_2,w_2)$)

Sorting process

C_{ST}=SORT(C_T) in descending order
E_{ST}=SORT(E_T) in descending order

Scaling process

E_{AST}=E_{ST} * α

S_{ST}=C_{ST}+E_{AST}

Resorting process

R_S=RESORT(S_{ST})

Apply IDTWT

I_{RS}=IDTWT(R_S)

Quantization process

S_Q=QUAN(I_{RS})
=Stego image

END

Fig. 3 The flow chart of the embedding process

Two levels 2D Wavelet
Packets applied to the

The Sorting process
based on the secret
key

Resorting and Multiplying
by a factor of $1/\alpha$

The Stego

Two levels 2D Wavelet Packets
applied to the cover image

The Sorting process

Subtruction process

One Level Inverse Wavelet
Packets and quantization

The Cover image

The Reconstructed
image
$\alpha=0.2$, PSNR $=38.13$

Fig.(4) The images of the extracting process

START

Read cover image file
Read stego image file

$C(h_1, w_1)$=Cover image file data

S_Q=Stego image file data

Apply DTWT

C_T=DTWT($C(h_1, w_1)$)
S_T=DTWT(S_Q)

Sorting process

C_{ST}=SORT(C_T) in descending order
S_{ST}=SORT(S_T) in descending order

$R_{ST} = S_{ST} - C_{ST}$

Rescaling process

$R_{AST} = R_{ST} * 1/\alpha$

Resorting process

R_{SE}=RESORT(R_{AST})

Apply IDTWT

R=IDTWT(R_{SE})

Quantization process

R_Q=QUAN(R)
=Reconstructed image

END
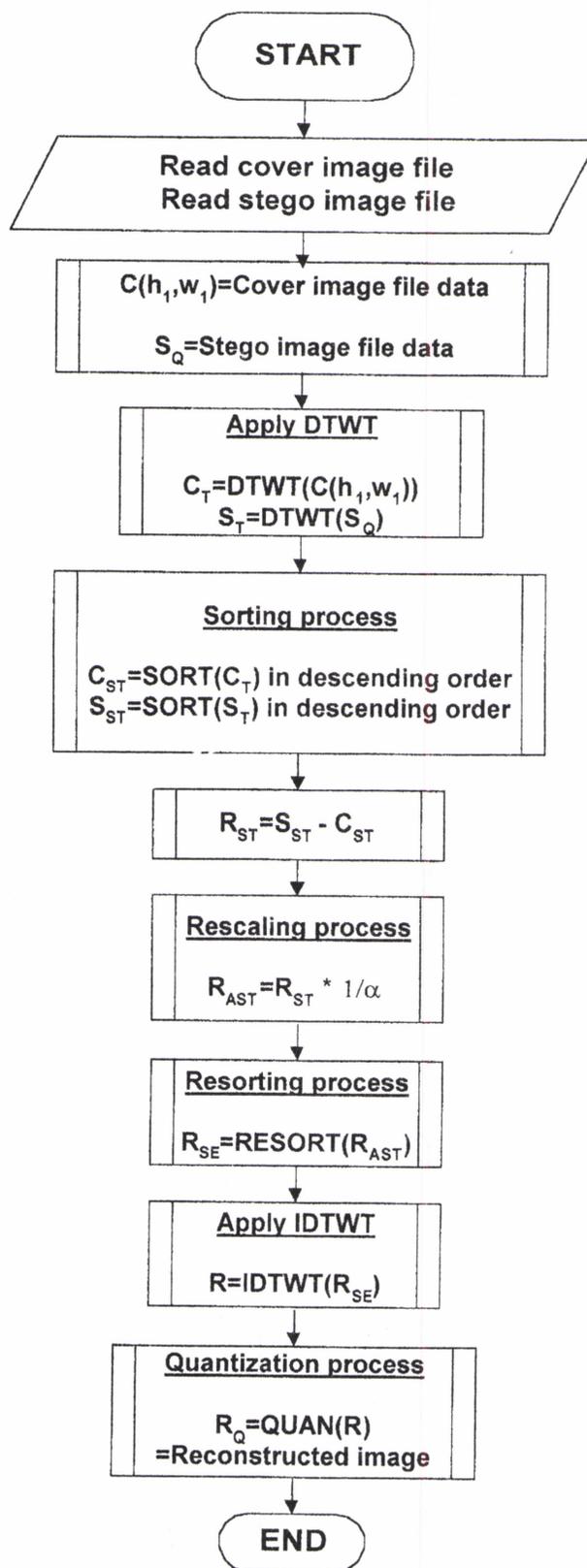
Fig. (5) The flow chart of the extracting process

Image 1 Original Lena image

Image 2 Stego image
Four decomposition levels
$\alpha_{opt.}$=0.18, PSNR=29.5

Image 3 Stego image
Five decomposition levels
$\alpha_{opt.}$=0.155, PSNR=31.5
dB

Image 4 Stego image
Six decomposition levels
$\alpha_{opt.}$=0.12, PSNR=34 dB
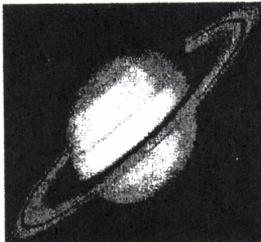
Image 5
Original Saturn
image
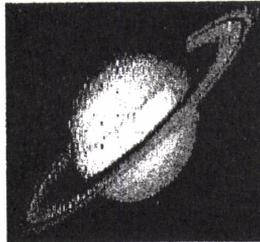
Image 6
Reconstructed
image related
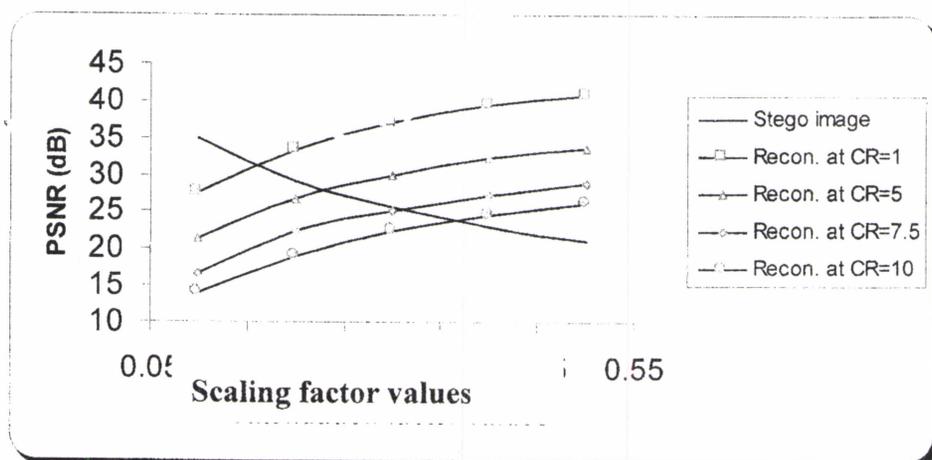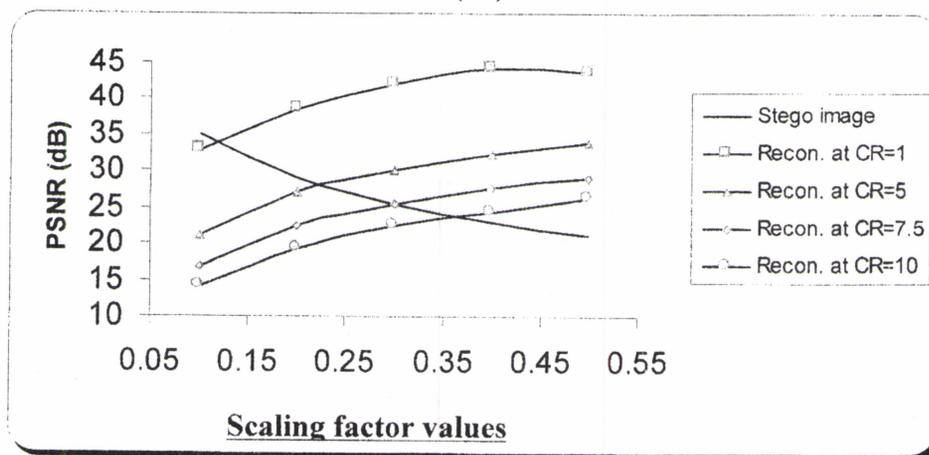to image 2
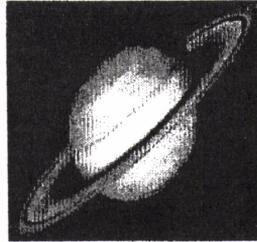
Image7
Reconstructed
image related
to image 3
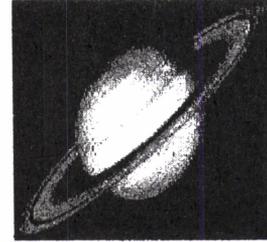
Image 8
Reconstructed
image related
to image 4

Fig. (6) The stego images and the corresponding reconstructed images for
different parameters
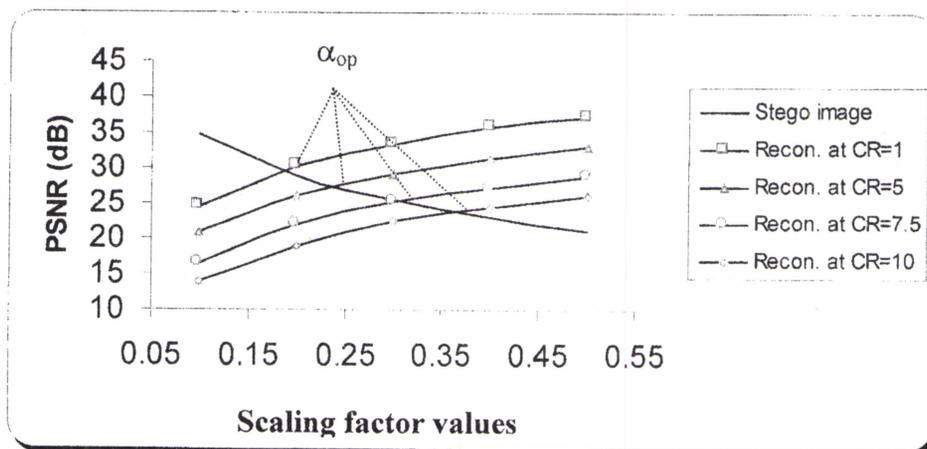
(a)

(b)

(c)

Fig.(7) PSNR's for both stego and reconstructed images vs. the scaling factor for:
(a) Four decomposition levels and different compression ratios
(b) Five decomposition levels and different compression ratios
(c) Six decomposition levels and different compression ratios
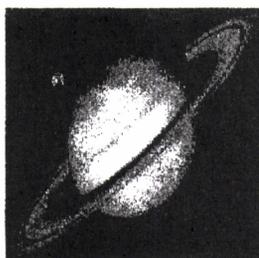
345

Image 9 Stego image
Six decomposition levels
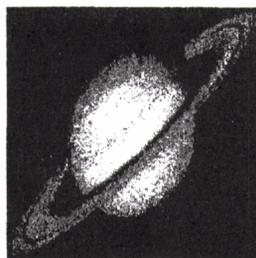$\alpha_{opt.}$=0.225, PSNR=28 dB
Compression ratio=5

Image 10 Stego image
Six decomposition levels
$\alpha_{opt.}$=0.3, PSNR=26.2 dB
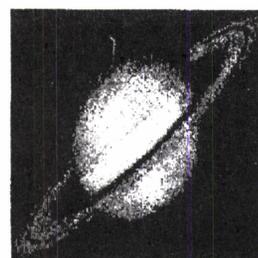Compression ratio=7.5

Image 11 Stego image
Six decomposition levels
$\alpha_{opt.}$=0.36, PSNR=24.25
dB

Image 12
Reconstructed image
related to image 9

Image13
Reconstructed image
related to image 10

Image 14
Reconstructed image
related to image 11

Fig. (8) The stego images and the corresponding reconstructed images of the
compression test for different parameters