ABSTRACT

STUDY OF JOINT EMBEDDING AND COMPRESSION ON JPEG COMPRESSION SCHEME USING MULTIPLE CODEBOOK DATA HIDING

By

Amol Nishikant Sukerkar

This thesis studies a direct application of multiple codebook data hiding technique in the multimedia applications. It studies the practical implementation of a joint embedding and compression scheme. It presents a study of Type III data embedding technique using multiple codebook design on JPEG-85 compression scheme. The application of the above technique is compared with the Type III data embedding techniques using single codebook design. The comparison is carried out in terms of the parameters such as mean square error and normalized correlation between the embedded and extracted watermark.

The performance of data hiding rate against the embedding distortion is also studied and on the basis of which, an effort is made to reach an optimal tradeoff between the hiding rate and embedding distortion.

On the basis of normalized correlation between the embedded watermark and extracted watermark, an effort is made to ascertain the use of multiple codebook data hiding using type-III methodology and show its advantages over single codebook data hiding.

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by
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APPROVAL PAGE

STUDY OF JOINT EMBEDDING AND COMPRESSION ON JPEG COMPRESSION SCHEME USING MULTIPLE CODEBOOK DATA HIDING

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To my beloved parents and sister
who
mean everything to me

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CHAPTER 1

INTRODUCTION

1.1 Objective

The objective of this thesis is to practically implement the Type III data hiding technique which uses QIM [2], using multiple codebook design in the popular image compression algorithm such as JPEG and study the feasibility of the data embedding technique mentioned above using the statistical tools such as normalized correlation between embedded and extracted watermark and Mean Square Error.

The thesis states a direct application of the multiple codebook design technique in the multimedia applications and tries to standardize the embedding of watermark in JPEG algorithm.

1.2 Background Information

Data hiding refers to embedding 'watermark' signal in a 'host' signal to form a 'stego' signal. The data hiding field provides tools for different applications such as copyright issues, ownerships, covert communication, etc. The core issue in the data hiding field is to design optimum embedding and detection techniques that give the best tradeoff among conflicting goals such as hiding rate, robustness and distortion.

Today, significant research has been done in the field of data hiding and it is an ongoing process. One of the primary goals of the researchers in the data hiding field is to make the data hiding technique oblivious, that is, the embedder has no access to the host signal.

Taha, *et al.* in [1] showed that the data hiding framework can be presented as follows:

Let $C \in \Re^N$ be some sampled real valued information signal, and $W \in \Re^N$ the auxiliary message signal. An embedder ε embeds the message signal W in the host signal C to yield the stego signal $S \in \Re^N$ given as

$$S = \varepsilon(C, W) \tag{1.1}$$

Let $d(.,.)$ be a predefined distortion metric suitable to information signal C. In other words $d(S, C)$, is the "distance" between S and C. A commonly used metric or distance measure is the mean squared error given by

$$d(S,C) = \sum_{i=1}^{N} \frac{(S-C)^2}{N} \tag{1.2}$$

The embedding distortion, $d(S, C)$ is constrained to be less than a defined threshold P to ensure that the cover signal C and the stego signal S are perceptually the same or very similar.

The stego signal is corrupted by a noise signal $Z \in \Re^N$ before it reaches the detector D. At the detector, an estimate $\hat{W} \in \Re^N$ of the message signal W is obtained from the received signal $Y = S + Z$ as

$$\hat{W} = D(Y) \tag{1.3}$$

The basic problem is to obtain an optimum design of embedder ε and detector D to maximize the fidelity of $\hat{W}$, subject to the distortion constraint $d(S,C) < P$. Consequently, the main goal of a data hiding method is to design practical codebook and

all noise levels and at the same time, maximize the data hiding rate so as to produce a system which is not only robust to mild as well as severe attack levels but also gives an excellent performance in terms of maximizing the payload. The ideal system would be the one in which the payload will me maximum that would allow a higher degree of embedding distortion but , at the same time, would not compensate with the robustness at this higher degree of distortion.

Costa's [7] framework and results serve as a test-bed for comparing and evaluating the performances of various practical embedding-detection techniques. Taha *et al.* [1] modified Costa's framework to obtain the Channel Adaptive Encoding and Channel Independent Decoding (CAE-CID) framework for data hiding.

CHAPTER 2

DATA HIDING METHODS AND CODEBOOK GENERATION

2.1 Data Hiding Methods

Practical data hiding methods can be categorized into three main types based on the design of embedder-detector pair, namely type-I, type-II and type-III [1].

Type-I methods are the ones that use additive schemes where the stego signal is generated by adding the watermark signal to the host signal [1]. This type of methods suffer severely from host signal interference due to the non-optimal design that assumes the host signal C as a noise and tries to cancel it. These methods have satisfactory performance only if channel noise is very strong or the host signal is available at the extractor.

Type-II methods are identified by the use of quantization procedures and by the (ε, D) pair which are exact inverses [1]. Although very suitable for oblivious data hiding applications at low noise levels, the major drawback of these methods is that they perform well only if the attack is not severe.

Based on the CAE-CID framework, type-I and type-II methods correspond to designs of U = X + C with the statistics of $\sigma_X^2 = \sigma_C^2 + \sigma_Z^2$ when ρ = 1 and $\sigma_X = \sqrt{P}$ when $X_t = 0$ respectively. An optimal design is the one that designer has control over the operating characteristics of the method [1]. This imposes some sort of dependency on the channel noise instead of the fixed severe noise (type-I) or low noise (type-II) assumptions. The methods operating on this principle are termed as type-III methods [1].

The codebook design for type-III is made on such a way that U = X + C where ρ = 1 and $\sigma_X = \frac{P+\sigma_Z^2}{\sqrt{P}}$ within the CAE-CID framework [1]. Therefore, data hider has the freedom to adapt the codeword to the host signal at the presumed noise level. These methods are known to be ideal for data hiding.

In short, it can be summarized as type-I is additive scheme, type-II is the quantization based scheme and type-III is the quantization based channel adaptive scheme.

In type-II and type-III methods, each message symbol is assigned a particular quantizer $Q_\Delta(.)$. The base quantizer $Q_\Delta(.)$ may be a high dimensional vector quantizer or a Cartesian product of scalar quantizers with Δ as the distance between the reconstruction points. In type-III embedding, C is quantized with respect to the watermarked signal, $Q_\Delta(C,W)$. Consequently, the codeword X is the quantized error introduced to the host signal C, $X = Q_\Delta(C,W) - C$. In type-III methods, the quantization error (type-II codeword), undergoes processing P, which generates the codeword $X_n = X - P(X)$.

The data hiding rate vs. robustness performance of type-II methods is substantially improved by enhancing the functionality of the embedder with further processing capabilities [1].

Thus, it can be proved that at higher Δ, the embedding distortion is reduced by the processing distortion introduced while embedding and hence, the type-III data hiding technique shows a considerable improvement over the type-II embedding detection technique. Type-III method is the optimal technique for mild as well as severe attacks [1].

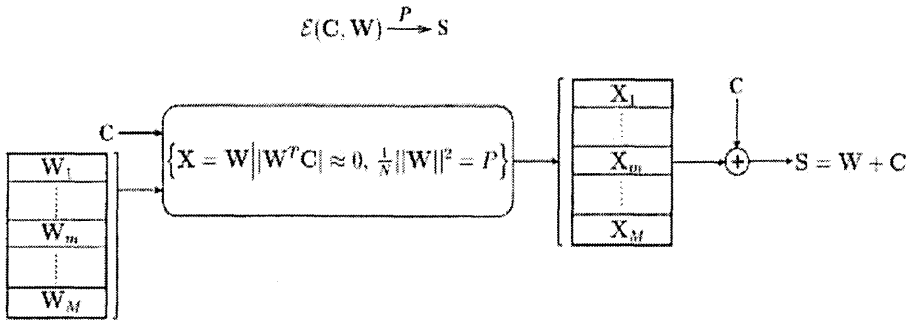

Figure 2.1 Encoding of message m in type-I methods

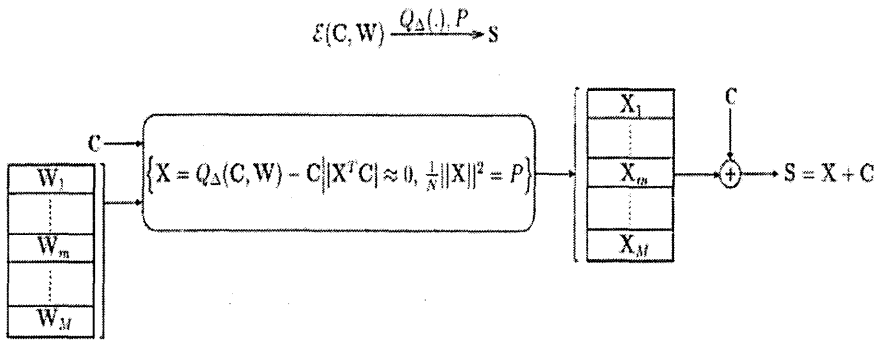

Figure 2.2 Encoding of message m in type-II methods

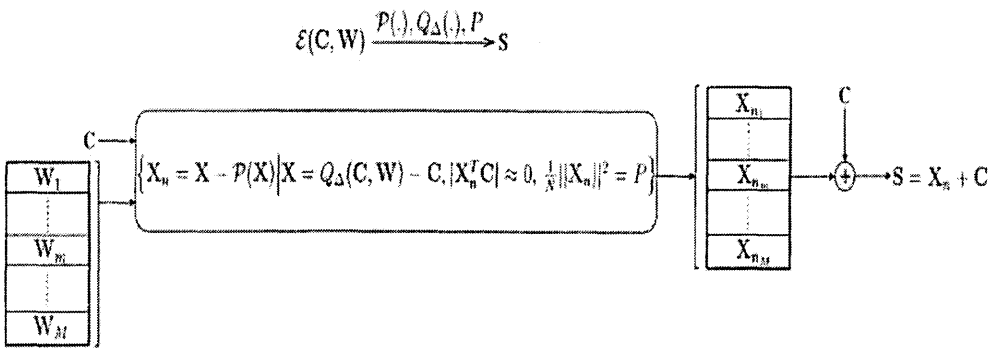

Figure 2.3 Encoding of message m in type-III methods

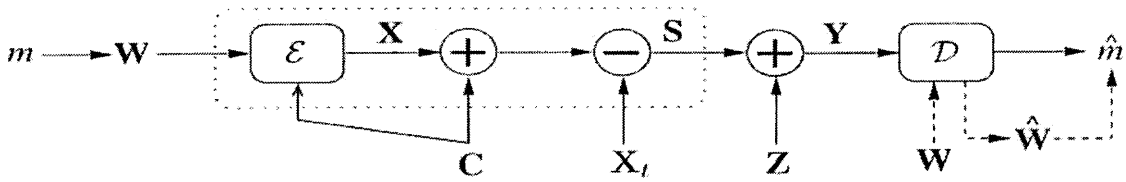

Figure 2.4 Type-III Embedding and Detection Stages

2.2 Type-III Embedding and Detection Methods

In type-III methods, quantization is followed by a processing stage that generates the stego signal. The channel model for type-III data hiding method is given in fig. In the model, X is the type-II codeword (embedding distortion introduced due to the quantization).

X_t is the processing distortion, and the channel output is $Y = C + X - X_t + Z$. The processing distortion X_t is the post-processed X depending on the expected noise level. The type-III codeword that yields the stego signal, $S = C + X_n$, is defined as $X_n = X - X_t$. The embedder imposes the power constraint as $P = \frac{1}{N}\|X_n\|^2$ where P is the embedding distortion.

In type-III methods, since the detector is not aware of the processing at the embedder, the processing distortion X_t, can be considered as a part of the channel noise at the detector [1]. Therefore, type-II codeword X, which would yield an errorless extraction of the watermark signal W, is distorted by two sources of noise, namely, the attack Z and the processing distortion X_t. Therefore, the effective noise at the detector that distorts the embedder watermark signal is represented as $Z_{eff} = Z - X_t$. In type-III

methods, the invertibility condition on the ε, D pair is sacrificed as a result of the processing that follows the quantization of the host signal, $D(\varepsilon(C,W)) \neq W$. On the whole, the performance of type-III data hiding methods vary based on three factors: the type of post-processing that is incorporated with type-II embedding, the choice of demodulation function used in the message extraction, and the criterion used for optimizing the embedding and detection parameters [1].

In type-III methods, the parameters α, β and σ_v, depending on the type of post-processing, are selected in such a way that the power constraint $\mathrm{P} = \frac{1}{N}\|\mathrm{X}_n\|^2$ is satisfied and the performance at the presumed attack level is maximized. Although, high dimensional embedding and detection or scalar embedding and detection is employed in type-III methods, we restrict our study to scalar embedding and detection. When scalar embedding is used, the embedding operation of all embedding-detecting techniques can be represented by dithered quantization [1]. Each component X is assumed to be uniformly distributed.

The detection of the sent message is accomplished using either minimum distance detector or using maximum correlation detector [1]. In this study, we make use of the maximum correlation detector. In this form of demodulation, an estimate $\hat{\mathrm{W}}$ of the embedded signal is extracted from the received signal by soft decisions [1]. Then, the sent message is detected by matching the estimate of the embedded watermark signal to one of the watermark signals using a correlation based similarity measure as

$$\hat{\mathrm{W}} = D(Y) \tag{2.1}$$

$$\hat{m} = \arg\max_{m} \frac{W_m \hat{W}}{\|W_m\| \|\hat{W}\|}, 1 \le m \le M \tag{2.2}$$

2.3 Optimization Criteria for Embedding and Detection Parameters

In data hiding methods, the embedding and detection parameters are controlled by a pair of parameters. The values of these parameters are optimized for given channel noise and embedding distortion levels, σ_Z^2 and P. The choice of Δ which is the distance between the reconstruction points of the embedding quantizers and other parameter which controls the processing distortion, i. e., β can be optimized to enhance the performance of type-III data hiding methods [1]. The pdf and statistics of processing distortion X_t and the codeword X_n are given as follows:

$$f_{X_t}(x_t) = \frac{\beta}{\Delta}\delta(x_t) + \frac{1}{\Delta}\mathrm{rect}(\Delta - \beta) \tag{2.3}$$

$$m_{X_t} = 0 \tag{2.4}$$

$$\sigma_{X_t}^2 = \frac{(\Delta - \beta)^2}{12\Delta} \tag{2.5}$$

$$f_{X_n}(x) = \frac{1}{\Delta}\mathrm{rect}(\beta) + \frac{\Delta - \beta}{2\Delta}\left(\delta(x_n - \frac{\beta}{2}) + \delta(x_n + \frac{\beta}{2})\right) \tag{2.6}$$

$$m_{X_n} = 0 \tag{2.7}$$

$$\sigma_{X_n}^2 = \frac{\beta^2}{12\Delta}(3\Delta - 2\beta) \tag{2.8}$$

The selection of Δ and β, which are quantization step size and processing distortion, respectively, is based on maximizing the normalized correlation between the embedded and extracted watermark signals [1]. The selection of embedding and detection parameters should also comply with the perceptual distortion constraint [1]. This puts an upper bound on the selection of Δ for embedding. Too large a Δ value distorts the image and the image does not comply with the perceptual constraint anymore.

CHAPTER 3

MULTIPLE CODEBOOK DATA HIDING

3.1 Purpose

In order to further improve the performance, embedding-detection techniques are required to make performance and complexity tradeoffs depending on the embedding signal size [1]. The two extreme possibilities are when the embedding signal size N is very large or very small.

For large signal size N, spread transforming is used. On the contrary, when signal size is small, multiple codebook data hiding is used [1]. Multiple codebook data hiding facilitates better adaptation of codeword to the host signal at the expense of increased complexity at lower distortion levels.

Taha *et al.*, in [1] proposed the use of multiple codebook data hiding scheme with type-III embedding technique. In this case, the distortion P introduced to host signal C due to embedding is calculated over all stego signal coefficients as $P = \frac{1}{N}\|\mathrm{X}_n\|^2$. Given two host signals with similar statistics, if the same watermark signal is embedded in both signals using the same parameters, the resulting distortion due to embedding may differ significantly for the two signals depending on the size of N [1]. Hence, more sophisticated optimization techniques are needed for determining the embedding-detection parameters for limited N. Multiple codebook hiding considers this by choosing a transformation C which yields the minimum distortion when W is embedded. The

ability to embed a watermark at lower embedding distortion, rather than at the permitted distortion level, is transmitted into more robust embedding of watermark signal. Since the

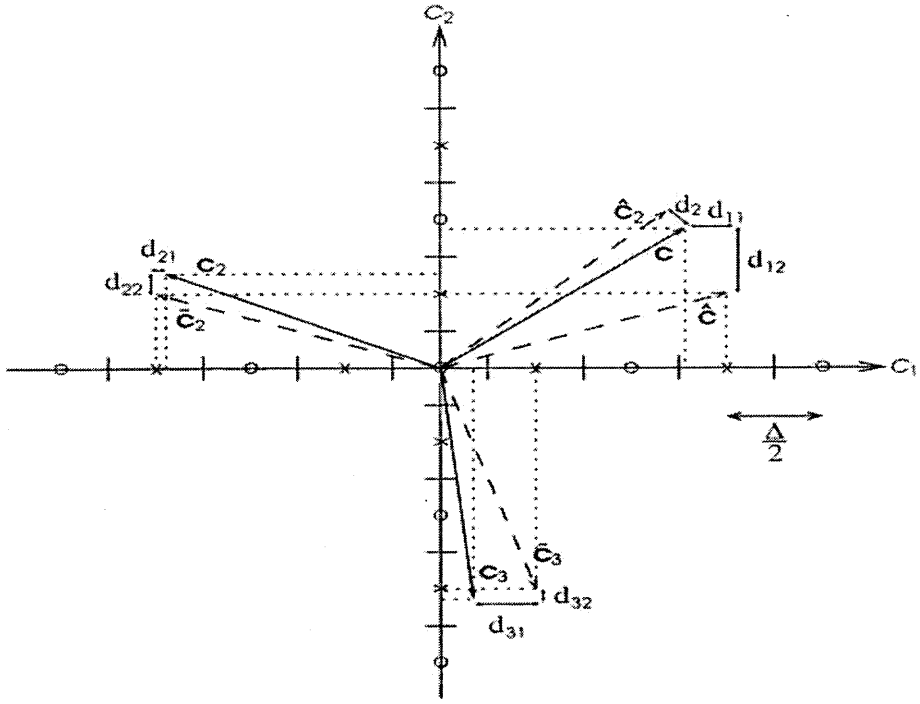

Figure 3.1 Embedding two binary symbols into host signal vector C = (c1, c2) and its two transformations using uniform scalar quantizers.

employment of transformations enables embedding at lower distortion levels, the difference between the permitted and actual embedding distortions can be utilized by the type-III embedder to either reduce the processing distortion at given Δ or to further increase the Δ at a fixed processing distortion.

In multiple codebook data hiding scheme, the embedder generates a number of codewords and chooses the best among them. So also, detector searches over all the codewords for a successful extraction of the message. This can be termed as a type-III method [1]. In multiple codebook data hiding, each codeword is generated from a unitary transform of the host (cover) signal. This is done by taking projections of the cover signal

with data embedded in it over a number of unitary transforms that are orthogonal to each other. The best codeword is selected on the basis of metrics such as lowest mean square error, highest PSNR or maximum normalized correlation between embedded and extracted watermark after compression. Due to the freedom of selecting from a number of codebooks, the method is called multiple codebook hiding.

3.2 Channel model for Multiple Codebook Data Hiding

Taha, in [1], showed the embedding of a binary watermark signal in the host signal vector and its two unitary transformations as shown in [Figure 3.1]. The channel model that was used for this is as follows:

In multiple codebook data hiding, the embedder and detector share two sets of information [1]. One is the set of sequences $\mathrm{W}_1,\ldots,\mathrm{W}_\mathrm{M} \in \Re^N$ that are associated with M distinct messages while the other is the set of L, $N \times N$, unitary transform bases.

$$\mathbf{I} = \mathbf{T}_i^T \mathbf{T}_i, i = 1,\ldots,\mathrm{L}$$

where $\mathbf{I}$ is the identity matrix and ^{T} is the matrix transpose operation. The data hiding system is given as

$$W : m \rightarrow \mathrm{W}_m,$$

$$\hat{\mathrm{S}} = \varepsilon(\mathbf{T}_k \mathrm{C}, \mathrm{W}_m),\ 1 \le k \le L,$$

$$\mathrm{S}_k = \mathbf{T}_k^T \hat{\mathrm{S}}_k,$$

$$\mathrm{Y} = \mathrm{S}_k + \mathrm{Z} = \mathrm{C} + \mathrm{X}_{n_k} + \mathrm{Z},$$

$$\hat{\mathrm{W}}_m^i = D(\mathbf{T}_i, \mathrm{Y}),\ i = 1,\ldots,L,$$

$$W^{-1} : \hat{\mathrm{W}}_m^{i} \rightarrow \hat{m}$$

In the model, C is assumed as uniformly distributed host signal and Z is the AWGN vector. The transform $\mathbf{T}_i$, is selected on the basis of maximization of the following criterion,

$$E[\|\mathbf{T}_k r - \mathbf{T}_i r\|^2, \ 1 \le i,k \le L \text{ and } i \ne k$$

where r is the random signal vector and the expectation is performed over all $r \in \Re^N$. Among the L unitary transformations, $\mathrm{C}_i = \mathbf{T}_i\mathrm{C}, i = 1,...,L$, embedder picks the one that is expected to yield highest detection statistics at the permitted embedding distortion. Assuming k is the index of the selected transform basis, the sequence W_m, corresponding to the message index $m, 1 \le m \le M$, is embedded into $\mathbf{T}_k$ transformation of the host signal, C_k. Then, the stego signal, $\hat{\mathrm{S}}_k$, is inverse transformed to signal domain, S_k. Uninformed of the particular transform $\mathbf{T}_k$ used for embedding, detector generates L transformations of the received signal Y and detects the hidden message $\hat{m}$ in a blind manner. With the use of multiple codebooks, the choice of $\mathbf{T}_k$ determines X_{n_k} among codewords $\{\mathrm{X}_{n_1},...,\mathrm{X}_{n_L}\}$. In short, embedder chooses one of the L codewords based on the given host signal C and the message m to be conveyed.

The most important step involved in this operation is the selection of the transformation basis $\mathbf{T}_k$, $1 \le k \le L$, which generates the codeword that adapts best with the host signal at the permitted embedding distortion. So, the watermark signal W_m is embedded into L transformations of the host signal, $\mathrm{C}_i = \mathbf{T}_i\mathrm{C}$, $i = 1,...,L$, consecutively.

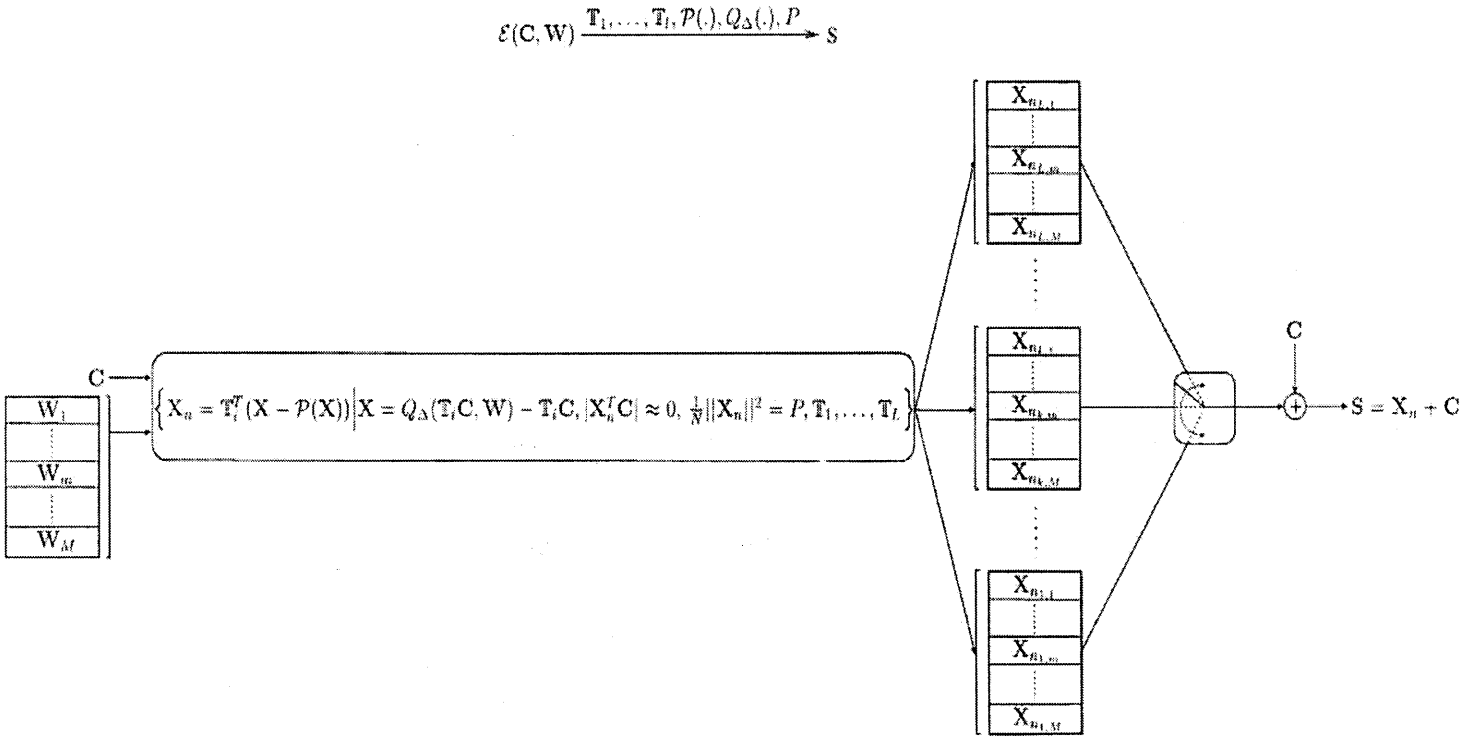

Figure 3.2 Encoding using multiple codebooks.

The extracted signal $\tilde{W}_m^i$ will differ from the embedded signal as a result of embedding and processing distortion. Hence, the signal is determined using either of the two decision metrics: maximum correlation criterion and minimum distance criterion [1].

The parameters computed for permitted distortion (P_E) and the given channel noise (σ_Z^2) assume N large and host signal uniformly distributed in each quantization interval. However, due to the limitations over N, the embedding distortion introduced in

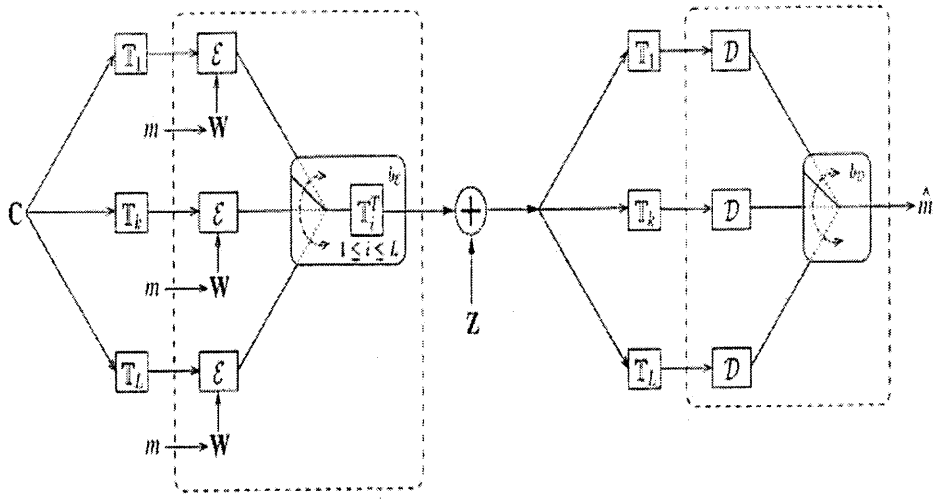

Figure 3.3 Multiple codebook embedding and detection.

C differs from Δ. Since, Δ is known to the detector, the only parameter that can be manipulated to obtain the given Δ is β. It is shown in [1] that as the value of β is decreased, the normalized correlation increases and the distance decreases.

The drawback in this scheme is the increase in the probability of error [1]. This is due to two sources: the channel noise and the interference from other transformations.

CHAPTER 4

EMBEDDING AND DETECTION IN LOSSY (JPEG) COMPRESSION

4.1 Overview

Data compression is the most common application in multimedia. Therefore, optimal design of any watermarking method should take the compression into account. By making use of the quantization tables given in a compression scheme, one can account for the compression noise that a stego signal undergoes. Hence, compression can be considered as an attack where the ability of an embedder to introduce embedding distortion in a stego signal decreases [1].

Type-III methods optimize the embedding and detection parameters to take into account the distortion due to compression [1].

4.2 Joint Embedding and Compression

The modification of the embedder with respect to the compression characteristics is justified by the fact that the user has control over both compression and embedding. This results in an optimal system that handles embedding and compression jointly rather than considering them independent [1].

The embedder, as seen, introduces the embedding distortion and processing distortion as two forms of noises in the stego signal. When embedding of the signal is followed by compression, the quantization values will introduce a further compression distortion in the signal which is the difference between the watermarked signal and the compressed watermarked signal. Hence, the embedder has to be modified to take into

account the compression distortion that follows the embedding operation. By using the *a priori* information from the quantization tables of the compression schemes, the embedding and detection parameters (Δ, β) can be optimized to maximize the hiding rate and thus compensate for the distortion introduced by the compression [1].

4.3 Implementation of Joint Embedding and Compression in JPEG Compression

The above method is studied on JPEG-85 compression scheme on a grayscale image. The size of the image was selected to be 128 X 128 pixels. The watermark was embedded in the signal in the DCT transform domain. The embedding channels were selected in such a way that they would have highest signal power after compression which would yield a higher data embedding rate and they would approximately have the same quantization step so that the (Δ, β) pair can be optimized once for all the channels.

In this study, the scale factor for the compression and embedding distortion was fixed. The (Δ, β) pair was varied in such a way that the required embedding distortion was always achieved. Also, the (Δ, β) pair was limited to the extent that the condition for perceptual constraint was always met.

The technique was tested on two images viz., Lena and Elaine. The tests were divided into two categories, viz. single channel embedding and multiple channel embedding. In the first case, the data was embedded into only one channel (single coefficient) of the signal in transform domain (DCT). In the latter case, the watermark was embedded into 8 channels of the signal. The coefficients were selected in such a way that they would have the highest signal power and similar quantization step for compression. The technique was tested for different embedding distortions.

The technique was incorporated in the JPEG-85 compression scheme as follows. The cover signal (image) was DC shifted by 128. The DC shifted image was partitioned into 8x8 blocks and 8x8 DCT transform was applied to each block. The multiple codebook data hiding technique was applied to the cover signal in DCT domain. The cover signal was projected over L unitary transformations. The watermark signal W was embedded in all these transformations of cover signal. Each of these cover signals was then compressed with a fixed quantization table (constant scale factor). The signals were reconstructed to produce stego signals in spatial domain. This was done by reversing the above procedure.

After compression, the watermark was extracted. The normalized correlation was calculated between embedded and extracted watermark signals. The transformation that gave maximum correlation would be selected to be transmitted to detector.

This technique does not take into account the distortion due to channel noise. The technique considers all the possible distortions at the fixed compression distortion. The only parameter that is varying in this case is the distortion due to embedding into the cover signal as the other parameters such as the distortion due to compression, the signal power of the channels to be embedded in are constant.

The experiment is repeated for a fixed embedding distortion but with various (Δ, β) pairs with the Δ bounded by the perceptual distortion constraint.

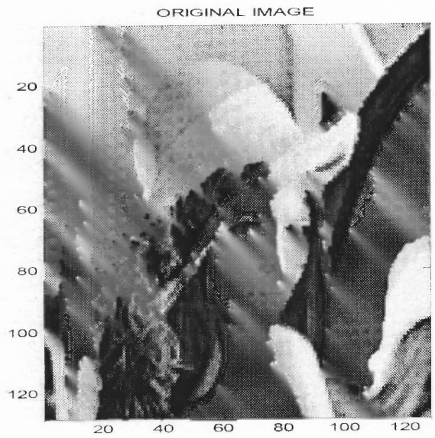

Figure 4.1

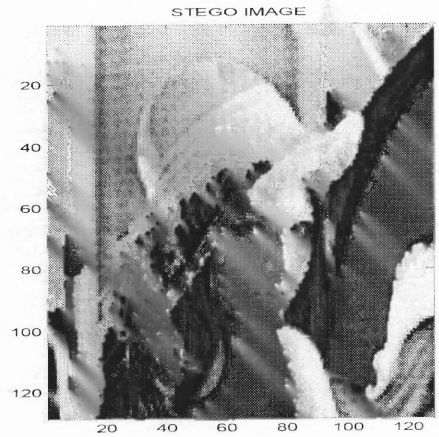

Figure 4.2

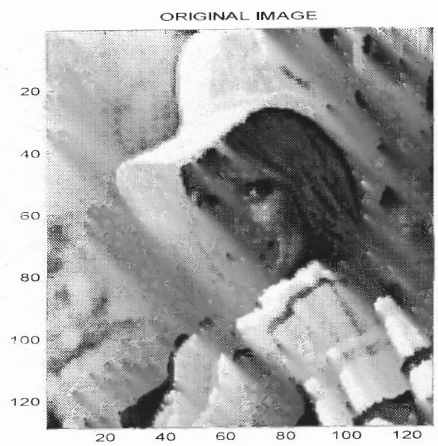

Figure 4.3

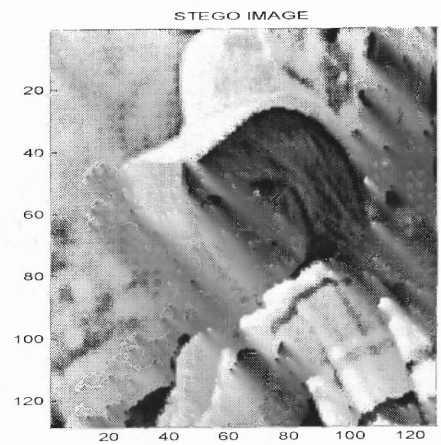

Figure 4.4

Figure 4.1 **(a)** Original Lena image, **(b)** Stego Image, **(c)** Original Elaine image and **(d)** Stego Image.

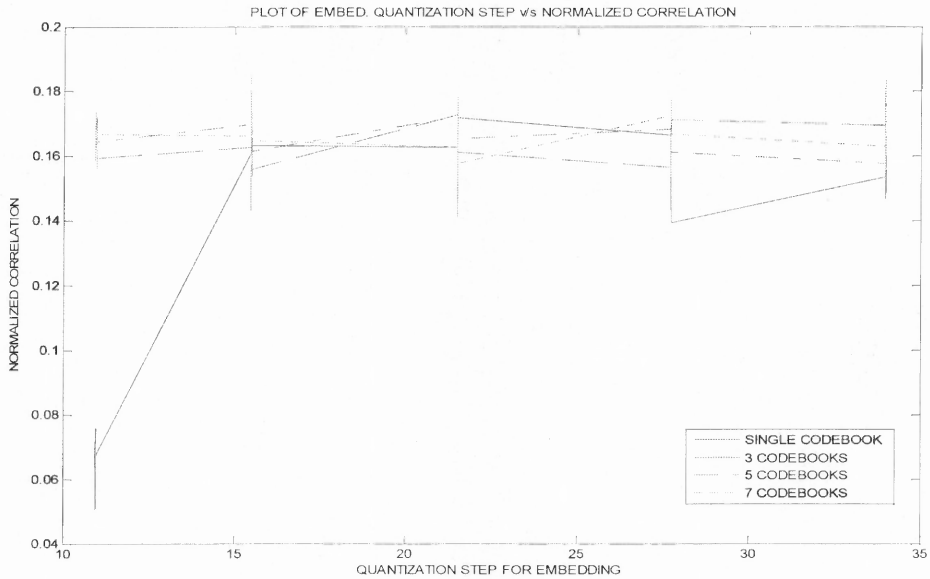

Figure 4.2 The plot of normalized correlation between W and $\hat{W}$ against the embedding quantization step (Lena Image) with single channel embedding.

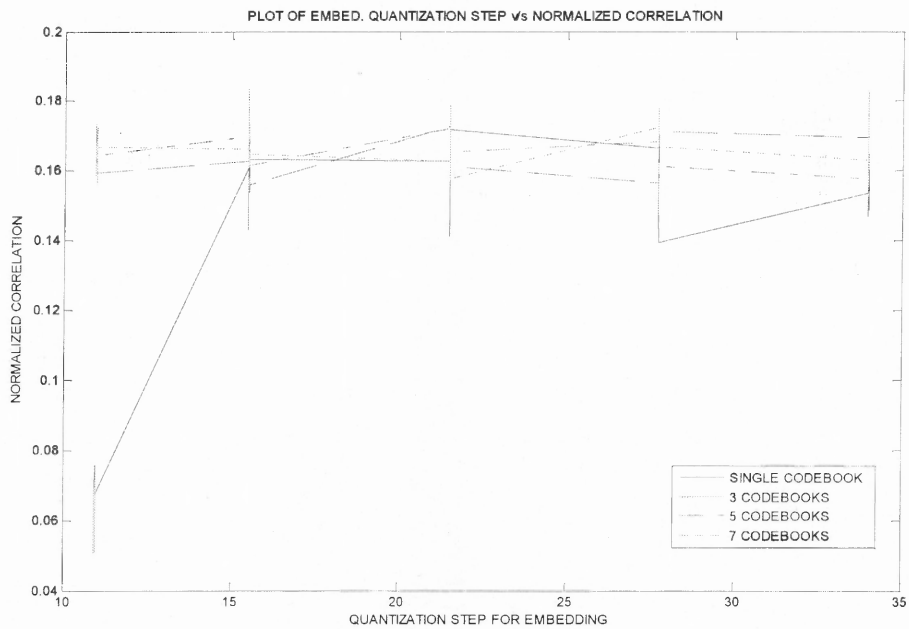

Figure 4.3 The plot of normalized correlation between W and $\hat{W}$ against the embedding quantization step (Elaine Image) with single channel embedding.

Figure 4.4 - 4.7 show the comparison of the normalized correlation obtained from Lena and Elaine images for single channel for various number of codebooks. It is clear that the cover signals in DCT domain follow the same distribution due to which the result obtained for one particular cover signal can be generalized for any image as cover signal.

The matter of concern is the selection of particular channels in the cover signal. The embedding step size would depend on the amount of compression a channel undergoes. The embedding distortion introduced in two cover signals would be identical if the channels selected for embedding in the two cover signals are identical and both the cover signals are subjected to identical compression noise.

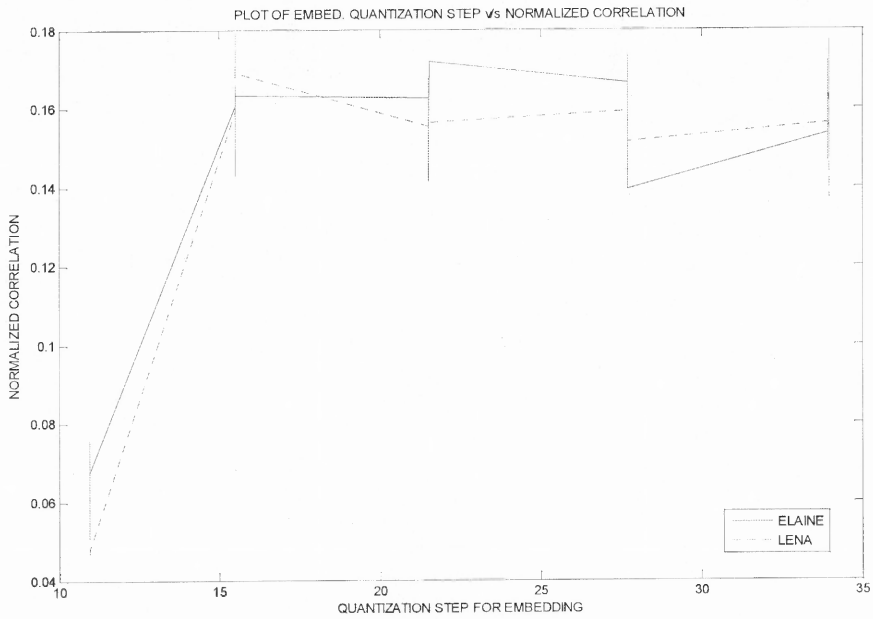

Figure 4.4 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for single codebook with single channel embedding.

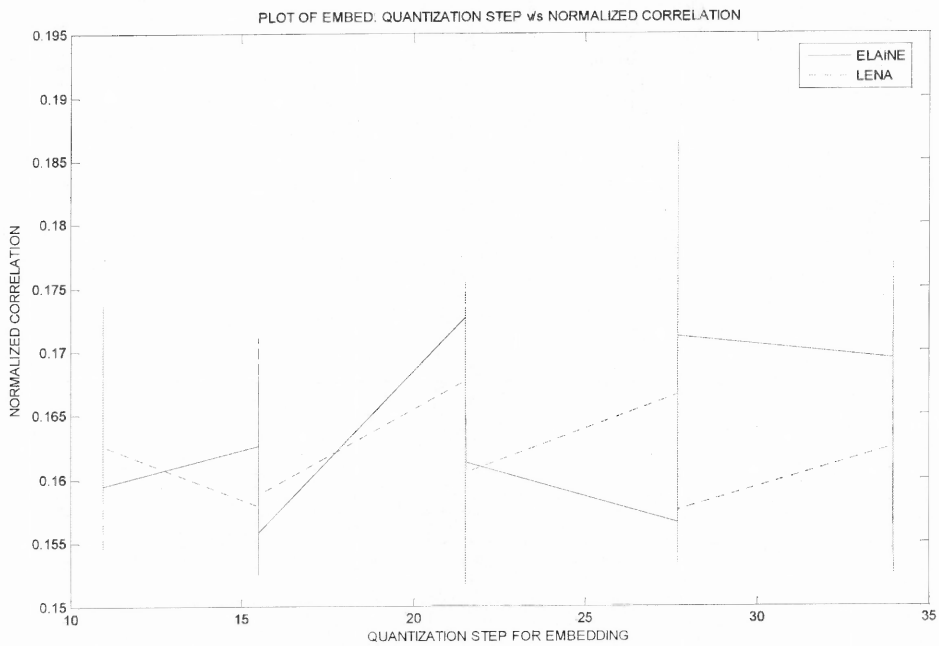

Figure 4.5 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 3 codebooks with single channel embedding.

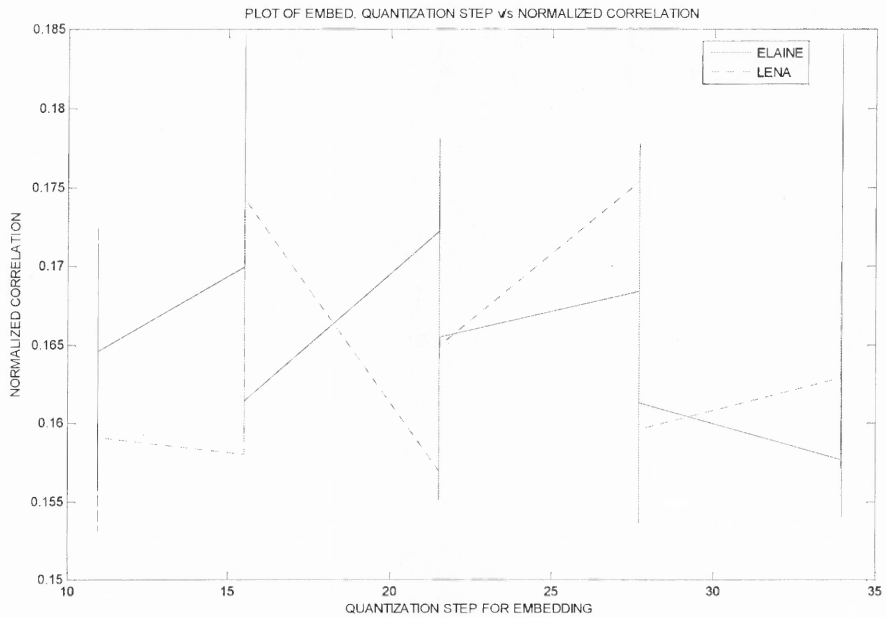

Figure 4.6 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 5 codebooks with single channel embedding.

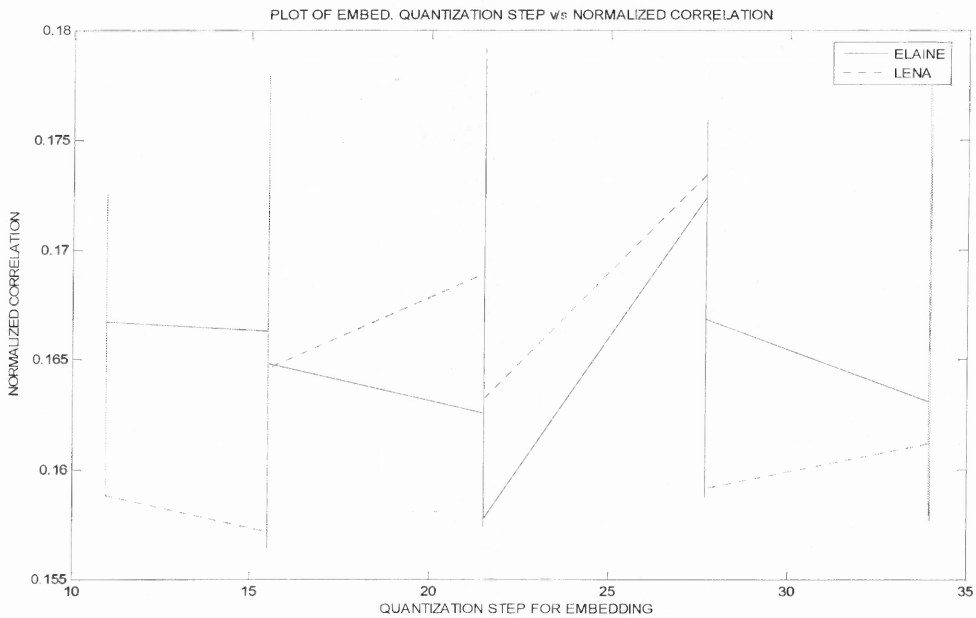

Figure 4.7 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 7 codebooks with single channel embedding.

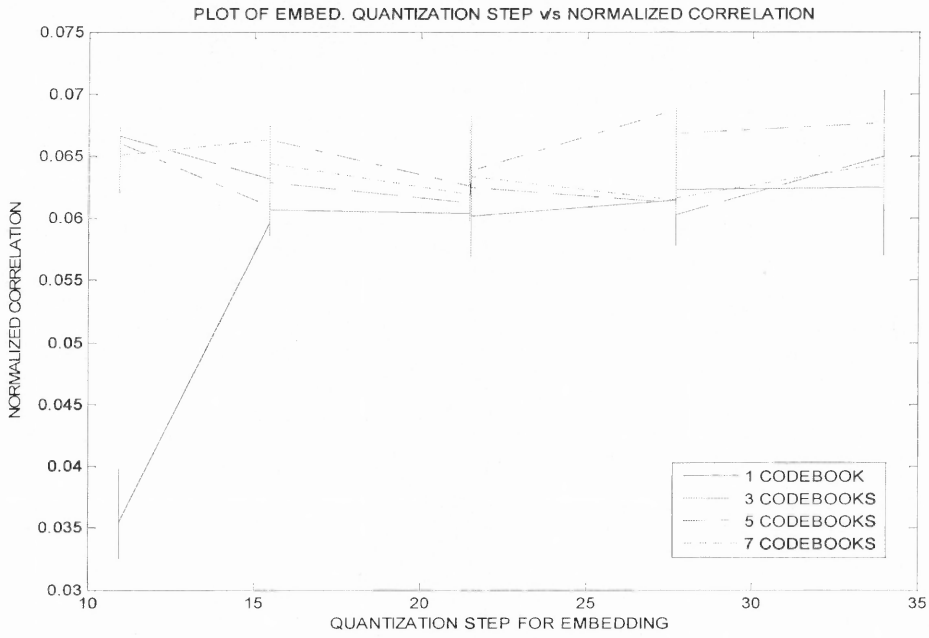

Figure 4.8 The plot of normalized correlation between W and $\hat{W}$ against the embedding quantization step (Lena Image) with multiple channel embedding.

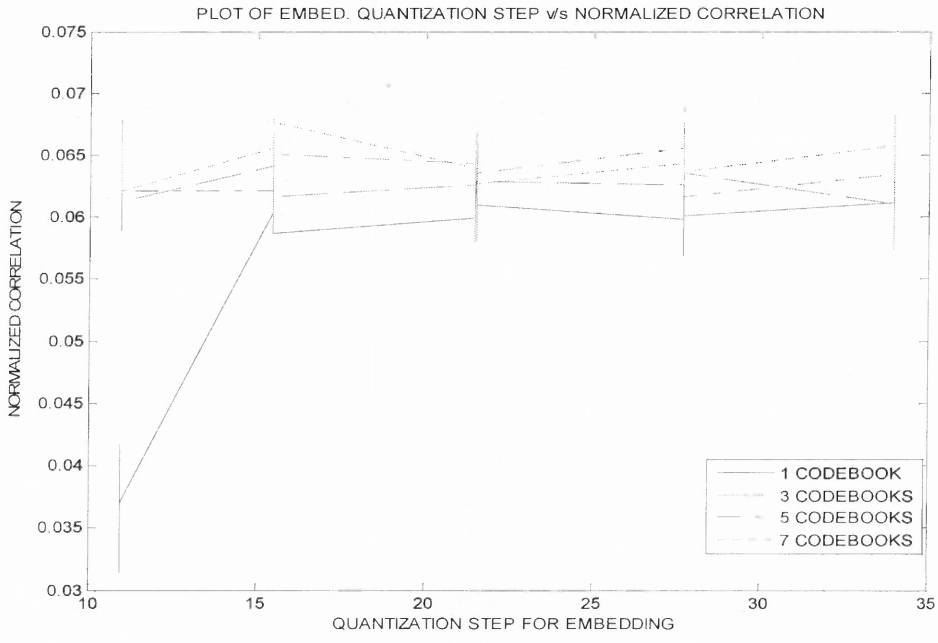

Figure 4.9 The plot of normalized correlation between W and $\hat{W}$ against the embedding quantization step (Elaine Image) with multiple channel embedding.

Figure 4.10 – 4.13 shows the comparison of the normalized correlation obtained from Lena image and Elaine image with 8 channel embedding. The channels have identical compression. It is again noted that the multiple channel embedding displays the same characteristics as the single channel embedding except the fact that the correlation reduces due to the introduction.

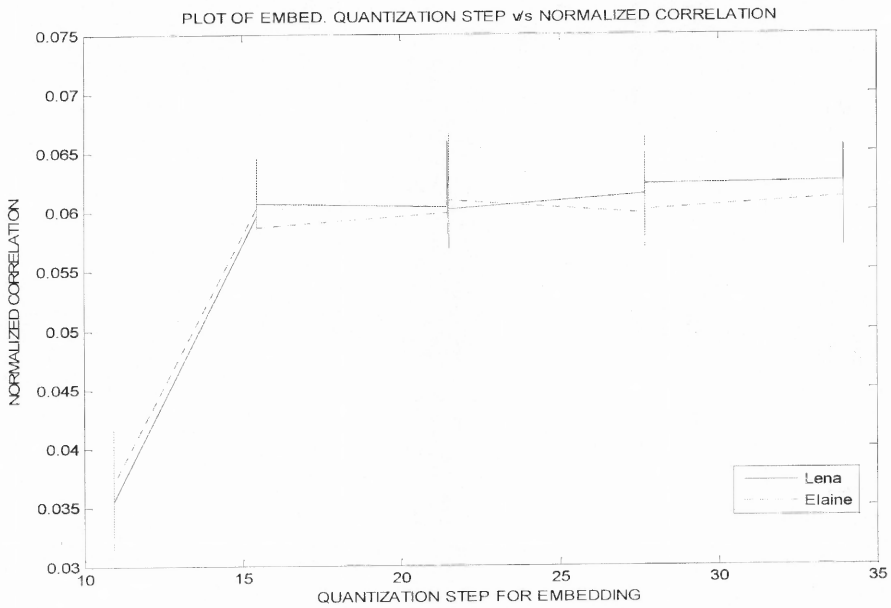

Figure 4.10 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for single codebook with multiple channel embedding.

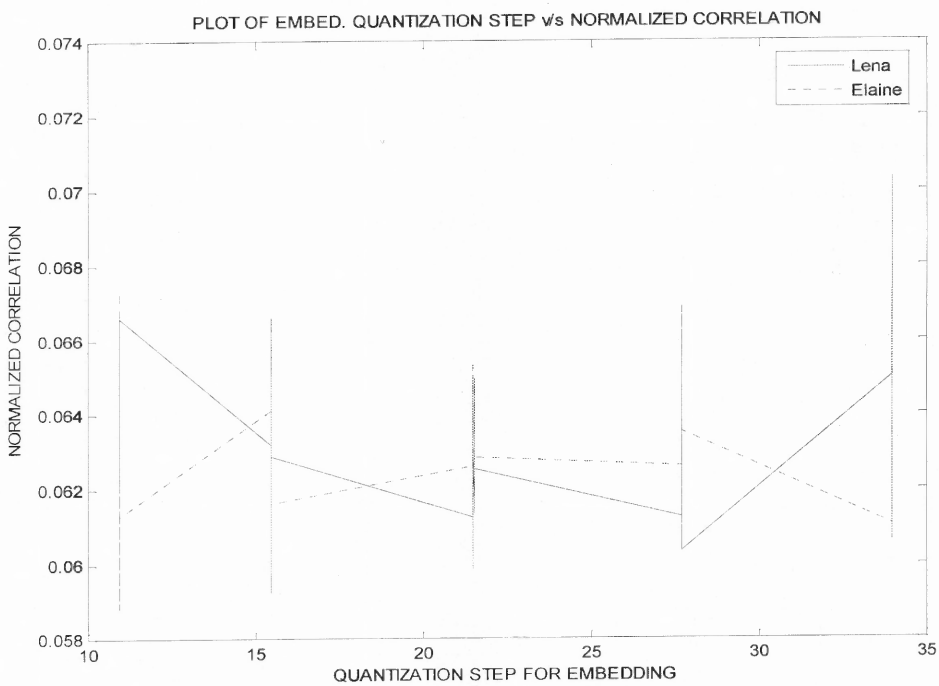

Figure 4.11 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 3 codebooks with multiple channel embedding.

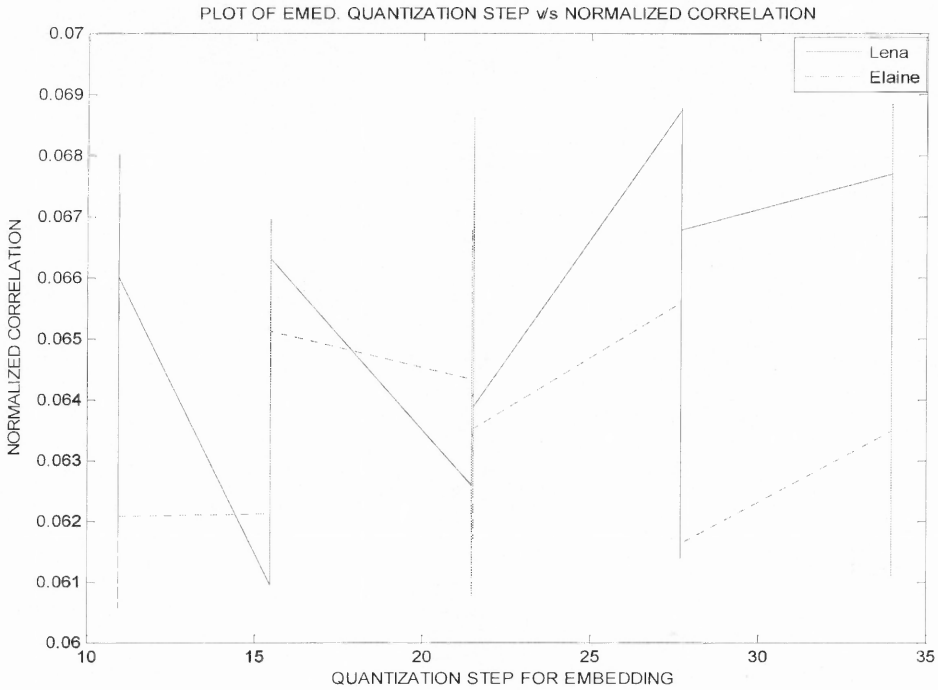

Figure 4.12 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 5 codebooks with multiple channel embedding.

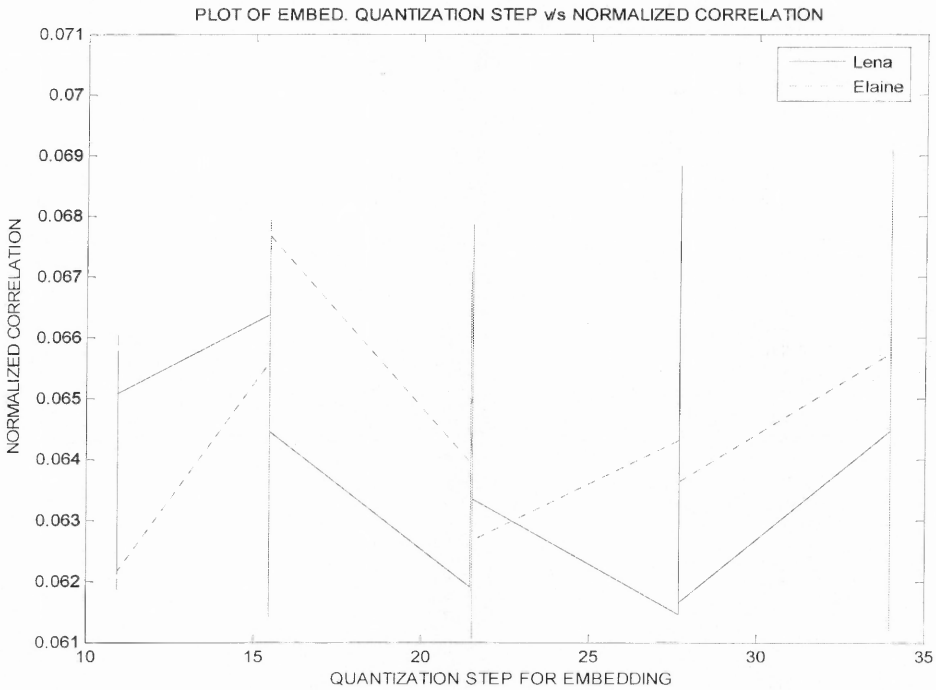

Figure 4.13 Comparison between Lena and Elaine images on the basis of normalized correlation between W and $\hat{W}$ for 7 codebooks with multiple channel embedding.

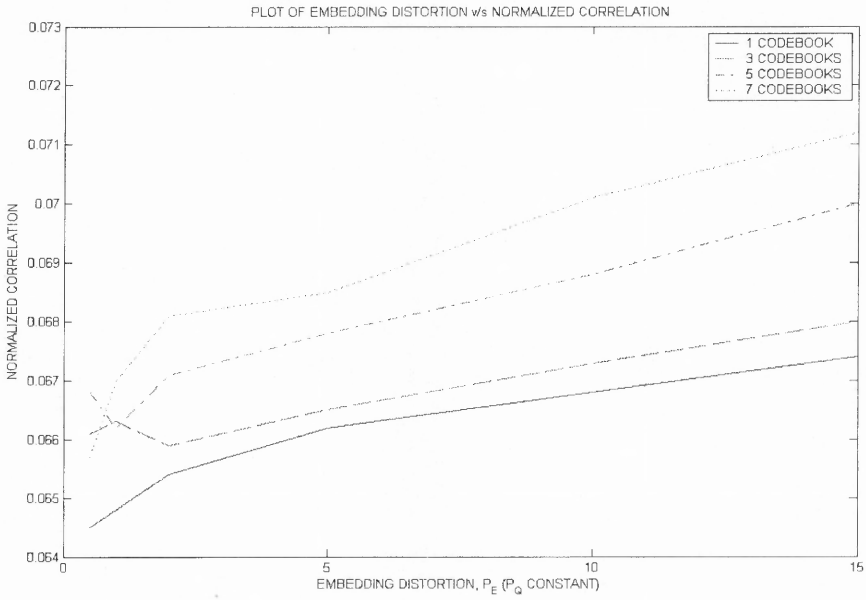

Figure 4.14 Plot of embedding distortion v/s normalized correlation.

The performance of multiple codebook data hiding is shown in Figure 4.14. It is observed that as the embedding distortion is increased, the normalized correlation between embedded watermark and extracted watermark increases and is improved as the number of codebooks are increased.

4.4 Evaluation of Measure of Distortion

The MSE in the Discrete Cosine Transform (DCT) domain of the image after embedding the watermark signal is an indicative of the measure of distortion due to embedding.

In this particular data embedding model, the DCT coefficients are assumed to follow uniform distribution. The formulae for type-III data embedding technique are modeled on the same. However, it is shown that the DCT coefficients are best modeled when the DC coefficients are modeled by a Gaussian distribution and the other coefficients are modeled by Laplacian distribution [5]. Hence, the theoretical

computation of the embedding distortion in the image is not a good indicative of the simulated performance as shown in the Figures 4.15.

By using the appropriate model for DCT coefficients, the theoretical performance gives an indicative of the actual performance.

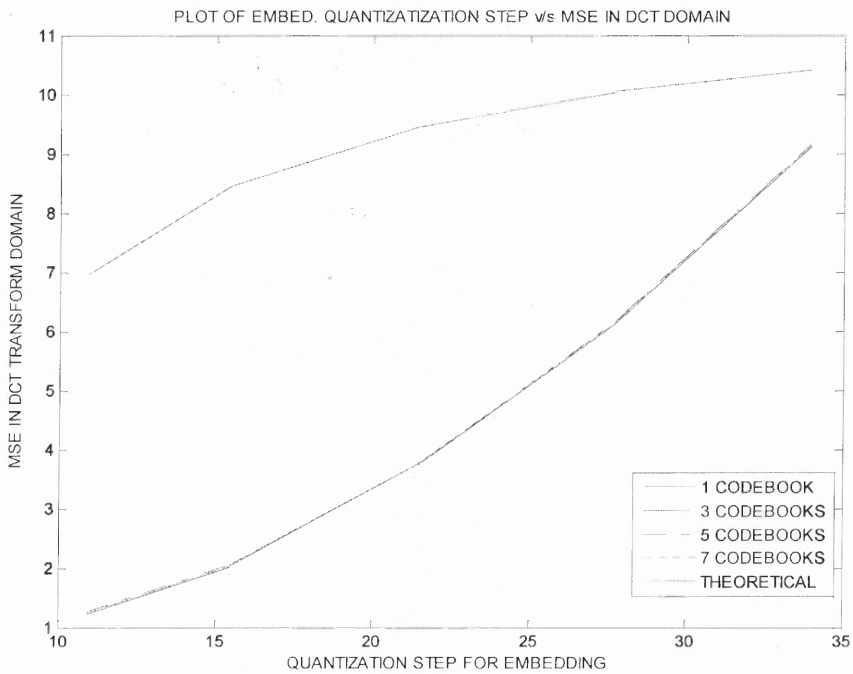

Figure 4.15 Comparison of theoretical distortion with the distortion obtained after embedding in multi-channel embedding (keeping embedding distortion constant for all codebooks).

CHAPTER 5

CONCLUSIONS

5.1 Optimizing Quantization Step for Joint Embedding and Compression

The study proposes a standard to implement type-III embedding-detection technique on JPEG compression scheme. The total distortion introduced in the stego image due to the joint embedding and compression scheme remains approximately constant considering the perceptual constraint. The amount of embedding distortion to be introduced in a signal certainly depends on the quality factor of the JPEG image and it is inversely proportional to the compression. More compression in the image will result in less data embedding rate and vice versa.

In this particular study, the type-III embedding-detection technique using multiple codebook data hiding scheme was studied on JPEG-85 compression scheme. The result showed that the optimum quantization step for embedding in JPEG-85 compression scheme is $15.5\,\Delta$.

5.2 Interpretation of Embedding Distortion, PE v/s Normalized Correlation

As shown in Figure 4.16, the normalized correlation increases with the increase in the embedding distortion as the stego signal which yields minimum signal distortion is selected [1]. The cover signal that is distorted less will yield maximum correlation between embedded and extracted watermark.

It can be concluded that the multiple codebook data hiding gives higher correlation values at higher embedding distortion as compared to the single codebook

data hiding. Higher embedding distortion enables higher embedding rate, hence, with multiple codebook data hiding, the data hiding rate is substantially increased. More number of codebooks enable better hiding rate. The normalized correlation was used as the metric to evaluate the performance of the multiple codebook data hiding as the theoretical embedding distortion is not a clear indicative of the observed embedding distortion.

5.3 Observation of MSE (DCT Domain) as Distortion Metric

The amount of embedding distortion produced due to embedding with the optimum quantization step was compared with the theoretical calculation. The Mean Square Error calculated in the DCT domain before compression can be taken as a measure of embedding distortion introduced in the stego image. If the cover signal coefficients are uniformly distributed, then the embedding distortion introduced in the signal is uniformly distributed over the quantization interval [1]. The theoretical calculation assumes that the cover signal is uniformly distributed. However, the DCT coefficients are best modeled when the DC coefficient is modeled on Gaussian distribution and the non-DC coefficients are modeled on Laplacian distribution [5]. As a result, the theoretical calculation of the distortion measure was not found to be a clear indicative of the simulated performance.

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