Chapter-VI

ANALYSIS OF EXPERIMENTAL RESULTS
6.1. Introduction to Evaluation Metrics

In this chapter, mainly demonstration on the robustness of four proposed watermarking methods is described. The resistance of the proposed watermarking algorithms to various distortions was studied in a series of experiments on grayscale images. Each algorithm is tested with a variety of images, but for the sake of space, here only the results are given for host gray image Lena and robustness test for various image processing operations and geometric transformations.

It is already mentioned in sec 1.6. that the algorithms proposed in this thesis are the thought of as an extension of Subhash Kak et al. [74, 79] and Feng Liu et al. [98]. In chapter ‘3’ blind watermarking algorithm exclusively based on d-sequences is explained. In chapter ‘4’ non-blind watermarking algorithm exclusively based on content based features is described. In chapter ‘5’ blind watermarking algorithms which are developed based on both combined properties of content based features and d-sequences is described. All algorithms are implemented based on MATLAB 7.0.1. image processing toolbox for experimental analysis.

How one can provide metrics for the evaluation of watermarking techniques? Capacity and speed can be easily evaluated using the number of bits per cover size, and computational complexity, respectively. The systems use of keys, in this research work d-sequence acts as a key which gives security to the system, and the imperceptibility by correlation between the original images and watermarked counterpart.

The more difficult task is providing metrics for perceptibility and robustness. Metrics suggested for the evaluation of perceptibility are Peak Signal to Noise Ratio (PSNR) and Weighted Peak Signal to Noise Ratio (WPSNR). The similarity of the host image and the watermarked one is evaluated by their two dimensional CORRELLATION (CORR) coefficient. The robustness is declared based on the number of attacks and improvement on three parameters.

In this research work the results are evaluated based on CORRELLATION, PSNR and WPSNR for the resultant images. CORRELLATION is calculated between watermark image and extracted watermark image. PSNR and WPSNR are the
measurements between host image and watermarked image. The normalized correlation is given by the equation 6.1.

\[
NC = \frac{\sum_{i} \sum_{j} (x_{i,j} - x) (x'_{i,j} - x)}{\sqrt{\sum_{i} \sum_{j} (x_{i,j} - x)^2 \sum_{i} \sum_{j} (x'_{i,j} - x')^2}}
\] (6.1)

Watermark image is denoted by \( x \), and the retrieved watermark is denoted by \( x' \).

Signal to noise ratio (SNR) effectively measures the quality of the watermarked image as compared to the original image. This difference is represented as an error function that shows how close the watermarked image is to the original image and it is written as shown in equation 6.2.

\[
e(x,y) = |l(x,y) - lw(x,y)|
\] (6.2)

The larger the value of \( e(x,y) \) the greater is the distortion caused by the watermark and the attacks. One of the simplest distortion measures is the mean square error (MSE) function which is given by the formula as shown in equation 6.3.

\[
MSE = \frac{\sum_{i} \sum_{j} [f(i,j) - F(i,j)]^2}{N^2}
\] (6.3)

The peak signal to noise ratio (PSNR) is calculated by using the formula \( \sqrt{MSE} \) which is called the root mean square error and 255 is the maximum value of luminance level and is given by the equation 6.4.

\[
PSNR = 20 \log_{10} \left( \frac{255}{\sqrt{MSE}} \right)
\] (6.4)

It should be noted that PSNR does not take aspects of the HVS into consideration although it provides an overall evaluation of the difference between
the host or original and the watermarked image. For this reason, another perceptual quality measure called the weighted peak signal to noise ratio (WPSNR) will be used. This metric takes into account the objective measure as well as the HVS. The human eye is less sensitive to changes in highly textured areas and hence an additional parameter called the noise visibility function (NVF) is introduced [16]. This helps to calculate the change in the perceptual quality more accurately. The formula for WPSNR is given by equation 6.5.

\[
WPSNR = 20 \log_{10} \left( \frac{255}{\sqrt{MSE \times NVF}} \right)
\]  

(6.5)

NVF uses a Gaussian model to estimate the amount of texture content in any part of an image. In regions with edges and texture NVF will have a value greater than 0 while in smooth regions the value of NVF will be greater than 1. The formula to calculate this factor as a simplified function is given by the equation 6.6.

\[
NVF = \text{NORM} \left( \frac{1}{1 + \delta^2 \text{block}} \right)
\]  

(6.6)

Where ‘\( \delta \)’ is the luminance variance for the 8x8 blocks and NORM is normalization function.

Evaluation of the robustness of the developed watermarking algorithms is done, by performing a set of attacks on the host images using StirMark 3.1 [71, 85] and carried out the watermark detection steps. Most of the complex image manipulations such as projection can be modeled as local RST operations. Some of the basic attacks are listed in section 1.3 of first chapter. All attacks were performed using StirMark and Matlab.

6.2. Attacks and Analysis of Results

In chapter ‘3’ algorithm using exclusively decimal sequences is explained.

For evaluation of the developed algorithm, experiments are conducted using various gray scale images. The host image used is Lena as shown in the Figure.3.2.a of size 512x512. The prime number that is used to generate the d-sequence is ‘17’
and on using the appropriate scaling factor and threshold it is noticed that the watermark is recovered perfectly well. Here a watermark image of size 16x16 pixels as shown in Figure.3.2.b. is used.

In this proposed algorithm original or host image is first subdivided into sub blocks of size 8x8 pixels, then DCT is applied to each sub block. In this proposed work, in prior the three metrics or parameters CORR, PSNR and WPSNR are calculated for all the locations of sub block 8x8. Among all the locations one best location is chosen to embed the d-sequence based on the watermark bit, for which the three parameters are optimum. Experimental analysis is done for various host and watermark images.

The proposed algorithm is based on the d-sequence. Since the watermark bit is embedded in the best location, the rate of watermark withstanding capacity is very high, the quality of the watermark image is good in terms of perceptibility, PSNR and WPSNR. From the experimental results of table 3.1 it was noticed that the proposed algorithm is superior to all other watermarking algorithms using d-sequence in terms of both PSNR and robustness [66, 67, 68, and 79]. The proposed algorithm is shown to be more robust for median filter attack, compared to all other d-sequence algorithms, this is the exclusive feature of this algorithm. This algorithm is also tested for salt & pepper noise based on the chosen random values the CORR, PSNR and WPSNR will be varied. This indicates that an embedded watermark is still recoverable even after the common image processing operations on the watermarked image. And hence this algorithm is highly suitable for the Copyright protection, Owner identification and Copy control.

(1) Analysis of Scaling factor or Gain factor (‘k’)

The scaling or gain factor ‘k’ denotes the strength of the watermark and it can be used to control the overall robustness and the quality of the image. Increasing this value increases the strength of the watermark but introduces a gradual visible distortion while decreasing this value would result in better hiding of the watermark and hence better quality but decreases the strength of the watermark. An optimal value needs to be decided upon depending on the watermark and the d-sequence
before embedding. Upon inverse transformation the watermark will be scattered over the entire image and watermarked image is obtained.

In this proposed work as mentioned earlier the scaling or gain factor 'k' is set according to the content and the required quality of the Watermarked image to 20 which is an optimum value. The 'k' value is chosen such that the watermarked image should resemble the host image i.e. as if no watermark is embedded. How the CORR, PSNR and WPSNR vary with the variation of 'k' is shown in the Table 6.1.

Table 6.1: CORR, PSNR and WPSNR with the variation of 'k'.

<table>
<thead>
<tr>
<th>Watermarked Image</th>
<th>Recovered watermark</th>
<th>k_gain</th>
<th>CORR</th>
<th>PSNR</th>
<th>WPSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$$</td>
<td>3</td>
<td>0.8700</td>
<td>60.1720</td>
<td>45.9856</td>
<td></td>
</tr>
<tr>
<td>$$</td>
<td>10</td>
<td>1</td>
<td>55.9302</td>
<td>42.1239</td>
<td></td>
</tr>
<tr>
<td>$$</td>
<td>20</td>
<td>1</td>
<td>52.9704</td>
<td>40.3639</td>
<td></td>
</tr>
<tr>
<td>$$</td>
<td>40</td>
<td>1</td>
<td>46.1066</td>
<td>34.7071</td>
<td></td>
</tr>
</tbody>
</table>

The scaling factor denotes the strength of the retrieved or extracted watermark image and this can be observed from the Table 6.1. If the 'k' is low value chosen as '3' the PSNR and WPSNR is very high i.e. the overall robustness and the quality of the watermarked image, but CORR is decreased which indicates the degradation in retrieved watermark. By increasing this 'k' value as '40' increases the strength of the watermark image which has maximum CORR but introduces a
gradual visible distortion in watermarked image for which PSNR and WPSNR are very low, which can be observed from the Table.6.1.

Hence an optimal value of gain factor ‘k’ chosen in the proposed work is ‘20’ needs to be decided for which the three metrics CORR, PSNR and WPSNR are optimum and the watermarked image is nearly equal to host image which can be observed from the Table.6.1.

(ii) Analysis of Embedding Time Evaluations

Computational costs are compared by measuring the embedding time taken by each of the embedding methods. Intuitively, the HVS model has the highest amount of computation because the weight function calculation involves many Summation/convolution operations. On the contrary, the constant energy embedding method should be the fastest because there is no computation of weight function.

Experiments showed that the Simplified embedding method takes as little time as the constant energy embedding. On the other hand, it is observed that the HVS embedding method requires longer processing duration. The detection of watermark prior to attacks was done on each of the embedded images. In all cases, the watermarks were detected successfully.

But the proposed algorithm is exclusively for Copyright protection, Owner identification and Copy control, for which there is no much importance of embedding time.

(iii) Analysis of Imperceptibility Evaluations

Metrics suggested for the evaluation of imperceptibility are CORR, PSNR and WPSNR. To evaluate the imperceptibility quality of watermarked images, WPSNR of each watermarked image is measured. WPSNR is chosen due to its higher accuracy over PSNR metric. The PSNR and WPSNR values of watermarked images produced by the proposed embedding method after each of the attack is measured their values are shown in Table.3.1.

The Simplified proposed embedding method uses gain factor ‘k’ = 20. Such arrangements are necessary since the major interest is in performance factors
comparison. Although the ‘k’ values of the embedding methods are different, the
effective embedding strengths after multiplication with its respective weight
functions do not differ much. This can be noticed from the Table 6.1. Constant
energy embedding method has the lowest visual quality overall, and the Human
Visual System (HVS) embedding method achieves the highest visual quality in
general. It is also noticed that the Simplified embedding method obtained visual
qualities slightly lower than the HVS embedding method.

(iv) Analysis of Data Payload or Capacity

In the proposed watermarking algorithm instead of 8x8 blocks processing
4x4 block processing is considered, the data payload can be increased but robustness
decreases i.e. PSNR and WPSNR decreases. Imperceptibility quality is also reduced
i.e. CORR value decreases. This can be observed from experimental results		tabulated in Table 3.1. So it can be noticed that while processing an algorithm there
must be a tradeoff maintained among the three parameters Data payload,
Imperceptibility and Robustness if the algorithm has to workout perfectly.

This method how data payload can be increased is shown by considering
two transforms in section 3.4.2 namely DCT and IntDCT. Both the transforms have
the advantages in their own way. Even though IntDCT reduces the computational
complexity, the clarity of the retrieved watermark images is much by using DCT.
But by using IntDCT blocking artifacts can be reduced.

In chapter ‘4’ non blind watermarking algorithm using exclusively content-
based features is explained.

For evaluation of the developed algorithm, experiments are conducted using
gray scale images. The host image considered for the experimentation is 512x512
Lena. The watermark image is of 64 x 64 size which is a cameraman image.
According to the proposed algorithm the host image of size $512 \times 512$ Lena is chosen and $8 \times 8$ DCT block processing is used, then the $64 \times 64$ size matrix is generated using DC values. The generated $64 \times 64$ matrix is used for further analysis of watermark embedding and retrieving process. In this particular analysis if the host image size is $512 \times 512$, inevitably the maximum watermark size can be $64 \times 64$. This Proposed algorithm Jnd_dct_svd is an improved method of Feng Liu et al. method also called as dct_svd method [98].

The results are evaluated using PSNR between the host image and watermarked image and CORR coefficient between the original watermark and extracted watermark. In order to show the proposed algorithm is better over watermark algorithm using dct_svd [98] comparative experimental results are shown in Table.3.1.

By adding content based features in the process of embedding how best the robustness of proposed algorithm was improved compared to Feng Liu et al. method is shown in the Table.3.1. From the results of Table.3.1 how best robustness and correlation of the proposed method is improved compared to Feng Liu et al. method is computed, this analysis is shown in Table.6.2 and Table.6.3.
Table 6.2: Robustness of proposed method in terms of PSNR.

<table>
<thead>
<tr>
<th>Test method</th>
<th>Proposed method (Ind_dct_svd)</th>
<th>Feng Liu et al method (dct_svd)</th>
<th>IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>No attack</td>
<td>75.2235</td>
<td>65.3335</td>
<td>9.8900</td>
</tr>
<tr>
<td>Median filter</td>
<td>38.6091</td>
<td>37.2094</td>
<td>1.3997</td>
</tr>
<tr>
<td>Salt&amp; pepper</td>
<td>44.0978</td>
<td>44.0231</td>
<td>0.0747</td>
</tr>
<tr>
<td>Rotation</td>
<td>32.7569</td>
<td>32.5486</td>
<td>0.2083</td>
</tr>
<tr>
<td>Cropping</td>
<td>27.4043</td>
<td>27.4040</td>
<td>0.0003</td>
</tr>
<tr>
<td>Jpeg compression (45Coeff)</td>
<td>49.7032</td>
<td>45.9954</td>
<td>3.7078</td>
</tr>
<tr>
<td>Resize</td>
<td>39.3958</td>
<td>37.7409</td>
<td>1.6549</td>
</tr>
</tbody>
</table>

From the above Table 6.2, it can be noticed by adding content-based features in the process of embedding the visual quality of watermarked image can be increased. In general on the whole the constant energy embedding method has the lowest visual quality, and the HVS embedding method achieves highest visual quality.

PSNR is measured to evaluate the imperceptibility quality of watermarked image. The PSNR value of watermarked image produced by the proposed embedding method after each of the attack is measured their values are shown in Table 6.2. From this Table 6.2, by observing the results, the improvement in PSNR of proposed algorithm is much greater in percentage compare to Feng Liu et al. method.
Table 6.3: Robustness of proposed method in terms of CORR (correlation).

<table>
<thead>
<tr>
<th>Test method</th>
<th>Proposed method (Jnd_dct_svd)</th>
<th>Feng Liu et al method (dct_svd)</th>
<th>IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>No attack</td>
<td>0.9991</td>
<td>0.9904</td>
<td>0.0087</td>
</tr>
<tr>
<td>Median filter</td>
<td>0.9697</td>
<td>0.9664</td>
<td>0.0033</td>
</tr>
<tr>
<td>Salt &amp; pepper</td>
<td>0.9642</td>
<td>0.9611</td>
<td>0.0031</td>
</tr>
<tr>
<td>Rotation</td>
<td>0.9344</td>
<td>0.9341</td>
<td>0.0003</td>
</tr>
<tr>
<td>Cropping</td>
<td>0.8288</td>
<td>0.8378</td>
<td></td>
</tr>
<tr>
<td>Jpeg compression (45Coeff)</td>
<td>0.9991</td>
<td>0.9904</td>
<td>0.0087</td>
</tr>
<tr>
<td>Resize</td>
<td>0.8288</td>
<td>0.9682</td>
<td></td>
</tr>
</tbody>
</table>

In this proposed work as mentioned earlier the scaling or gain factor ‘k’ is set according to the content and the required quality of the Watermarked image to ‘0.1’ which is an optimum value. The ‘k’ value is chosen such that the watermarked image should resemble the host image i.e. as if there is no watermark is embedded. How the CORR and PSNR vary with the variation of ‘k’. It is also noticed that by adding JND values in embedding method visual qualities of watermarked image can be improved.

Quality of the extracted watermark is evaluated visually and using the correlation coefficient between the original watermark image and extracted watermark image. At the same time from the Table 6.3, it can be observed from the improved CORR values that the retrieved watermark image visual quality can also be increased by adding JND values i.e. content based features.

This watermarking scheme is RST invariant due to its robustness against rotation, translation and scaling attacks. Moreover it is resilient to many other filtering and image processing attacks. Hence the proposed method is more robust in comparison with Feng Liu et al. method.

Finally it is also observed that the data payload of the proposed algorithm is max of 64x64. It is also observed that the PSNR values vary with the watermark image even though the host image is same. This is shown in the following Table 6.4.
Table 6.4: Results when different watermark images of same size are embedded into same host Lena 512x512 image.

<table>
<thead>
<tr>
<th>WATERMARK “64x64”</th>
<th>CORR</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena</td>
<td>0.9971</td>
<td>73.1150</td>
</tr>
<tr>
<td>Cameraman</td>
<td>0.9991</td>
<td>75.2235</td>
</tr>
<tr>
<td>Cube</td>
<td>0.9990</td>
<td>70.4523</td>
</tr>
</tbody>
</table>

So it is observed from the Table 6.4 that the CORR and PSNR values will vary with respect to the content based features such as texture, edges, corners and luminance of host and watermark images.

In chapter ‘5’ blind watermarking algorithms using both content-based features and d-sequences are explained.

In section 5.3 blind watermarking scheme using DCT_DWT_d-sequence and midband frequencies is explained and in section 5.4 blind watermarking algorithms using DCT_d-sequence and spread spectrum is described.

In section 5.3 Experimental results are evaluated by testing for various images, by using the same scaling factor for Subhash kak et al. method [79] and the
proposed method. JND-DCT are used in Subhash kak et al. method [79]. In the proposed method JND_DWT_DCT are used. The results obtained are shown in Table.5.1.

Proposed scheme utilizes the perceptual information of the image content, by taking advantage of frequency selectivity and assigns weights to provide some perceptual criteria in the watermarking process.

For experimental analysis on the proposed work gray scale host image Lena of size 512x512 and binary watermark image of size 50x20 are used. The prime number is of our choice that is used to generate the d-sequence and the prime number used in the proposed work is 2467 and on using the appropriate scaling factor ‘k’ and threshold ‘T’ it is noticed that the watermark is recovered perfectly well. As mentioned earlier the scaling factor is set according to the content and the quality of the watermarked image. The greater the scaling factor, the better is the watermark detection however reducing the overall quality of the image. Hence an optimum value is chosen accordingly and it is set to 0.084 for Lena.

For embedding purpose, the selected DCT coefficients are modified by inserting d-sequence based on the watermark bit along with JND values, for each block. The location of mid-frequency components of 8x8 DCT block is (shown in Fig.5.1) selected for embedding. Mid-frequency band is selected for embedding because it is believed that the DCT coefficients in the mid-frequency band have similar magnitudes. For each 8x8 transformed block the d-sequence multiplied by a scaling factor and the JND mask is added into the selected mid frequency DCT.
components while the low and high frequency coefficients are copied over unaffected.

The scaling factor denotes the strength of the watermark and it can be used to control the overall robustness and the quality of the image. Increasing this value increases the strength of the watermark but introduces a gradual visible distortion while decreasing this value would result in better hiding of the watermark and hence better quality but decreases the strength of the watermark. Hence an optimum value of gain factor is chosen accordingly and it is set to 0.084.

From the Table 5.1, it is noticed that there is an improvement in WPSNR by using proposed algorithm. This can be observed from Table 6.5.

**Table 6.5: Robustness of proposed method in terms of WPSNR**

<table>
<thead>
<tr>
<th>Test method</th>
<th>Proposed Method (JND_DCT_DWT)</th>
<th>Subhashkaketal. Method(JND_DCT)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No attack</td>
<td>31.8596</td>
<td>30.9275</td>
<td>0.9321</td>
</tr>
<tr>
<td>Cropping</td>
<td>12.0647</td>
<td>12.0517</td>
<td>0.0130</td>
</tr>
<tr>
<td>Rotation</td>
<td>18.7374</td>
<td>18.6408</td>
<td>0.0966</td>
</tr>
<tr>
<td>JPEG (recover with 45.coef)</td>
<td>31.3850</td>
<td>29.9174</td>
<td>1.4676</td>
</tr>
<tr>
<td>JPEG (recover with 60.coef)</td>
<td>31.7764</td>
<td>30.8060</td>
<td>0.9704</td>
</tr>
</tbody>
</table>

From the results of Table 6.5 it is observed that by modifying DCT values of mid-band frequencies using the proposed algorithm, there is tremendous improvement in WPSNR. Hence proposed method is more robust one.

Embedding the watermark in the high frequency components that carry less perceptually significant information, so there is chance of removal of watermark through compression and noise attacks, while adding it in the low frequency components, which carries perceptually important information, results in visible
changes in the watermarked image. Because of these problems in the proposed scheme for embedding purpose mid-band frequency is selected.

It is also observed that very good balance between robustness and imperceptibility, and also the quality of the watermark extracted is well. WPSNR is used to evaluate the perceptual quality of the image.

**Table 6.6: Robustness of proposed method in terms of CORR**

<table>
<thead>
<tr>
<th>Test method</th>
<th>Proposed Method (JND_DCT_DWT)</th>
<th>Subhashkaketal. Method(JND_DCT)</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No attack</td>
<td>0.8548</td>
<td>0.8438</td>
<td>0.0110</td>
</tr>
<tr>
<td>Cropping</td>
<td>0.6757</td>
<td>0.6557</td>
<td>0.0200</td>
</tr>
<tr>
<td>Rotation</td>
<td>0.6629</td>
<td>0.7301</td>
<td>___</td>
</tr>
<tr>
<td>JPEG(recover with 45.coef)</td>
<td>0.8493</td>
<td>-0.8384</td>
<td>0.0109</td>
</tr>
<tr>
<td>JPEG(recover with 60.coef)</td>
<td>0.8548</td>
<td>0.8438</td>
<td>0.0110</td>
</tr>
</tbody>
</table>

Proposed scheme is tested for robustness on various attacks and it is found that proposed algorithm performs excellently against JPEG compression and moderately well against common spatial attacks and very poor for median filter attack.

The JND value which is generated from content based features controls the strength of watermark for each block. The whole idea of block based JND watermarking is to incorporate the local perceptual masking effects as it provides local control of the strength of watermark based on the image content. This is because any changes made in this block are more perceptible to the human eye.

In section 5.4 the proposed algorithm is based on the content based features and d-sequence. Since the watermark bit is embedded in the best location, hence the rate of watermark withstanding capacity is very high, the quality of the watermark image is good in terms of perceptibility, PSNR and WPSNR.
For experimental analysis of the proposed work gray scale images are used. The host image is Lena of size 512x512 and the watermark of size 16x16 pixels has been used. The prime number that is used to generate the d-sequence is 17 and on using the appropriate scaling factor and threshold it is noticed that the watermark is recovered perfectly well. Hence an optimum value of 'k' chosen is 0.04, the scaling factor is set according to the content and the quality of the watermarked image. And JND values are added for the better results in imperceptibility.

In this proposed work the Correlation, PSNR and WPSNR are calculated in prior to embedding watermark for all the locations of sub block 8x8 and the best location is chosen for which the three parameters are optimum. Based on the watermark bit and in chosen location the d-sequence of selected prime number which acts as a key is embedded.

In section 5.3 and 5.4 two different robust watermarking algorithms which are improvement of Subhash kak et al. [79] method are explained. In section 5.3 'Content Based Hybrid Watermarking Algorithm using DCT_DWT' is explained and in section 5.4 'Content Based Hybrid Watermarking Algorithm using CDMA Technique' is explained.

It is observed that by using CDMA technique data payload can be increased to the maximum extent. In this process it can also be observed from the results of Tables5.1 and 5.2 that by spreading of the watermark throughout the message bits of the image ensure better security against unintentional or intentional attacks especially geometrical attacks including image compression as well as scaling.

This method is superior to all other watermarking algorithms using d-sequence in terms of both PSNR and robustness. For different attacks the results are shown in the Table.5.2. The proposed algorithm is shown to be more robust compared to JND_DCT method. This algorithm is also tested for salt & pepper noise based on the chosen random values the correlation, PSNR and WPSNR will be varied.

This indicates that an embedded watermark is still recoverable even after the common image processing operations on the watermarked image. And hence this algorithm is highly suitable for the "copyright protection, Owner identification and Copy control".