CHAPTER 4 EXPERIMENTAL SETTINGS

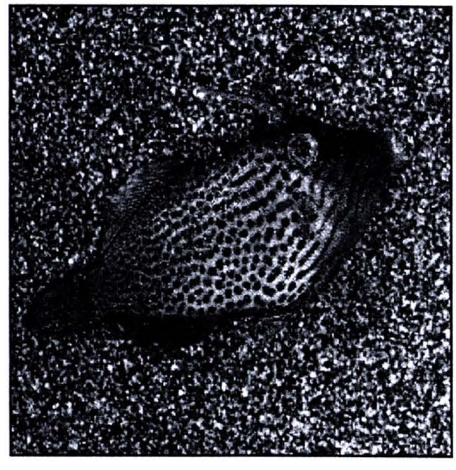
This chapter describes the experimental conditions, such as testing image, software and computer used in the system, and the steps of experiment. Also, the evaluation of experiment and the analysis of threshold are described.

4.1 Experimental Conditions

4.1.1 Testing Images in the Experiment

In all experiments, ten 256×256 pixels color images having various characteristics, i.e. '*Bird*', '*Fish*', '*Lena*', '*Tower*', *'Airplane'*, *'Baboon'*, *'House'*, *'Pepper'*, *'Sun flower'* and *'Bee'* were used as original testing images. A 256×256 pixels black & white image containing a logo '*CPE 2009*' was used as a watermark, i.e. by considering the black color pixel as -1, and white as 1. Some original host images are shown in Figure 4.1 and the watermark logo is shown in Figure 4.2.

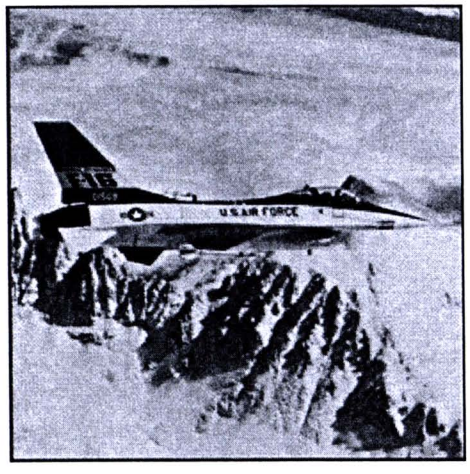
(a) '*Bird*'



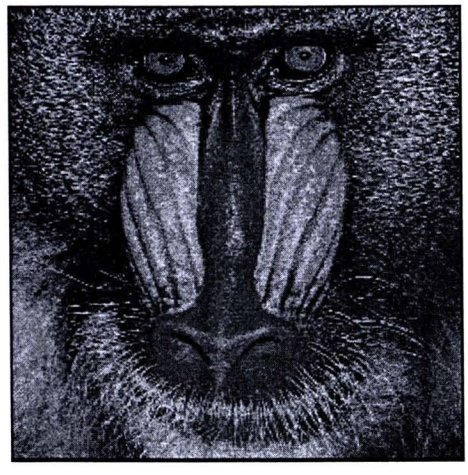
(b) '*Fish*'

(c) *'Lena'*

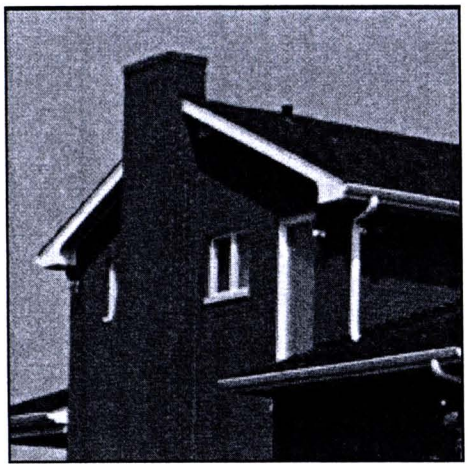
(d) *'Tower'*



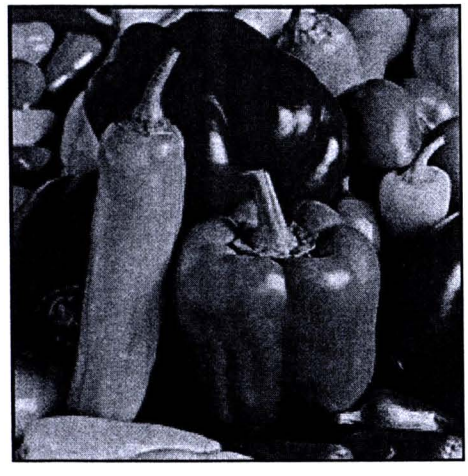
(e) *'Airplane'*



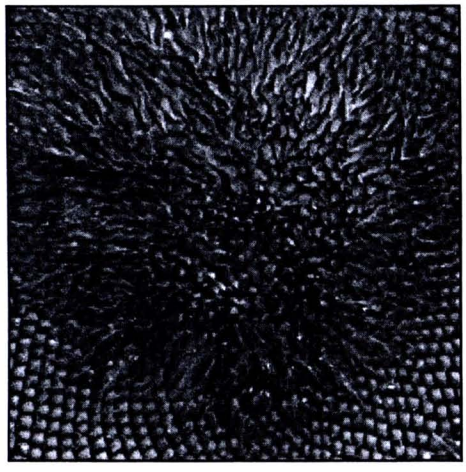
(f) *'Baboon'*



(g) *'House'*



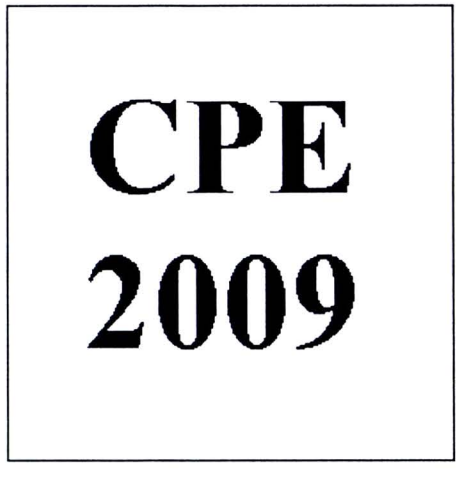
(h) *'Pepper'*



(i) *'Sun flower'*

(j) *'Bee'*

Figure 4.1 Original testing images



(g) '*CPE 2009*'

Figure 4.2 Watermark logo

4.1.2 Software and System Used

Software: MATLAB Version 7.8.0.347 (R2009a).

System: Microsoft Windows XP Professional Version 2002 Service Pack 3.

CPU: Intel(R) Core(TM)2 Duo CPU E8500 3.16GHz.

Ram: 3.25GB.

4.1.3 Steps of Experiment

4.1.3.1 Prepare the image input and the watermark logo input.

4.1.3.2 Experiment on the previous watermarking scheme [8].

4.1.3.3 Record PSNR and NC from the previous watermarking scheme [8].

4.1.3.4 Replace the adaptive algorithm to the retrieval process in the previous watermarking scheme [8].

4.1.3.5 Experiment on the previous watermarking scheme [8] which applied the adaptive algorithm.

4.1.3.6 Record PSNR and NC.

4.1.3.7 Compare with the previous watermarking scheme [8] in term of NC and PSNR.

4.1.3.8 Find a new threshold which will be used in the adaptive algorithm, such as derived from image variance, local variance, variance of local image region and standard deviation.

4.1.3.9 Apply a new threshold to the adaptive algorithm and go to 4.1.3.4 - 4.1.3.7.

4.2 Evaluation of Experiment

Peak signal to noise ratio (PSNR) is an engineering term for the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. PSNR was considered and used to evaluate the quality of the watermarked images.

Normal Correlation (NC) is the correlation of normalization between random variables at two different points in space or time. NC was considered between random variables representing the same quantity measured at two difference points. After retrieving the embedded watermark, NC was used to evaluate the fidelity of the embedded watermark.

The PSNR and NC are defined as follows.

$$PSNR\,(\mathrm{dB}) = 20\log_{10}\frac{255\sqrt{MN}}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(B'(i,j) \quad B(i,j))^2}} \tag{4.1}$$

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} w(i,j)w'(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} w(i,j)^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} w'(i,j)^2}} \tag{4.2}$$

Where M and N are the numbers of rows and columns in the images, respectively. $w(i, j)$ and $w'(i, j)$ are the original and the retrieved watermark bits at pixel (i, j), respectively.

4.3 Analysis of Threshold and Total of Eliminated Pixel

4.3.1 Image Variance

The optimum threshold was used to decide whether a surrounding pixel around *(i, j)* that gave most effects on the group variance was removed or not, and the maximum numbers of pixels to be removed were considered in the original pixel prediction process. To determine the optimum threshold in accordance with the image variance, we evaluated the retrieval performance at various values in proportion to the image variance. In the experiment, we set the testing range from -95 to 95% of the image variance. That is, the searching range for the optimum variance varied from 5% to 195% of the image variance. To determine the numbers of pixels used in the prediction process, we evaluated the retrieval performance at various numbers of surrounding pixels. In the experiment, we set the maximum number of pixel removal from one pixel to four pixels. The average NC values obtained from four different removal techniques at various percentages of σ_B^2 are shown in Figure 4.3.

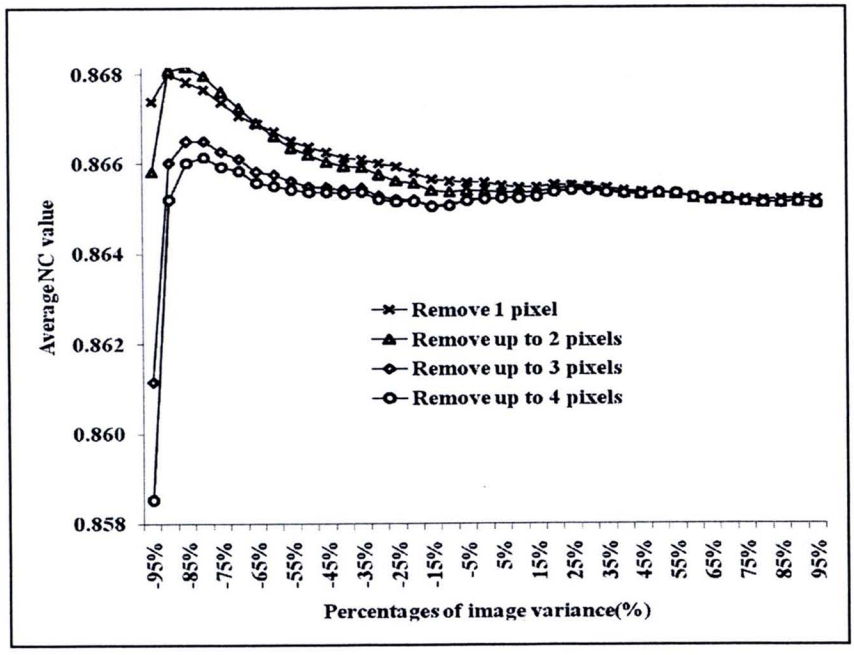


Figure 4.3 Average NC values obtained from four different removal techniques at various percentages of σ_B^2

According to the above figure, it can be clearly seen that on average the best performance of our retrieval method occurred at around -85% of the image variance. For the maximum number of pixel removal, removing up to 2 pixels obtained the highest NC value at around -85% of the image variance. However, on average, removing 1 pixel obtained the best performance.

4.3.2 Local Variance

The optimum threshold was used to decide whether a surrounding pixel around *(i, j)* that gave most effects to the group variance was removed or not, and what were the maximum numbers of pixels to be removed in the original pixel prediction process. To determine the optimum threshold, we evaluated the retrieval performance at various local variances derived from the image area with the window size of $m \times n$ pixels around the center pixel $B'(i, j)$, where $m = n$ = odd numbers ranging from 3, 7, 9, … Note that

B'(i, j) was not included in the calculation of the local variance. In the experiment, we set the window sizes of image of the image area ranging from 3×3 pixels to the image size of 256×256 pixels. To determine the numbers of pixels used in the prediction process, we evaluated the retrieval performance at various numbers of surrounding pixels. In the experiment, we set the maximum number of pixel removal from one pixel to four pixels. The average NC values obtained from four different removal techniques at various window sizes are shown in Figure 4.4.

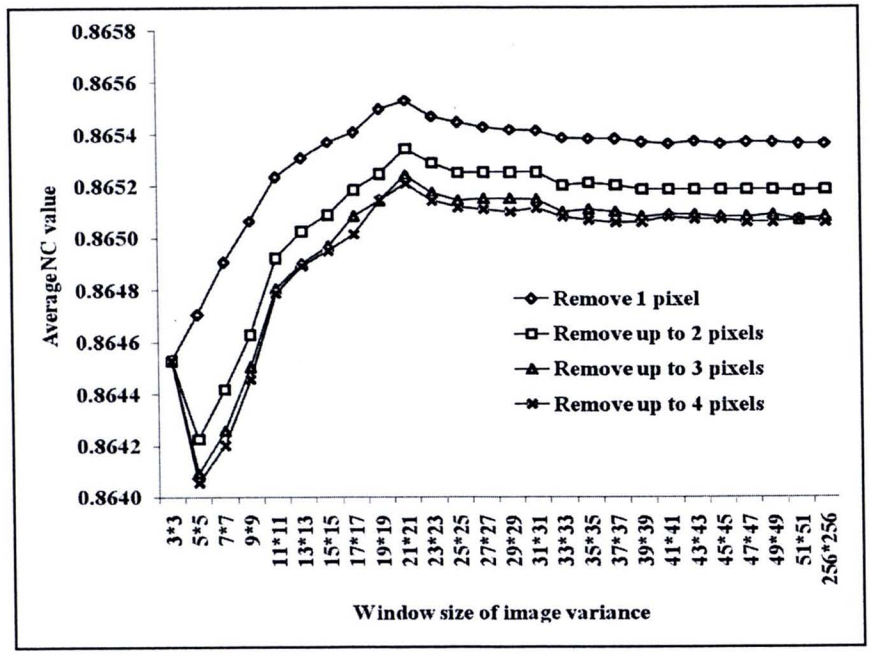


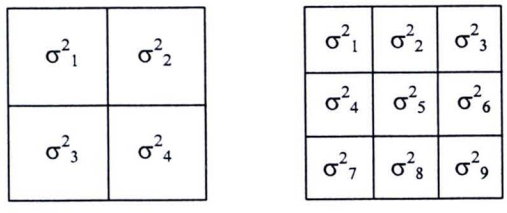
Figure 4.4 Average NC values obtained from four different removal techniques at various sizes of window variance σ_B^2

According to the results obtained, it can be clearly seen that on average the best performance of our retrieval method occurred at around 21×21 pixels window size of the image area around *(i, j)*. For the maximum number of pixel removal, on average, removing 1 pixel obtained the best performance. Hence, based on the results obtained, we selected the optimum threshold as the local variance derived from the image area

with 21×21 pixels around *(i, j)* and one maximum number of pixel removal as default set up.

4.3.3 Variance of Local Image Region

The optimum image region was used to establish a threshold while the optimum threshold was used to decide whether a surrounding pixel around *(i, j)* that gave most effects to the group variance would be removed or not, and the maximum numbers of pixels to be removed were considered in the original pixel prediction process. To determine a suitable image region, we evaluated the retrieval performance at various local variances derived from the different image regions ranging 2×2 pixels, 3×3 pixels, and so on. Nevertheless, from our observations, we found that a suitable threshold usually came from the variance of the large enough image region. Hence in the experiment, we divided the image into 4, 9, 16, 25 regions, and used the variance computed from the pixels within the corresponding region as a threshold. Figure 4.5 shows the example of 4 and 9 variances computed from 4 and 9 regions of an image respectively.



(a) 4 regions (b) 9 regions

Figure 4.5 The variances computed from the pixels within each region of an image

To determine the numbers of pixels used in the prediction process, we evaluated the retrieval performance at various numbers of surrounding pixels. In the experiment, we set the maximum number of pixel removal from one pixel to four pixels. The average NC values obtained from four different removal techniques at various image region sizes are shown in Figure 4.6.

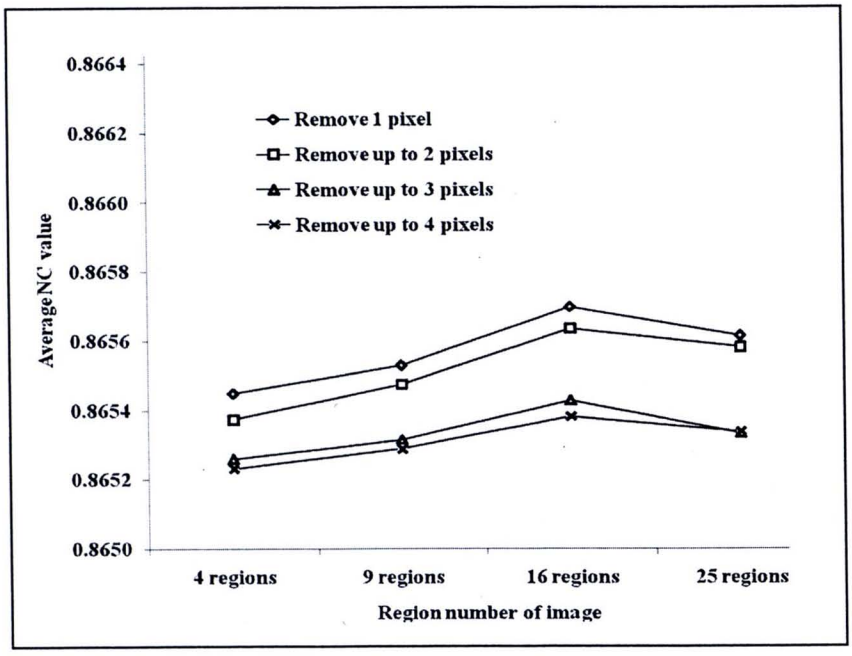


Figure 4.6 Average NC values obtained from four different removal techniques at various image region sizes

According to the results obtained, it can be clearly seen that, on average, the best performance of our retrieval method occurred at the variance computed from 16 image regions. For the maximum number of pixel removal, on average, removing 1 pixel obtained the best performance. Next, we determined the optimum threshold in accordance with the variance of each image region σ_{B16}^2 obtained. This time, we evaluated the retrieval performance at various values in proportion to σ_{B16}^2. In the experiment, we set the testing range from -95 to 95% of the σ_{B16}^2. That is, the searching

range for the optimum variance varied from 5% to 195% of σ_{B16}^2. The average NC values obtained from "16 regions" and "remove 1 pixel" at various percentages of σ_{B16}^2 are shown in Figure 4.7.

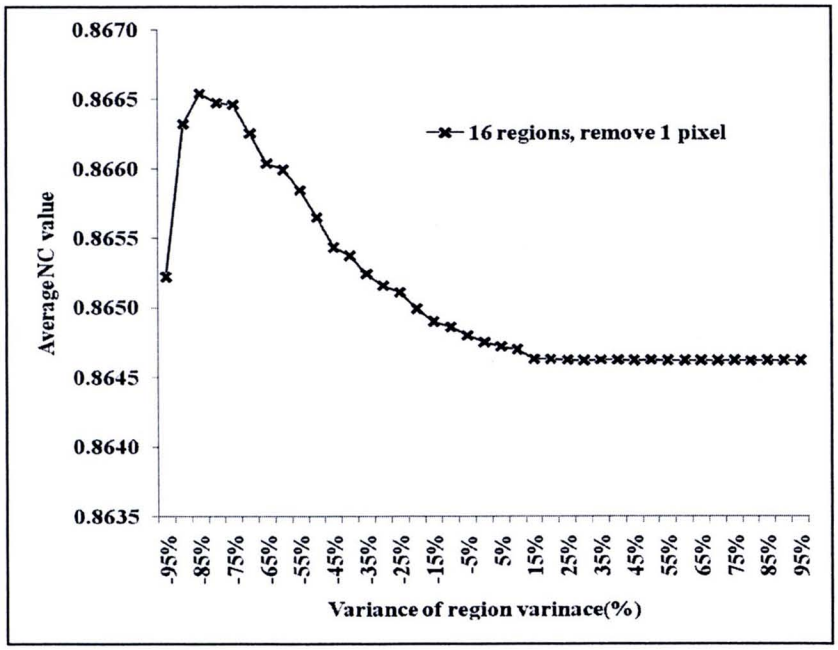


Figure 4.7 Average NC values at various percentages of σ_{B16}^2

It is obvious from the above figure that the best performance of our retrieval method occurred at around -85% of σ_{B16}^2. Hence, based on the results obtained, we selected the optimum threshold at -85% of each variance from 16 image regions and one maximum number of pixel removal as default set up.

4.3.4 Standard deviation

For the watermark retrieval, large different pixel values in the blue color channel can cause a bias in the estimation of the original pixel, which results in an erroneous original pixel value. Nevertheless, we can minimize this bias by removing the watermarked nearby pixel having the highest value from the prediction process. The

watermark bit can be either -1 or 1, adding the tuned watermark to the original nearby pixel to have the highest value, which may result in the highest or lowest watermarked pixel value, compared to other watermarked nearby pixels. Hence, a new watermark retrieval method is proposed to improve the accuracy of the original image pixel prediction. To obtain the best prediction result, based on our hypothesis, we examine the performance obtained from all possible watermarked pixels used in the prediction process, which mainly depends on the standard deviation. When the best suited watermarked pixels are found, those with minimum bias are then used to estimate the original pixel.

The performance of our proposed method is compared with these from the previous method [8]. The PSNR $\approx$ 30.83 dB was also used to tune up the signal strength, so that the accuracy of the retrieved watermark from different methods was fairly measured and compared. In the experiment, a range of the standard deviation is set between 0 and 80 and the result is shown in Figure 4.8.

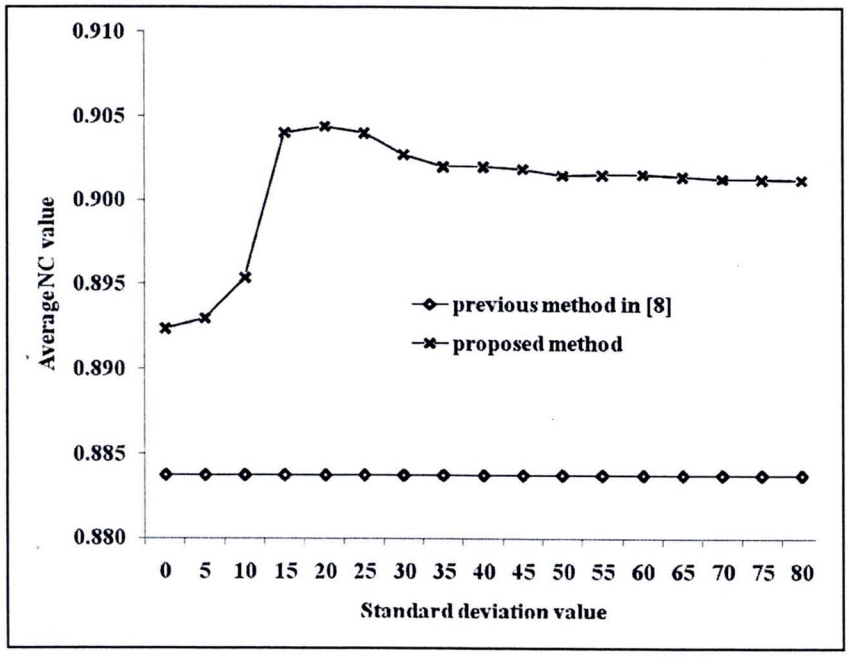


Figure 4.8 Average NC values at standard deviation values

It is obvious from the above figure that the result of the proposed method is better than the previous method. The result in the range of the standard deviation between 1 to 5 is equal, however, the result in the range of the standard deviation 6 suddenly increases until 25 and then slowly decreases. The reason is that the smaller standard deviation refers to the smaller pixel value distribution and the smaller difference pixel value. In the opposite way, more standard deviation indicates that more pixel value distribution and more difference pixel values then cause the result to increase. Thus, the standard deviation 20 was used to set the standard deviation threshold in the next experiment because it obtained the best performance when it was applied to the adaptive algorithm version 3.