ROBUST WATERMARKING TECHNIQUES FOR COLOR IMAGES

Presented By

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Introduction

Technologies for Security of Multimedia Data

- Fingerprinting
- Cryptography
- Stegnography
- Watermarking

Difference among Fingerprinting, Cryptography, Steganography and Watermarking

- Fingerprinting uses some kind of hash functions to create fingerprint, original file remain intact.
- Cryptography is about protecting the meaning of the document.
- Steganography is about concealing their very existence.
- Watermarking is about robustness against possible attacks, Watermark need not be hidden.

Watermarking can be applied to

- Images
- Text
- Audio
- S/W

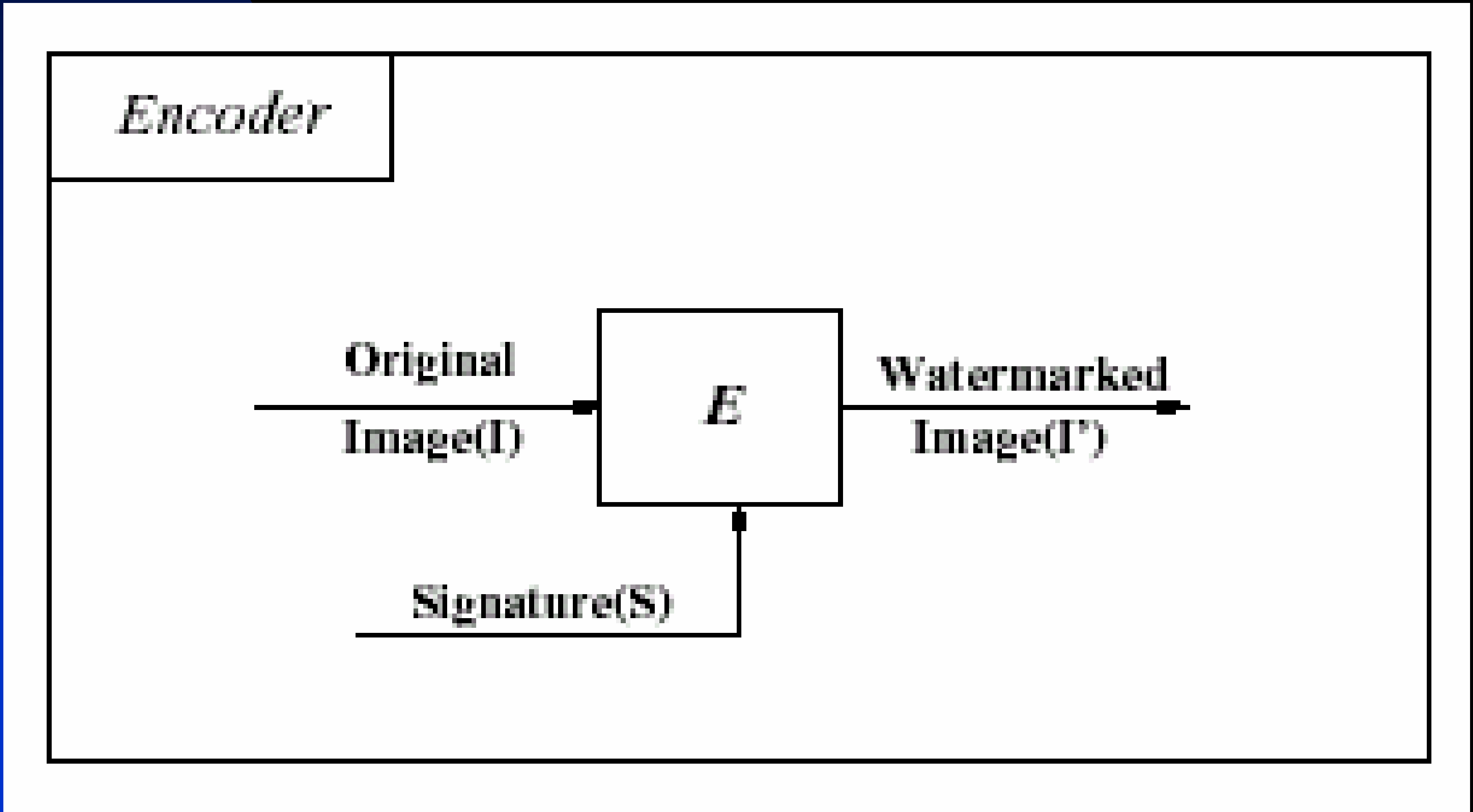
Digital Image watermarking

- A Digital Signal or pattern inserted into a digital image.

General Framework for Watermarking

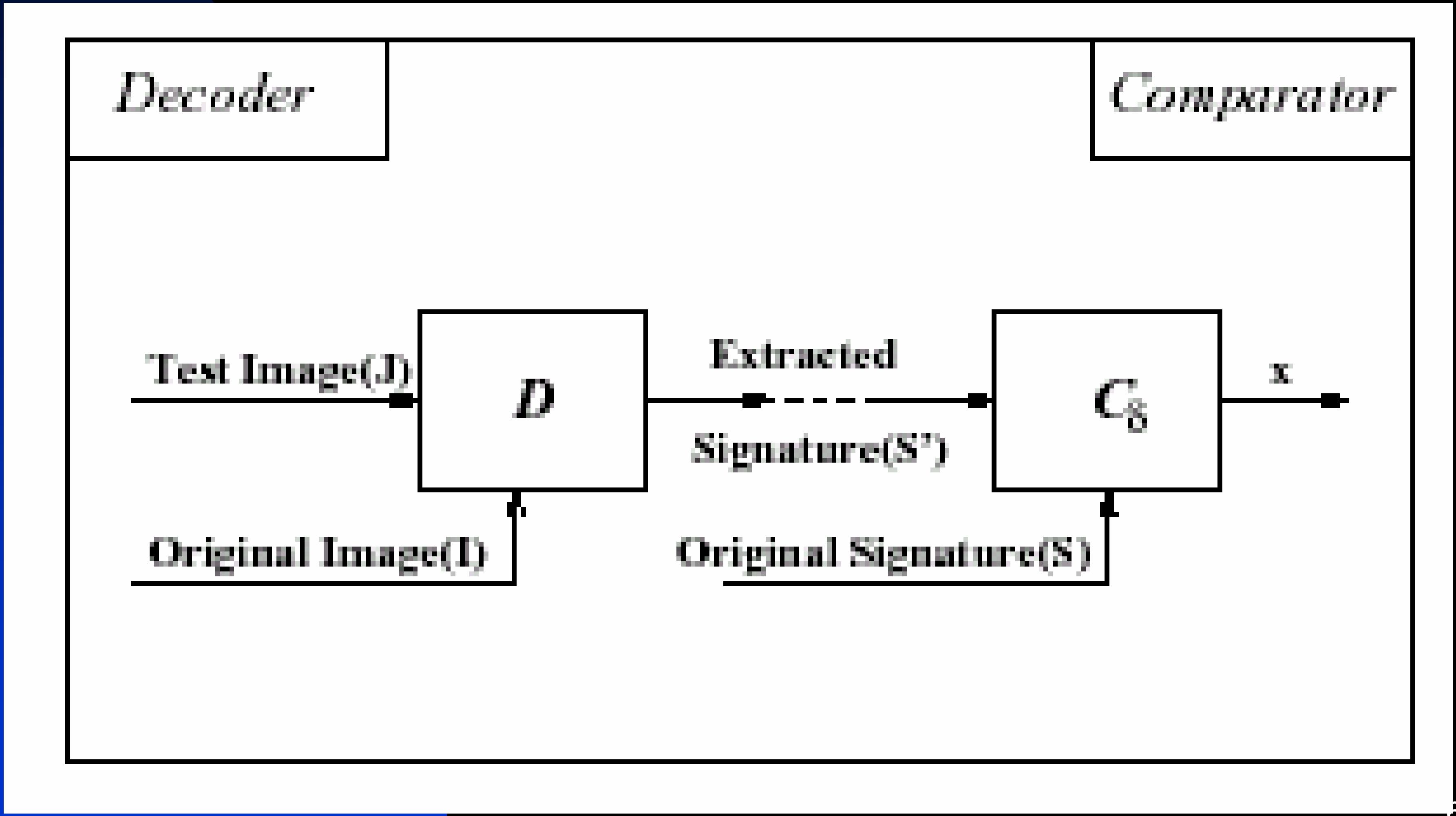
- **Encoding Process**

E(I,S) = Î



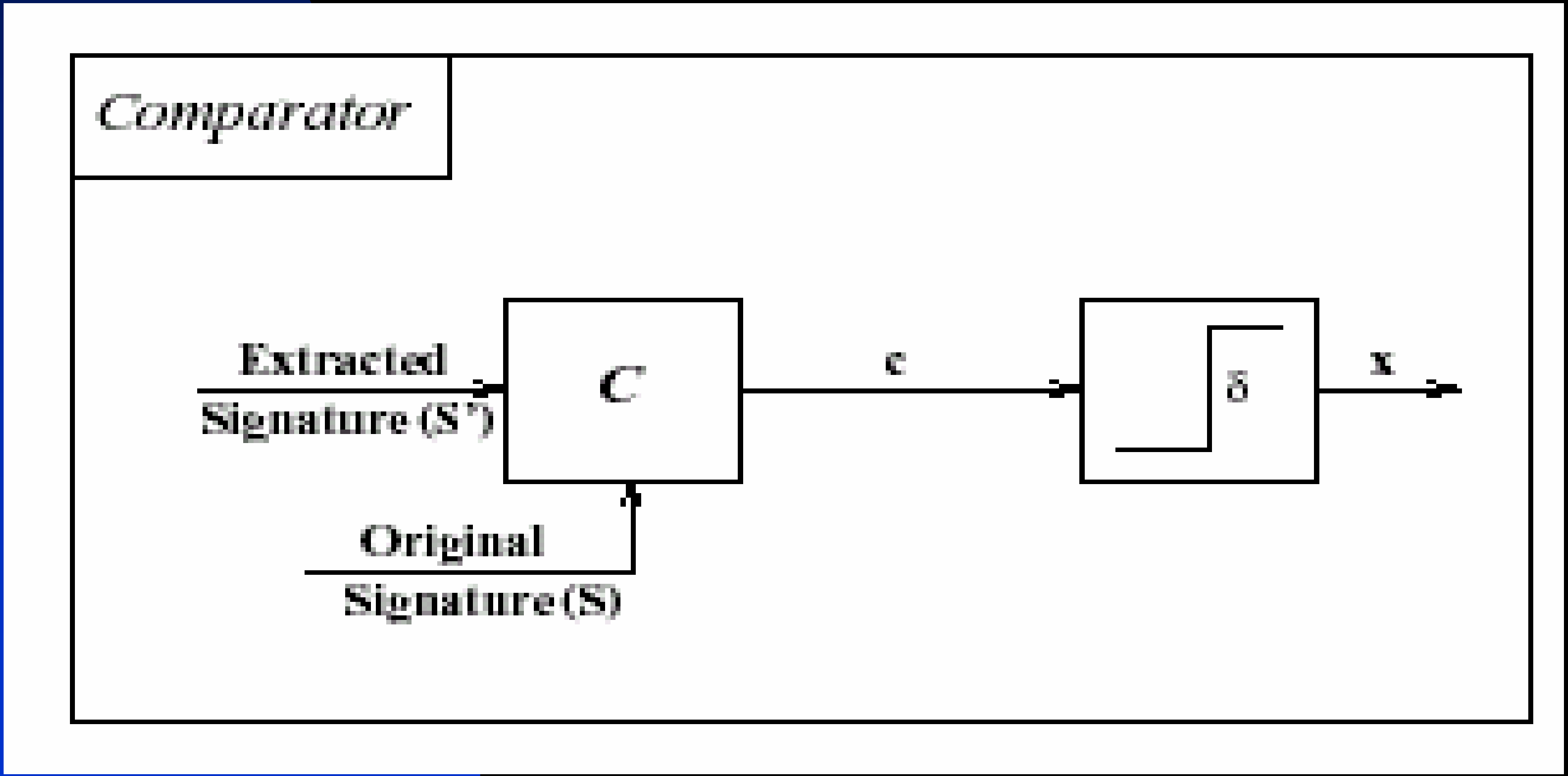
➢Decoding Process

$D(J,I) = S^{I}$



➢Comparator

$$C_\delta(S', S) = \begin{cases} 1, & c \leq \delta \\ 0, & \text{otherwise} \end{cases}$$



Applications of image watermarking

- IPR Protection
- Demonstration of rightful ownership
- Authentication
- Labeling for data retrieval
- Covert communication

Properties of Digital Watermark

- Perceptually invisible
- Robustness
- Cost
- Capacity
- Recoverable
- Reversible
- Undetectable
- Able to determine the true owner
- High bit rate

Attacks on Digital Watermarking

- Lossy Compression
- Geometric Distortions
- Common Signal Processing Operations
  - Linear filtering such as high pass and low pass filtering
  - Non-linear filtering such as median filtering
  - Addition of a constant offset to the pixel values
  - Addition of Gaussian and Non Gaussian noise
  - Local exchange of pixels
- Jitter Attack

Work Already Done On This Field

- Watermarking domain
  - Frequency domain
  - Spatial domain

- **Frequency domain**
  - Watermark is embedded in DFT, DCT and DWT domain coefficients

Representative work

- **Cox:-** DCT

  Watermark was a sequence of 1000 random numbers. Watermark was embedded in the 1000 largest DCT coefficients. Correlation based non-blind detection were performed

- **Xia Boncelet:-** DWT

  Proposed to add Gaussian noise as watermark in the middle and high frequency coefficient of DWT. Detection was correlation based.

- **FM Boland:-**DFT

  Embedded the watermark in the phase information in the discrete Fourier transform domain since the phase distortion is more sensitive to HVS than magnitude distortion . There fore it is more robust to tampering when compared to magnitude distortion.

Spatial Domain

- **Schyndel, Tirkel, and Osborne** :- LSB

  Generated a watermark using an m-sequence generator. The watermark was embedded to the LSB of the original image. Cross-correlation based detection was proposed. The watermark, however, was not robust to additive noise.

- **Bender** :- Statistical

  Described the patch work algorithm, it chooses randomly *n* pair of image point (a_i,b_i) and increased the a_i by one, while decreased the b_i by one. The watermark was detected by comparing the sum of the difference of a_i and b_i of the *n* pairs of the points with *2n* provided, certain statistical propriety like image intensity are uniformly distributed.

  The scheme is extremely sensitive to geometric transformation.

Spatial Domain

- **P.Bas, J. M. Chassery and B.Macq :-** Feature based

  Proposed to find feature points and apply Delaunay tessellation to obtain the triangular sequence. The watermark is right-angled isosceles triangular sequence generated from a random sequence depending on a secret key. After applying affined transform and visual mask watermark sequence is added to the image. Detection is performed by finding Delaunay tessellation of the test image and wiener filtering to obtain watermark and then performing correlation.

- **Ping Wah Wong and Nasir Memon** :- Block based

  Proposed partitioning both host and binary watermark Image into blocks, setting LSB's of each image block to zero, applying hash function (MD5) to image block. The watermark image block is ex-ored with the output of the hash function and output is inserted into the LSB of the image block to form watermarked image block. For extraction reverse steps are followed. Scheme is reported to detect and report any changes to the image.

Convolution Encoding and Decoding

In a general rate $R = b/c$, $b <= c$ binary convolution encoder (time-invariant and without feedback) the causal information sequence

$$u = u_0 u_1 \ldots\ldots\ldots\ldots\ldots = u_0^{(0)}\, u_0^{(1)} \ldots\ldots\, u_0^{(b)}\, u_1^{(0)}\, u_1^{(1)} \ldots\ldots\, u_1^{(b)} \ldots\ldots$$

is encoded as the causal code sequence

$$\mathbf{v} = v_{\mathbf{0}}\, \mathbf{v}_1 \ldots\ldots\ldots\ldots\ldots = v_0^{(0)}\, v_0^{(1)} \ldots\ldots\, v_0^{(c)}\, v_1^{(0)}\, v_1^{(1)} \ldots\ldots\, v_1^{(c)} \ldots\ldots$$

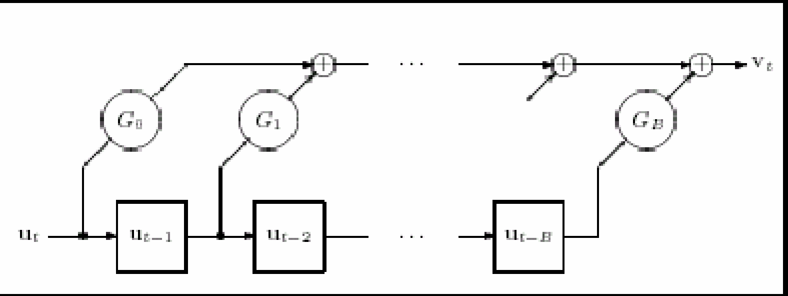
Where $\mathbf{v_t} = f(\mathbf{u_t}, \mathbf{u_{t-1}} \ldots\ldots\ldots \mathbf{u_{t-B}})$:

The function *f* must be a linear function. Furthermore, the parameter *B* is called the encoder memory.

$$\mathbf{u} = u_0 u_1 \ldots\ldots$$

$$\mathbf{v_t} = u_t G_0 + u_{t-1} G_1 + \ldots\ldots + u_{t-B} G_B;$$

$$G = \begin{pmatrix} G_0 & G_1 & \ldots G_B & & \\ & G_0 & G_1 & \ldots G_B & \\ & & \ddots & \ddots & \ddots \end{pmatrix}$$



Viterbi Decoding

➢it estimateS v_1 a sequence v that maximizes $P(r/ v)$. Where r is sequence , Probability p and

the starting and ending state is predetermined to be the zero-state

Why Viterbi Decoding

- A highly satisfactory bit error performance,
- High speed of operation,
- Ease of implementation,
- Low cost.
- Fixed decoding time.

Quad Tree Region Splitting Image Segmentation Method

Region Based Image Segmentation

Let R represent the entire image region, then we may view region based segmentation as a process that partitions R into n sub regions, $R_1, R_2 \ldots\ldots R_n$, such that

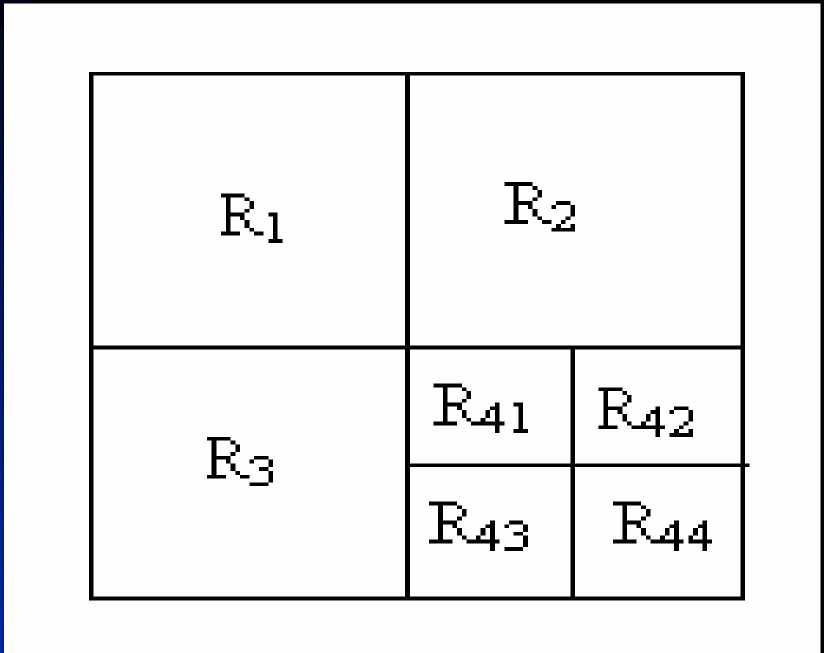
(a) $\bigcup_{i=1}^{n} R_i = R$.

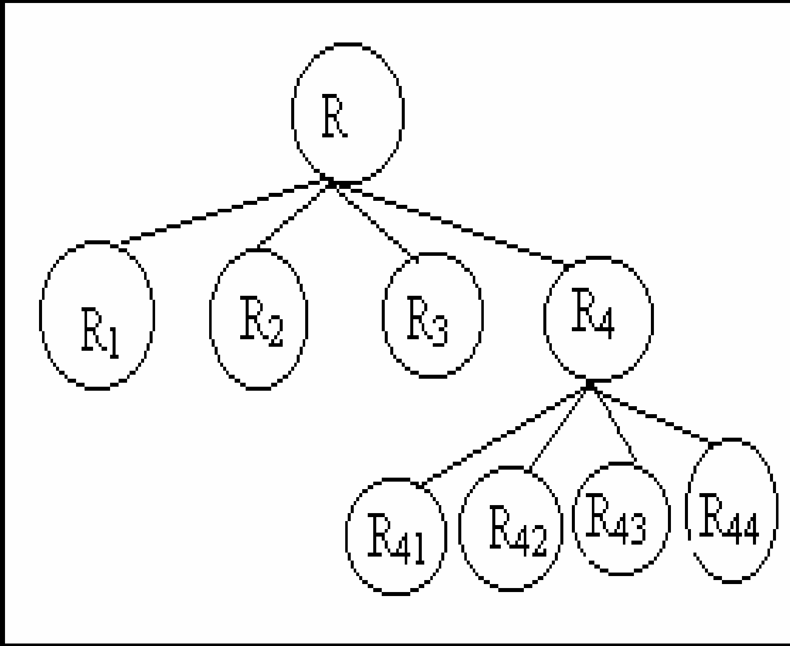
(b) R_i is a connected region, $i=1,2\ldots\ldots n$.

(c) $R_i \cap R_j = \Phi$ for all i and j, $i \neq j$.

(d) $P(R_i) = TRUE$ for $i=1,2\ldots n$.

Quad Tree Approach



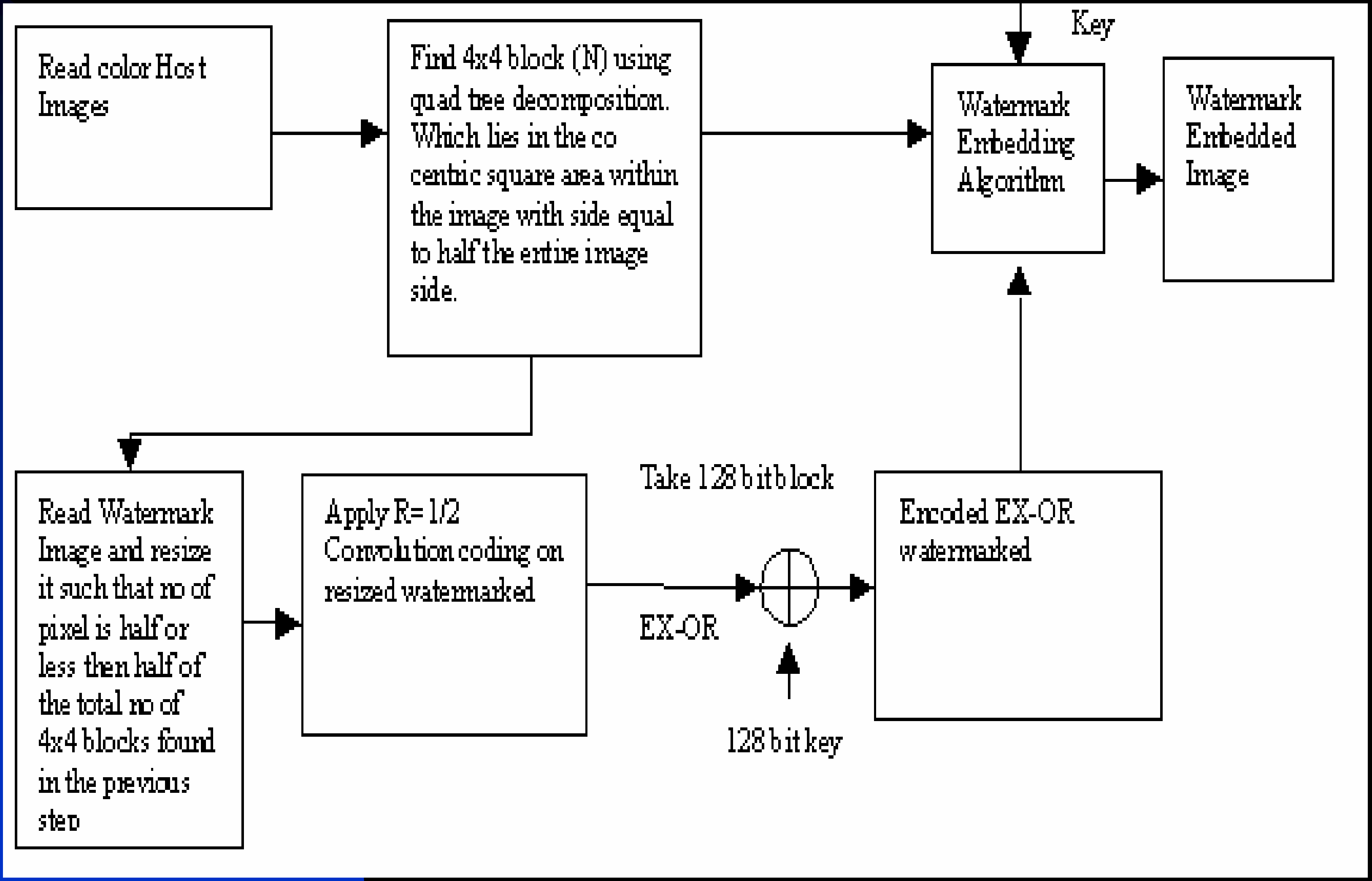


Quad trees

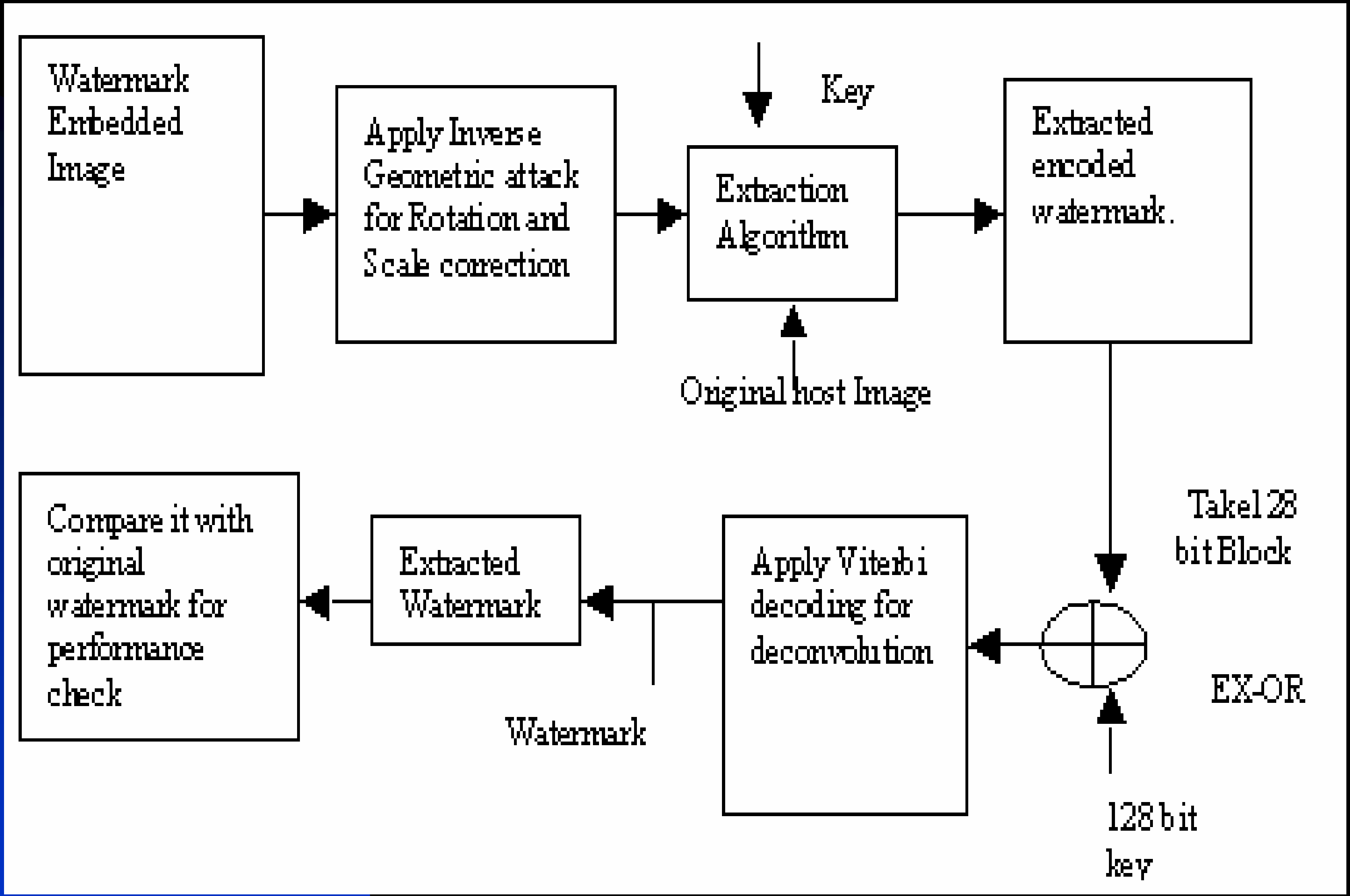
Advantage of Quad Tree Decomposition

- Small regions represent the presence of critical information of the image and hence are the good place for the watermark insertion

Spatial Domain Watermarking



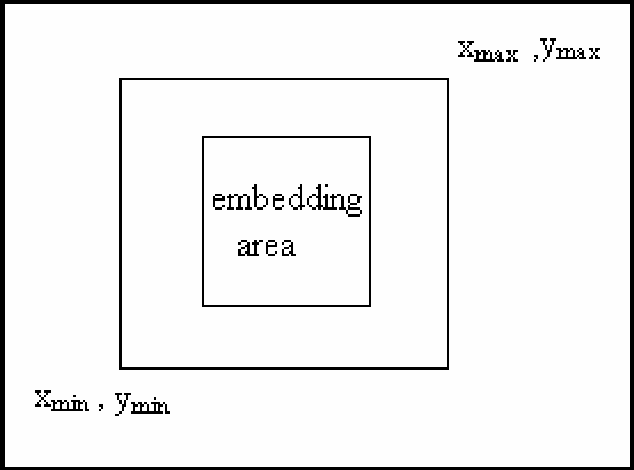
watermark insertion



watermark detection

Watermark Insertion Algorithm

Apply QUAD TREE decomposition on color image I (x, y) and select all 4x4 blocks in blue channels.



Watermark embedding region

Repeat (for each selected 4x4 block (H) of blue channel)

{ **Step 1:** Compute the average, I_{mean}, minimum, I_{min}, and maximum, I_{max}, of the the pixels in H.

Step 2: Classify each pixel into one of two categories, based on whether its intensity value is above or below the mean intensity of the block, i.e., the ijth pixel, bit_{ij} is classified depending on its intensity, I, as

$bit_{ij} \in Y_H$ if $I > I_{mean}$

$bit_{ij} \in Y_L$ if $I \leq I_{mea}$

whereY_H and Y_L are the high and low intensity classes, respectively.

Step3: Compute the means, $mean_L$ and $mean_H$, for the two classes, Y_L and Y_H.

Step 4: Define the contrast value of block H as

$$C_B = \max(C_{min}, \beta(I_{max}-I_{min}))$$

where β is a constant and C_{min} is a constant which defines the minimal value a pixel's Intensity can be modified.

Step5: Select a watermark bit (bit_w) randomly depending on the key value.

Step 6: Given the value of bit_w is 0 or 1, modify the pixels in H according to:

if $bit_w = 1$,

$I_{new} = I_{max} + \lambda$ if $I > mean_H$

$I_{new} = I_{mean} + \lambda$ if $mean_L \leq I < I_{mean}$

$I_{new} = I + \delta$ otherwise

if $bit_w = 0$,

$I_{new} = I_{min} - \lambda$ if $I < mean_L$

$I_{new} = I_{mean} - \lambda$ if $I_{mean} \leq I < mean_H$

$I_{new} = I - \delta$ otherwise

Where I_{new} is the new intensity value for the pixel which had original intensity value I and δ is a random value between 0 and C_B and λ is the watermark strength.

Step 7: The modified block of pixels, H_{new}, is then positioned the watermark image in the same location as the block, H, of pixels from the original host image.

} Until all watermark bits are inserted.

Step 8: Marge red, green and blue channel.

Watermark Extraction Algorithm

Apply QUAD TREE decomposition on original image I (x, y) and select all 4x4 blocks in blue channels that passes the homogeneity test, and whose all pixel coordinate (X, Y) values lies in the range $X_{min} + (X_{max} - X_{min})/4 <= X <= X_{max} - (X_{max} - X_{min})/4$ and $Y_{min} + (Y_{max} - Y_{min})/4 <= Y <= Y_{max} - (Y_{max} - Y_{min})/4$ where X_{min}, X_{max}, Y_{min}, Y_{max} are the minimum , maximum coordinate value in X and Y-axis of that image.

Repeat{

Step 1: take one 4x4 blocks of the host image and Corresponding 4x4 block of watermarked Image using the same coordinate value as of 4x4 block of host image .

Step2: a watermark bit is decoded by making the comparison of the two resultant values:

If $Average_w > Average_o$, then $bit_w = 1$

If $Average_w \leq Average_o$, then $bit_w = 0$

Where $Average_o$ and $Average_w$ are the averages for the 4x4 blocks of the host and Corresponding 4x4 block of watermarked Images, respectively.

} Until all watermark bit are extracted.

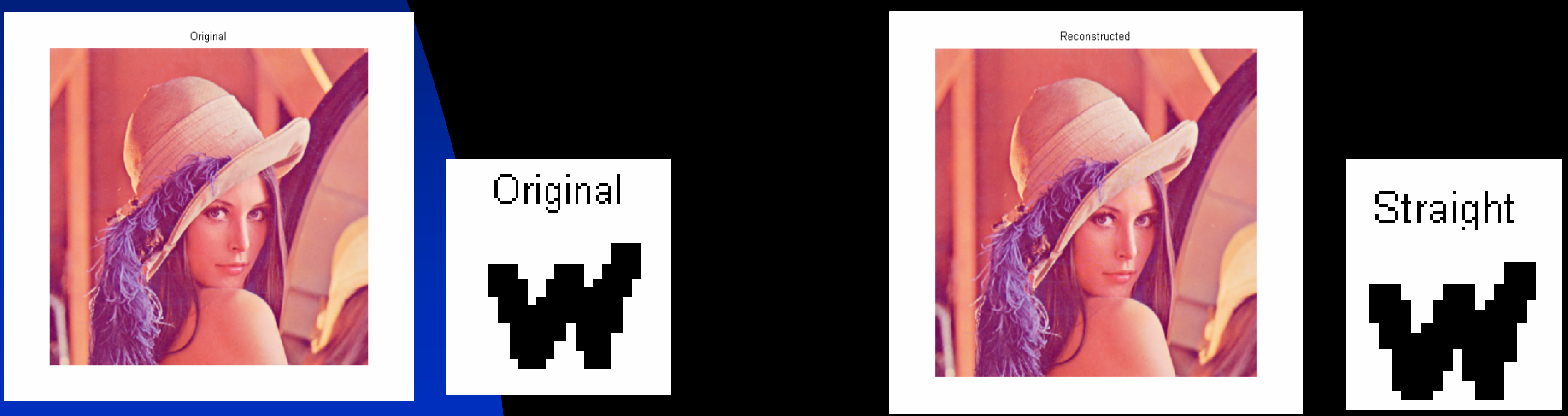
The decoded bits are then arranged in order using same key, which was used during embedding. Then, the encoded watermark is exclusive ored by 128 bit key and then decoded by viterbi decoding.

Results:

C_{min} =15, β=1 and λ=15 and convolution encoding rate R=1/2. Test Image LENA.BMP (512X512) ,Watermark is a 50x50 binary bitmap

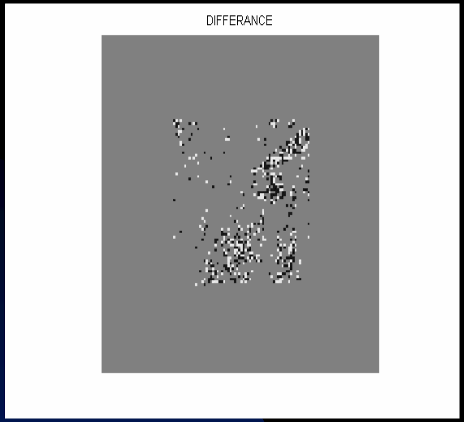
$$NCC = \sum_i \sum_j W_{ij} W'_{ij} \Big/ \sum_i \sum_j W_{ij}]^2$$

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{255^2}{\frac{MSE(R)+MSE(G)+MSE(B)}{3}}\right)$$

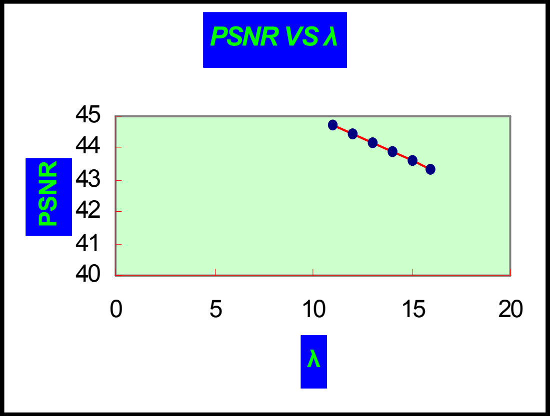


(a) (b) (c) (d)

Fig (a) original or host image (b) watermark image (c) watermarked images (d) Extracted watermark

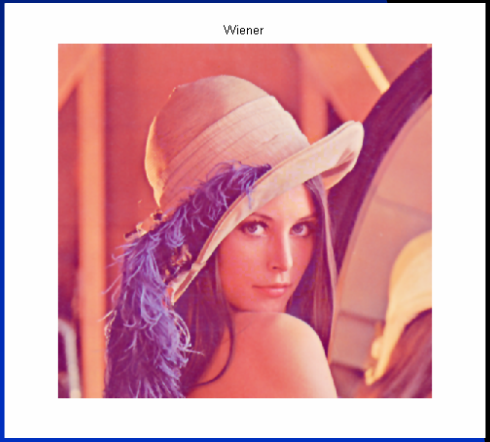


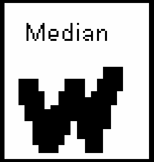
(e)



(f)

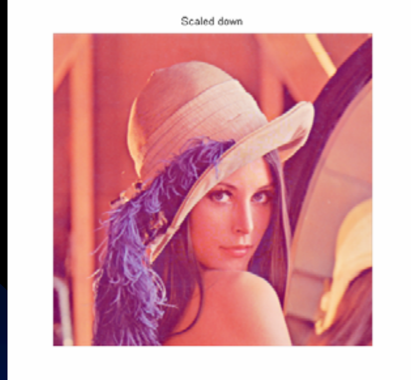
Fig (e) watermark embedded region. (f) the variation of PSNR w.r.t. Various values of λ.

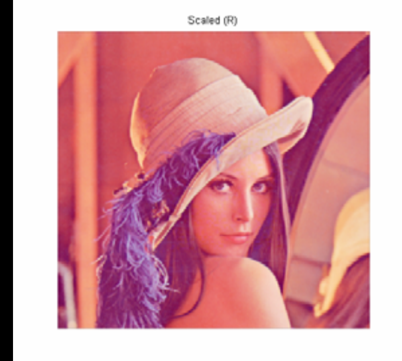


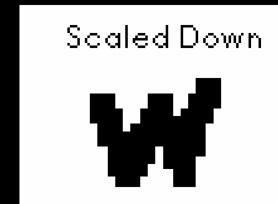


Wiener filtered watermarked image and extracted watermark ,mask(3x3)

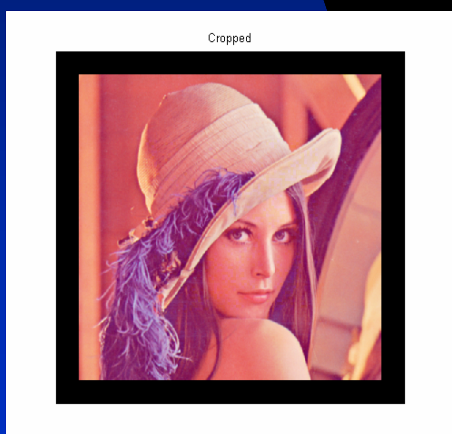
Median filtered watermarked image and extracted watermark,mask(3x3)

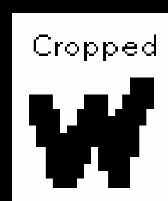




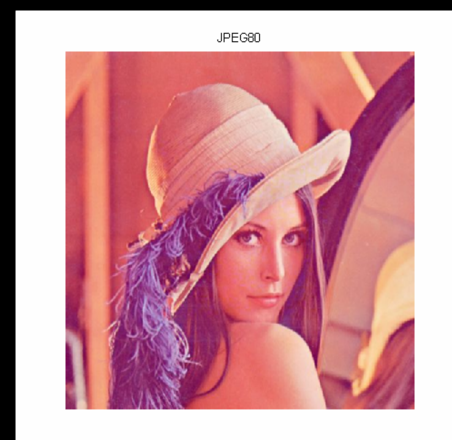


Scaled down watermarked image, rescaled image and extracted watermark, scale down factor=.75

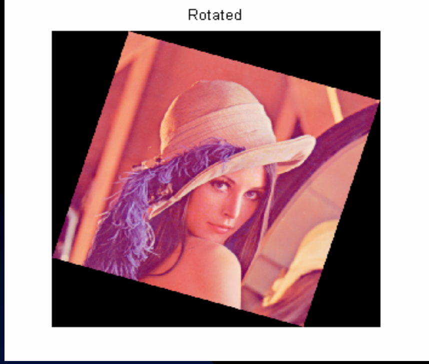


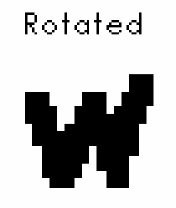


Cropped watermarked image and extracted watermark , mask(444x444)



Jpeg compressed watermarked image and extracted watermark





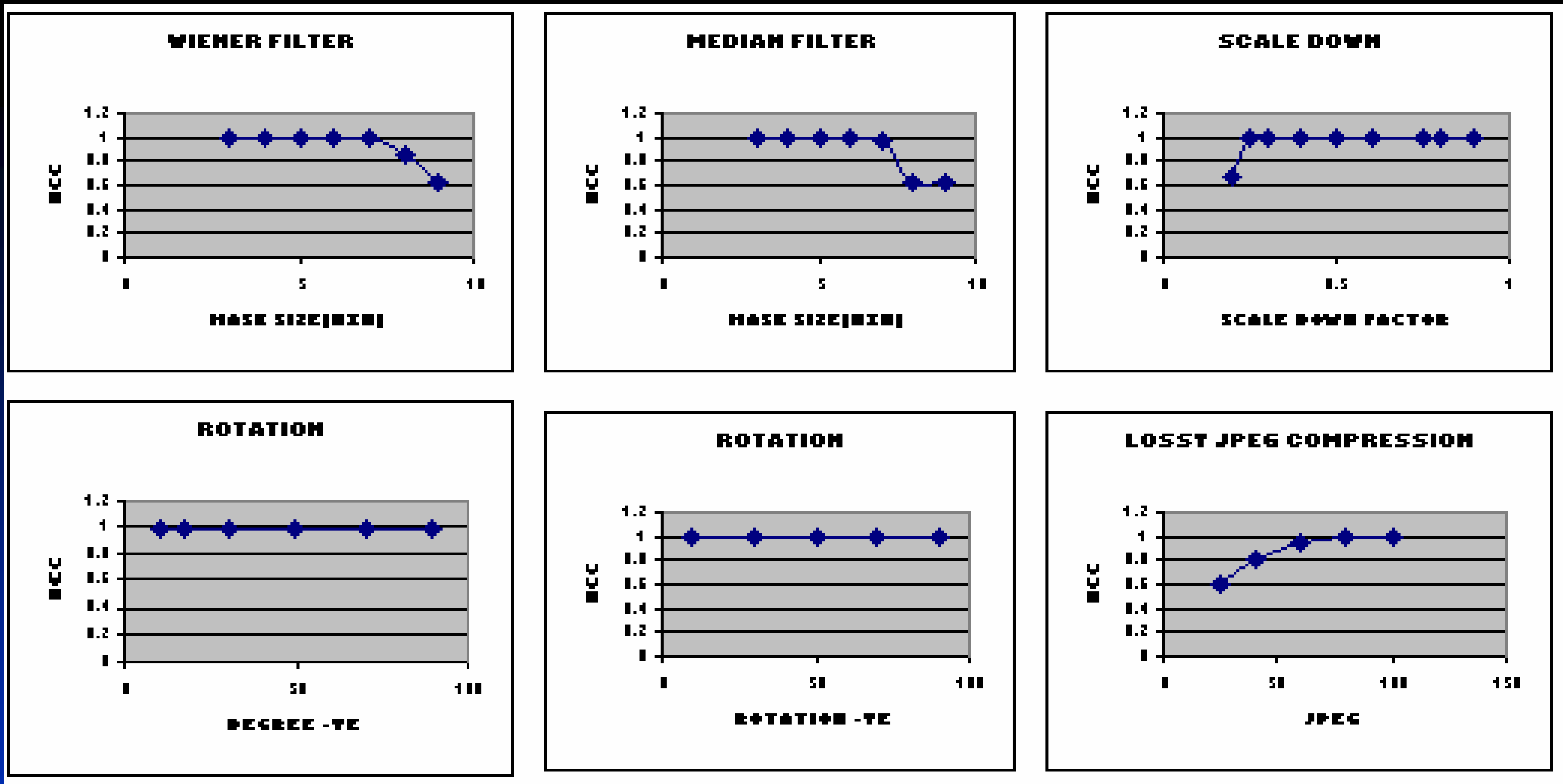
Rotated watermarked image, rotation corrected image and extracted watermark,angle=-17 degree

Table Showing the Normalized Cross correlation values for different operations

No.	Image processing Operation	NCC Value
1	Straight	1.0000
2	Wiener Filter	1.0000
3.	Median Filter	1.0000
4	Scaled down 0.75	1.0000
5	Jpeg 100	1.0000
6	Jpeg 80	1.0000
7	Jpeg 60	0.9487
8	Cropped	1.0000
9	Rotated –17 DEG	1.0000

Table lists the PSNR between original host image and watermarked image for various value of λ

λ	11	12	13	14	1 5	1 6
MSC	2.1753	2.3194	2.4751	2.6424	2.8212	3.0117
RMS	1.4749	1.5230	1.5732	1.6255	1.6797	1.7354
PSNR	44.7557	44.4771	44.1949	43.9108	43.6264	43.3427



Graphs for different operations showing variation of NCC value against various factors

Wavelet Domain Watermarking

Discrete wavelet Transform (DWT)

- The DWT and IDWT can be mathematically stated as follows

Let

$$H(\omega) = \sum_k h_k e^{-jk\omega}, \quad \text{and } G(\omega) = \sum_k g_k e^{-jk\omega}.$$

- A signal, x [n] can be decomposed recursively as

$$c_{j-1,k} = \sum_n h_{n-2k} c_{j,n}$$

and

$$d_{j-1,k} = \sum_n g_{n-2k} c_{j,n}$$

- the signal x [n] can be reconstructed from its DWT coefficients recursively

$$c_{j,n} = \sum_k h_{n-2k} c_{j-1,k} + \sum_k g_{n-2k} d_{j-1,k}.$$

- To ensure the IDWT and DWT relationship, the following orthogonality condition on the filters $H(\omega)$ and $G(\omega)$

$$|H(\omega)|^2 + |G(\omega)|^2 = 1.$$

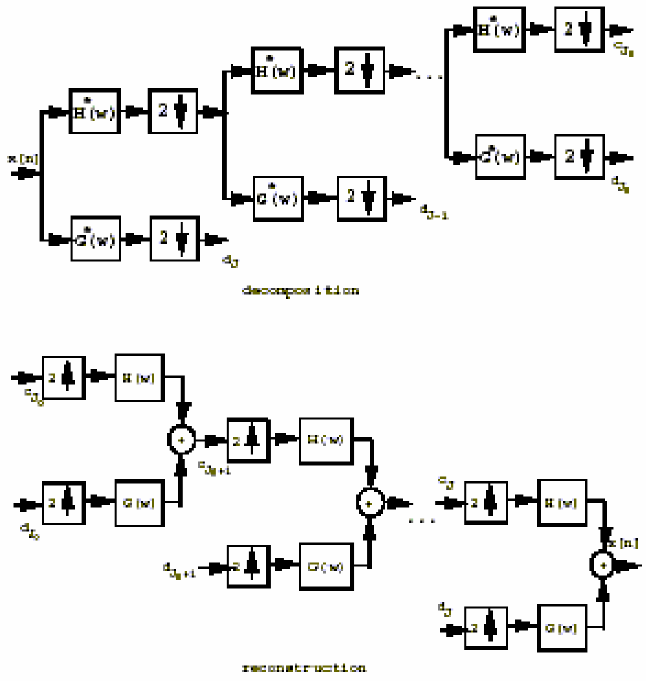


Figure 6.1 DWT for one dimensional signals.

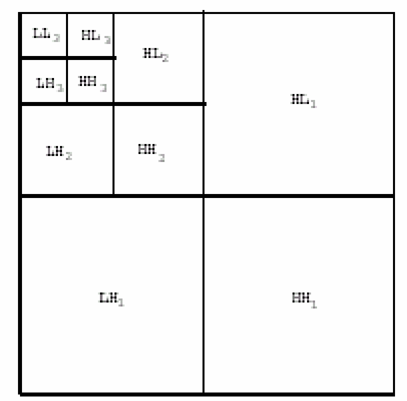


Figure. DWT pyramid decomposition of an image.

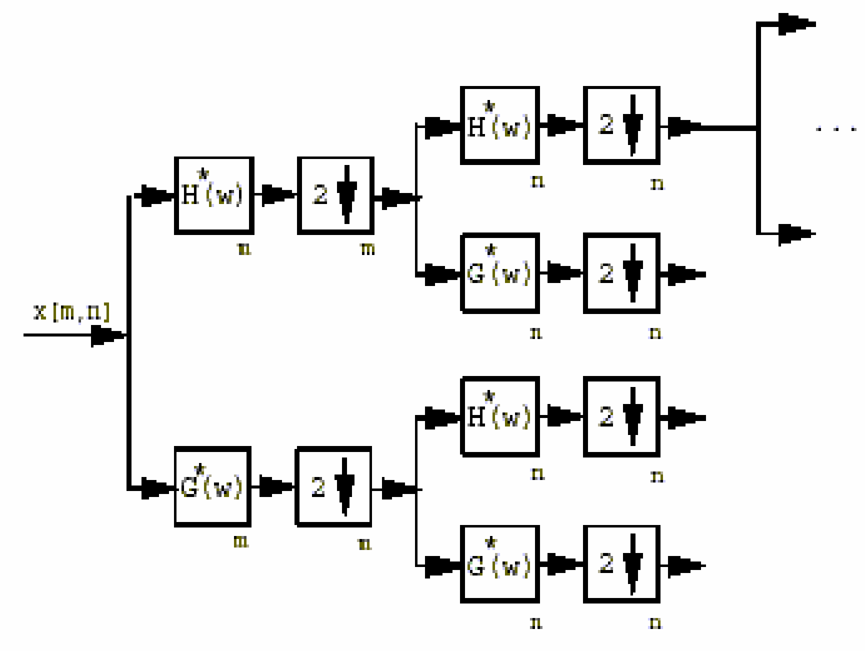


Figure 6.2 DWT for two dimensional images.

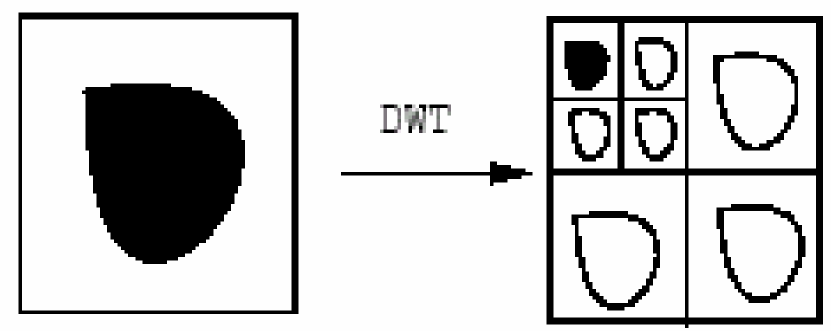
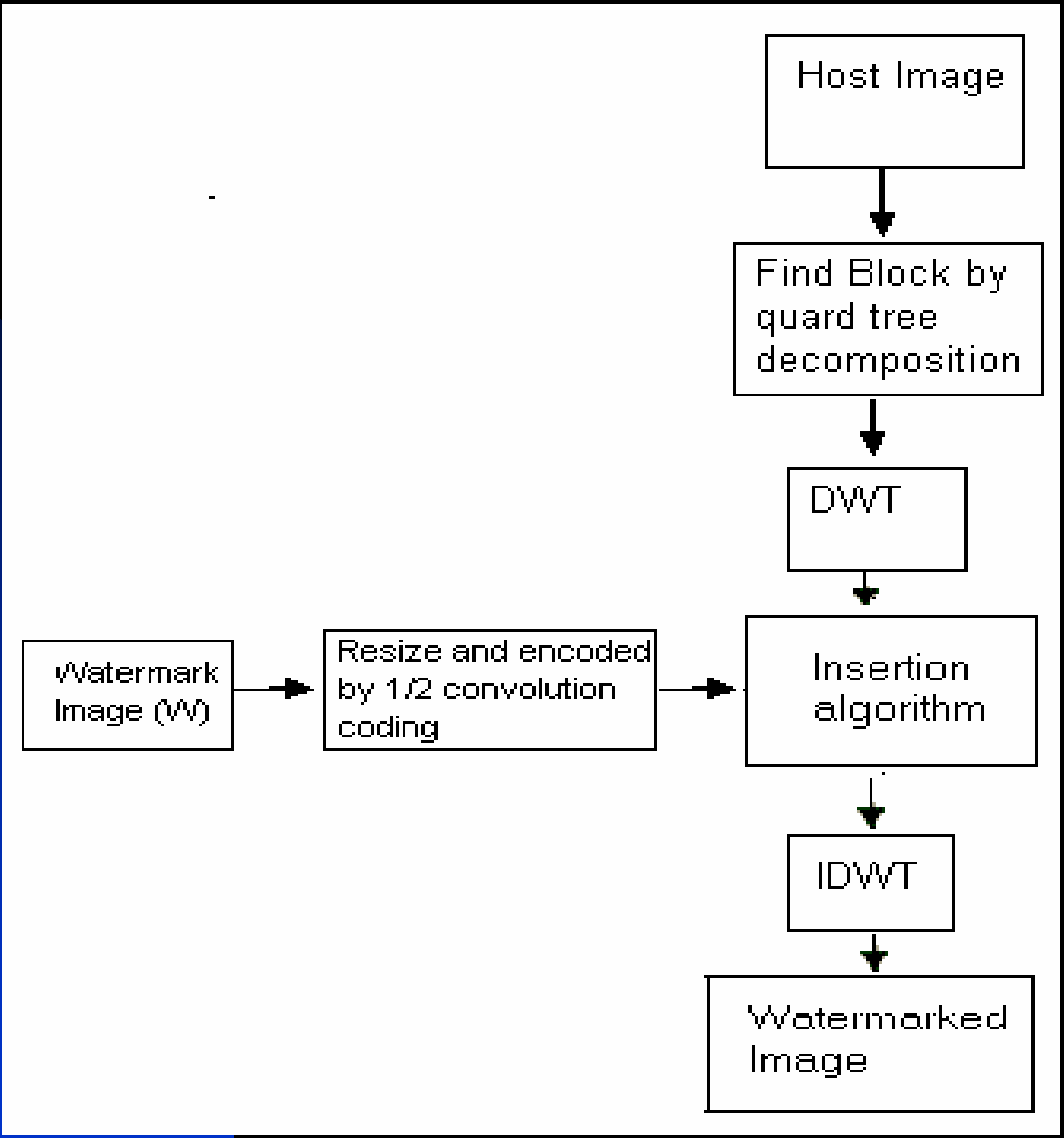
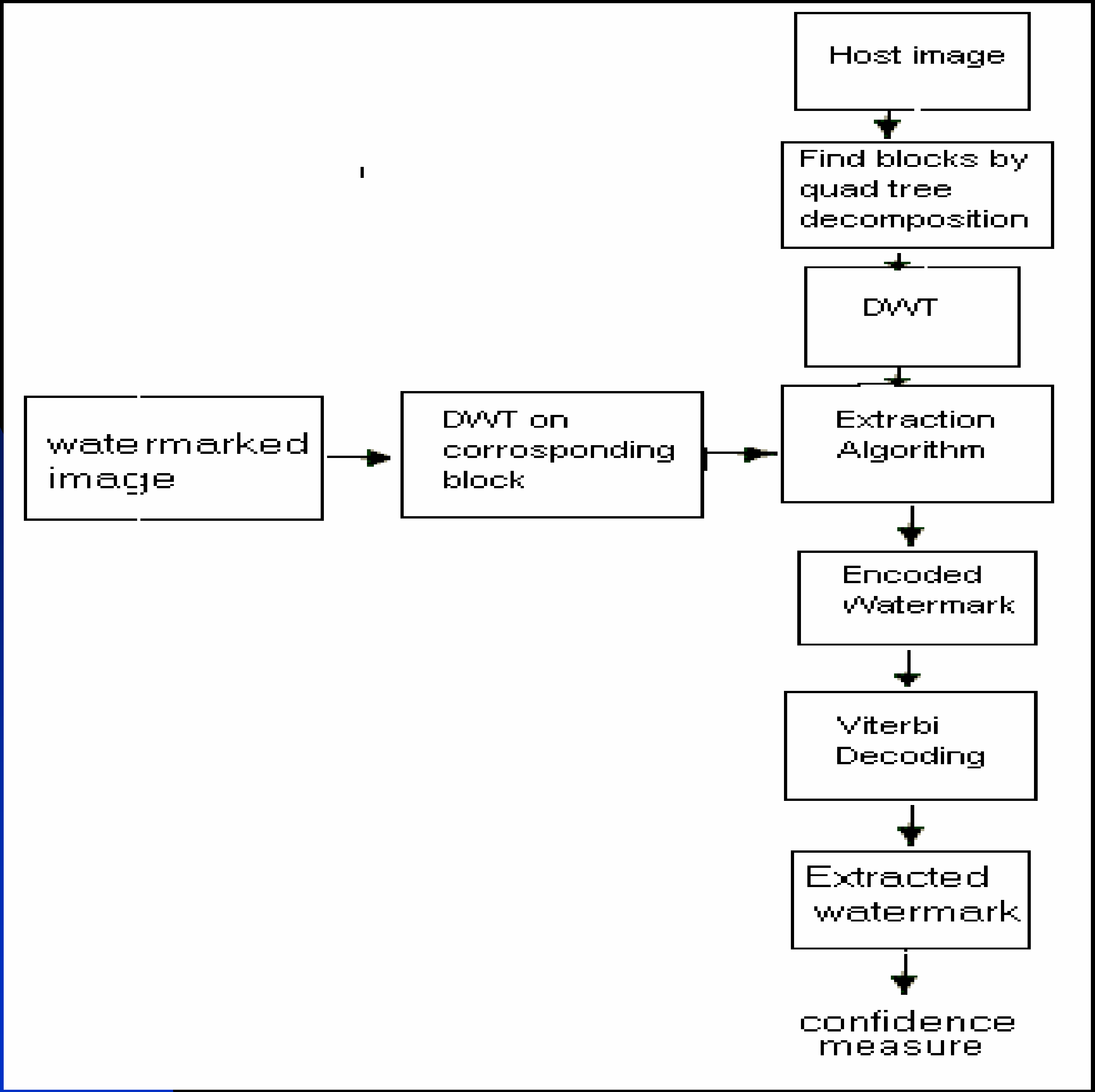


Figure. Examples of a DWT pyramid decomposition



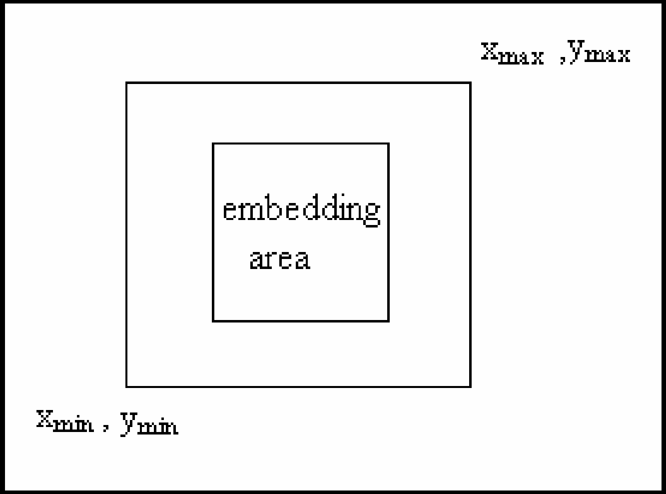
watermark insertion



watermark detection

Watermark Insertion Algorithm

The host image B (x, y), which is used to embed a watermark is segmented by quad tree decomposition to select all 4x4 blocks



Watermark embedding region

$B' = [b_1, b_2 \ldots\ldots b_M] = \text{Quadtree}(B,T)$

T=20 is the threshold value used by *Quadtree* and b_i denote i^{th} block such that $1 =< i <= M$ and function *Quadtree* is used for quad tree decomposition of image in spatial domain.

The bit embedding strategy is as follows.

Repeat (for blue component of each selected 4x4 block $b_i \in B'$)

{1: perform single scale wavelet transform of block b_i.

2: compute average(C_{avg}) of all coefficient C_i found in step 1.

$$C_{avg} = 1/16 \Sigma C_i$$

3: for all coefficients $C_H \in Ci$ such that $C_H > C_{avg}$

4: Select a watermark bit (bit_w) randomly depending on the key (k_2) value from watermark bit sequence (W'''_{2N}).

5: Given the value of bit_w is 0 or 1, modify all the coefficients $c_h \in C_H$ according to:

if $bit_w = 1$,

$$c'_h = c_h + \lambda * c_h$$

if $bit_w = 0$,

$$c'_h = c_h - \lambda * c_h$$

Where c'_h is the new value of coefficient in C_H which had original Coefficient value of c_h and λ is the watermark strength

6: perform inverse single scale wavelet transform after modification of Coefficient to get modified block b'_i.

7: The original block of pixels b_i is then replaced by b'_i

} Until all watermark bits are inserted.

8: Marge red, green and blue channel to get the watermarked image

Watermark Extraction Algorithm

Apply quad tree decomposition on original image B (x, y) and select all 4x4 blocks that passes the homogeneity test, and whose all pixels (X, Y) lies in the range $X_{min} + (X_{max} - X_{min})/4 <= X <= X_{max} - (X_{max} - X_{min})/4$ and $Y_{min} + (Y_{max} - Y_{min})/4 <= Y <= Y_{max} - (Y_{max} - Y_{min})/4$ where X_{min}, X_{max}, Y_{min}, Y_{max} are the minimum , maximum coordinate value in X and Y axis of the image

Repeat {

1: Take one 4x4 blocks (b_i) of the host image and Corresponding 4x4 block (b'_i) of watermarked Image using the same coordinate value as of 4x4 block of host image .

2: perform single level wavelet transform of block b_i and b'_i to get the Coefficient in wavelet domain which is defined as

$$C_i = WT(b_i)$$

$$C'_i = WT(b'_i),$$

where WT denotes single level wavelet transform. C_i and C'_i are the vectors of the same length representing wavelet coefficient

3: compute average of all coefficient C_{avg} of C_i .

4: initialize variable sum_w=0 and sum_o =0;

5: for j=1:16

```
        if  Ci (j) > C avg
                sum_w = sum_w + C'i (j);
                sum_o = sum_o + Ci (j);
        end
  end
```

6: a watermark bit (bit $_w$) is decoded by making the comparison

if sum_w < sum_o, then bit $_w$ = 0

if sum_w >= sum_o, bit $_w$ = 1

7: find original position (pos) of extracted watermark bit (bit$_w$) using Key (k_2) as seed.

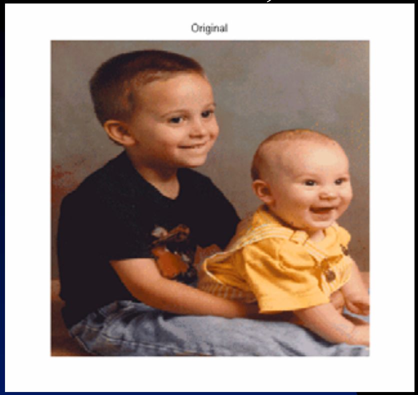
8: W^2 [pos]= bit $_w$. Where W^2 is an array for storing extracted Watermark bits.

} Until all watermark bit are extracted.

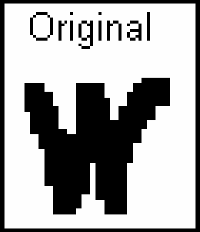
Then, the encoded watermark is exclusive ored by 128 bit key and then decoded by viterbi decoding.

Results:

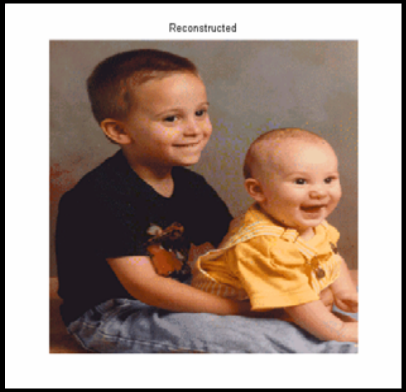
λ=.3 and convolution encoding rate R=1/2. Test Image kids.tif (512X512) ,Watermark is a 50x50 binary bitmap



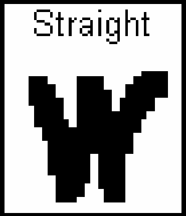
(a)



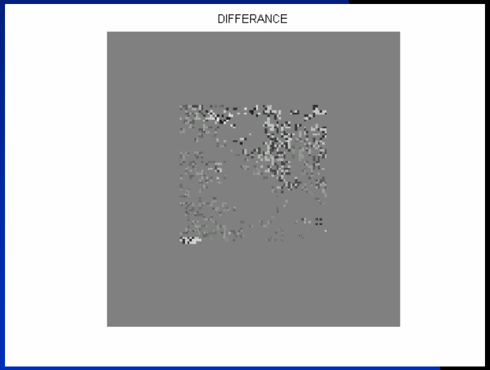
(b)



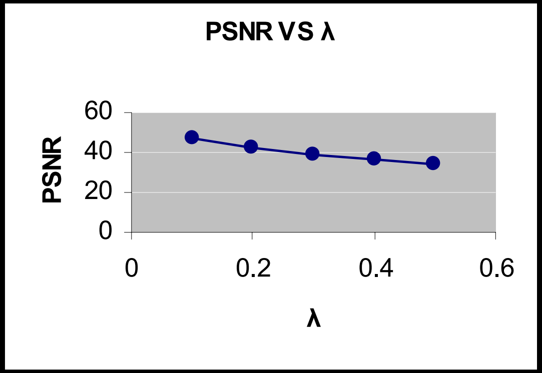
(c)



(d)

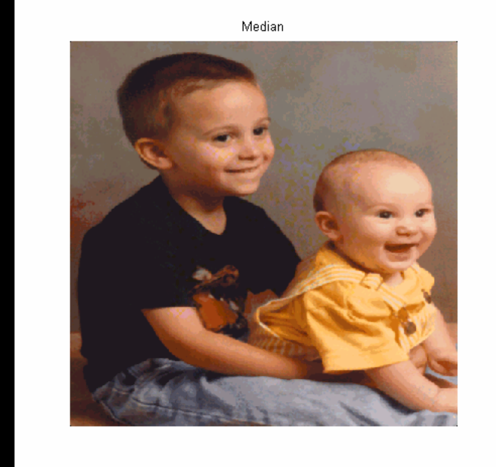


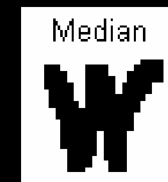
(e)



(f)

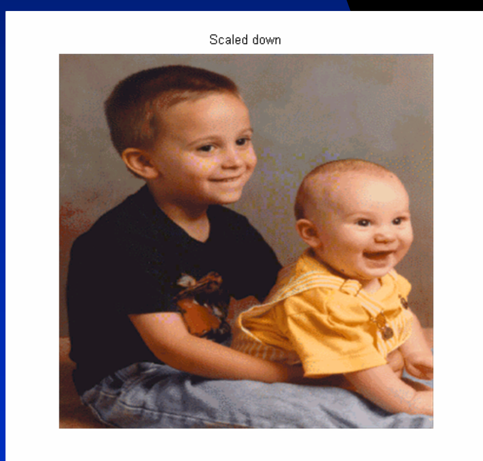
Fig (a) original or host image (b) watermark image (c) watermarked images (d) Extracted watermark (e) watermark embedded region. (f) the variation of PSNR w.r.t. various values of λ.

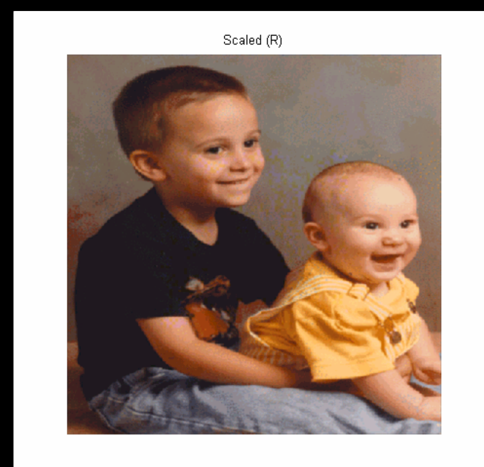


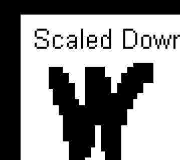


Wiener filtered watermarked image and extracted watermark,mask(3x3)

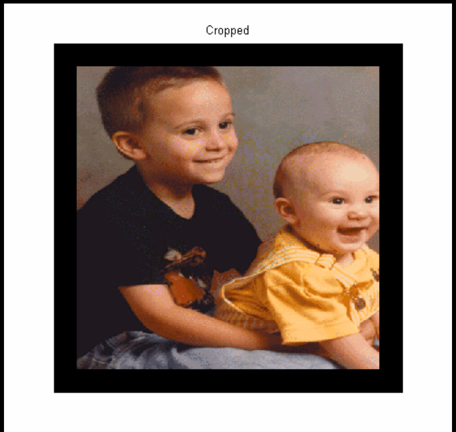
Median filtered watermarked image and extracted watermark,mask(3x3)

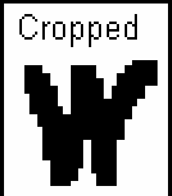




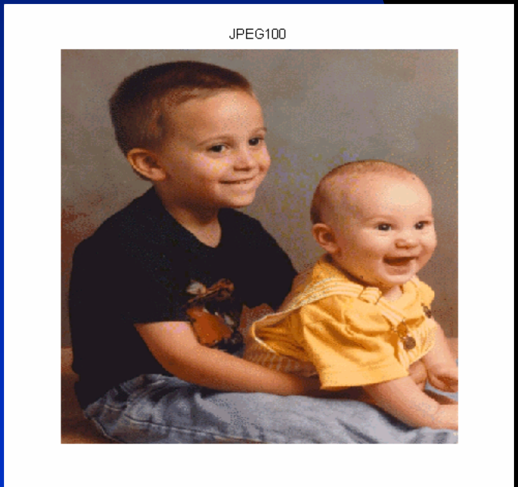


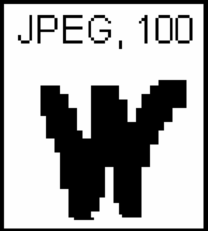
Scaled down watermarked image, rescaled image and extracted watermark,scale down factor=.75

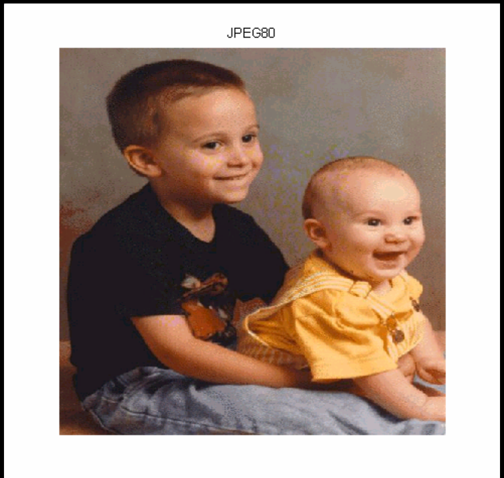


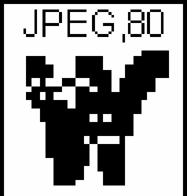


Cropped watermarked image and extracted watermark ,mask(444x444)

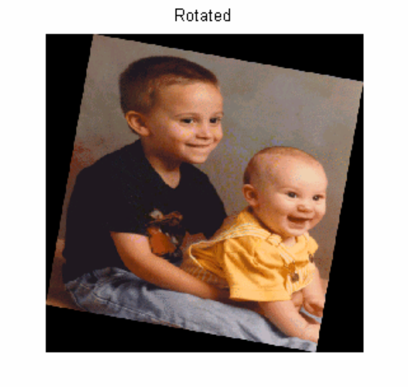


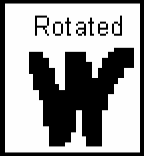






Jpeg compressed watermarked image and extracted watermark





Rotated watermarked image, rotation corrected image and extracted watermark,angle=-10 degree

Table Showing the Normalized Cross correlation values for different operations

No.	Image processing Operation	NCC Value
1	Straight	1.0000
2	Wiener Filter	1.0000
3.	Median Filter	1.0000
4	Scaled down 0.75	1.0000
5	Jpeg 100	1.0000
6	Jpeg 80	0.9825
7	Jpeg 60	0.8465
8	Cropped	1.0000
9	Rotated –10 DEG	1.0000

Table lists the PSNR between original host image and watermarked image for various value of λ

λ	.1	.2	.3	.4	.5
MSC	1.4380	4.0897	8.5074	14.6910	22.6406
RMS	1.1991	2.0223	2.9167	3.8329	4.7582
PSNR	46.5533	42.0139	38.8328	36.4603	34.5819

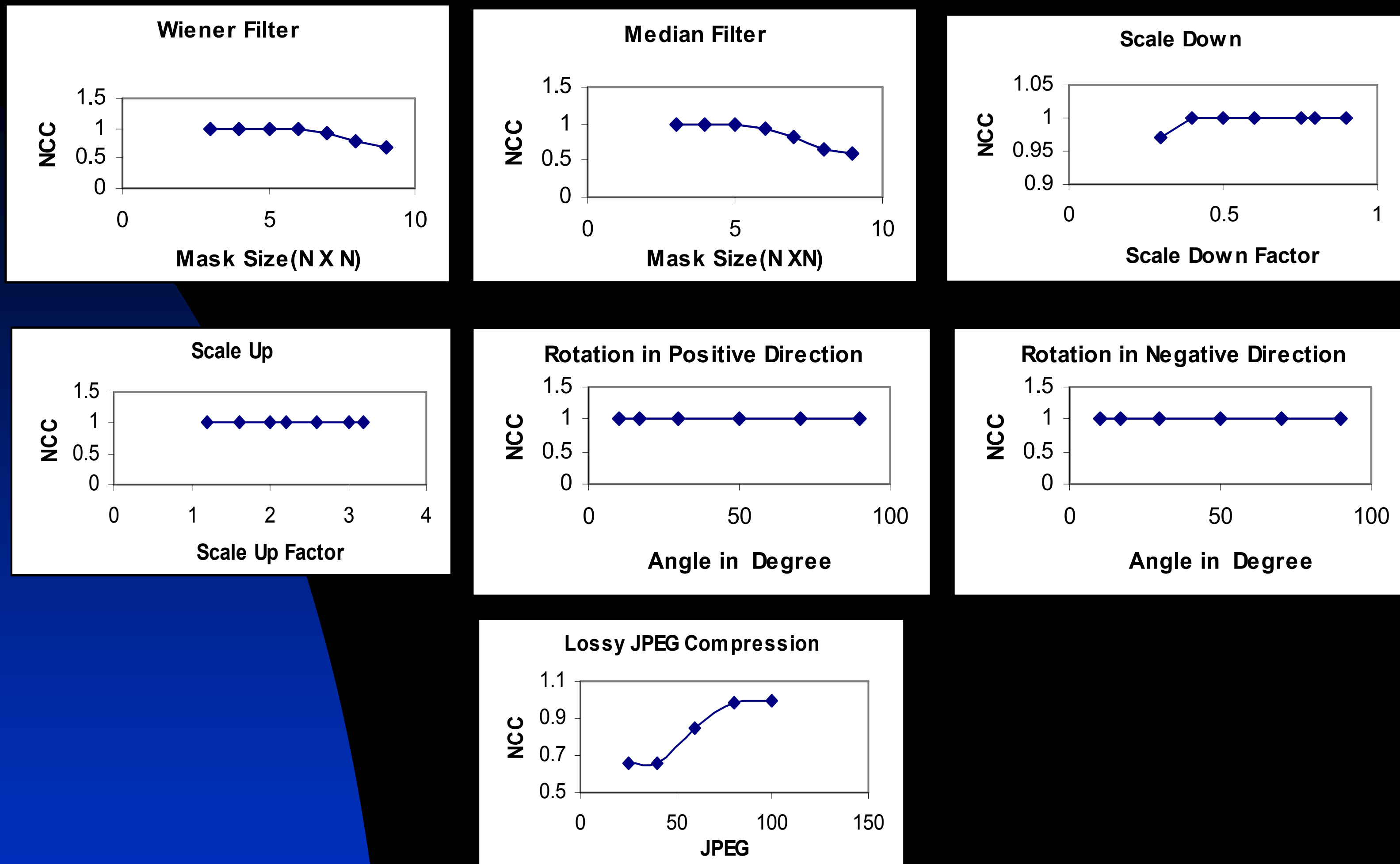


Fig Graphs for different operations showing variation of NCC value against various factors

Conclusion and Research Directions

- Both the algorithms are robust to common image processing operations, as shown by the results.
- But none of the techniques proposed so far seems to be robust to all possible attacks
- Most of the current methods require the original image at watermark recovery this may prove as serious limitation at certain moments, as the image may not be accessible
- Very few algorithms deal with the problems associated with geometric changes.
- Very few algorithms proposed in the literature consistently survive the random bending attacks.
- Bulk of the literature contains linear additive watermarks, few algorithms resist the watermark copy attack and ambiguity attack.
- Consequently further work needs to be done to improve the robustness of algorithms.

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1) Spatial domain robust blind Watermarking scheme for color image, *Image and Vision Computing (International Journal, Publisher Elsevier)*

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2) Quad Tree Region Splitting Approach to Spatial Domain Robust Color Image Watermarking, *International Journal of Image and Graphics (IJIG), (Publisher World Scientific)*.

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3) Region Splitting Approach to Robust Color Image Watermarking In Wavelet Domain, *International Journal of Information Technology, (Publisher* Computer Society of Singapore).

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