A COMPARATIVE STUDY OF DWT AND DCT BASED IMAGE WATERMARKING TECHNIQUES

SUBMITTED BY

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I hereby recommend the thesis, entitled "**A Comparative Study of DWT, DCT and Hybrid Watermarking based Image Watermarking Techniques**", prepared under my guidance by Pratik Sengupta, be accepted in partial fulfilment of the requirements for the degree of Master of Engineering in Software Engineering of Jadavpur University.

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Regards,

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ABSTRACT

Image watermarking with both insensible detection and high robustness capabilities is still a challenging problem for copyright protection up to now. Many proposed methods are already there which are more efficient against certain type of attacks. This paper compares between two major Frequency Transform Watermarking approaches - Discrete Cosine Transform and Discrete Wavelet Transform based Watermarking in coloured still image which are inherently collusion attack resistant.

Our DCT based Watermarking scheme for comparison is based on averaging of middle frequency coefficients of block DCT coefficients of an image which introduces high redundancy and can sustain malicious attacks. Experimental results show the robustness of the proposed scheme against the JPEG compression and other common image manipulations.

Whereas, the DWT based scheme is based on hiding the watermark data in blocks of the block segmented image by embedding the watermark data in the low pass wavelet coefficients of each block. Due to low computational complexity of the proposed approach, this algorithm can be implemented in real time. Experimental results demonstrate the imperceptibility of the proposed method and its high robustness against various attacks such as filtering, JPEG compression, cropping, noise addition and geometric distortions.

Finally we compare the results from the two schemes.

Contents

Chapter 1

Introduction

Nowadays, digital images can be copied and stored easily and without loss in fidelity. Therefore, it is important to use some kind of property rights protection system. With digital multimedia distribution over World Wide Web, authentications are more threatened than ever due to the possibility of unlimited copying. So, watermarking techniques are proposed for copyright protection or authentication of digital media. Many watermarking methods for images have been proposed [1]-[4].

More and more researchers are joining this area and number of publications is increasing exponentially. Most of the work is based on ideas known from spread spectrum communication [5] which is additive embedding a pseudo- noise watermark pattern and watermark recovery by correlation [6]. Cox et al suggested using the DCT domain [6], which has been extensively studied because this is the transform used in JPEG compression. Further advantage of using DCT domain includes the fact that frequency transform is widely used in image and video compression and DCT coefficients affected by compression are well known.

This paper proposes an efficient use of middle-band coefficients exchange to hide the watermark data. This paper uses the idea of Middle Band Coefficient Exchange which was discussed by Koch and Zhao [8] and further explained by Johnson and Katezenbeisser [9]. Later Hsu and Wu also used the DCT based algorithm to implement the middle band embedding [10]. Further one more efficient collusion attack resistant scheme has been presented based on middle-band coefficients exchange [7]. Collusion attack is the severe problem for some applications of watermarking like fingerprinting which involve high financial implications. So while designing a watermark scheme we are taking this attack as a prime. [11]- [12] Our main motivation behind selecting middle-band coefficients exchange scheme as a base is that this scheme has proven its robustness against those attacks which any how do not affect the perceptual quality of an image such as JPEG compression. Section 2 discusses the background studies. Chapter 3 describes the proposed method and Chapter 4 discusses the results.

Background

The term "digital watermark" was first coined in 1992 by Andrew Tirkel and Charles Osborne. Watermarks are identification marks produced during the paper making process. The first watermarks appeared in Italy during the 13th century, but their use rapidly spread across Europe. They were used as a means to identify the papermaker or the trade guild that manufactured the paper. The marks often were created by a wire sewn onto the paper mould. Watermarks continue to be used today as manufacturer's marks and to prevent forgery.

The information to be embedded in a signal is called a digital watermark, although in some contexts the phrase digital watermark means the difference between the watermarked signal and the cover signal. The signal where the watermark is to be embedded is called the host signal. A watermarking system is usually divided into three distinct steps, embedding, attack, and detection. In embedding, an algorithm accepts the host and the data to be embedded, and produces a watermarked signal.

Then the watermarked digital signal is transmitted or stored, usually transmitted to another person. If this person makes a modification, this is called an attack. While the modification may not be malicious, the term attack arises from copyright protection application, where third parties may attempt to remove the digital watermark through modification. There are many possible modifications, for example, lossy compression of the data (in which resolution is diminished), cropping an image or video or intentionally adding noise.

Detection (often called extraction) is an algorithm which is applied to the attacked signal to attempt to extract the watermark from it. If the signal was unmodified during transmission, then the watermark still is present and it may be extracted. In robust digital watermarking applications, the extraction algorithm should be able to produce the watermark correctly, even if the modifications were strong. In fragile digital watermarking, the extraction algorithm should fail if any change is made to the signal.

Research Objective

Contributions

Our research work has the following contributions:

- We proposed a new scheme which applies Discrete Cosine Transform and Discrete Wavelet Transform and a Hybrid approach to watermark an image. The scheme is robust against JPEG compression, cropping, rotation and other image attacks (see Chapter 4 for detail).

- We have experimented on these image watermarking schemes to test and show its performance against common attacks like JPEG Compression, Blurring, Rotation, Cropping, Sharpening and adding random noise.

- We compare our proposed schemes with the existing scheme in different aspects and discuss the advantages and the disadvantages of that.

The Structure of this Thesis

This Thesis is organized as 5 chapters. The next chapter introduces the issues related to multimedia security and different image watermarking techniques, and a survey on current watermark techniques. The proposed image watermarking schemes are described in chapter 3 and the experimental results in Chapter 4 are followed by. Finally, a conclusion is given in chapter 5.

Chapter 2

Literature Survey

Over the past few years, there has been tremendous growth in computer networks and more specifically, the World Wide Web. This phenomenon, coupled with the exponential increase of computer performance, has facilitated the distribution of multimedia data such as images. Publishers, artists, and photographers, however, may be unwilling to distribute pictures over the Internet due to a lack of security; images can be easily duplicated and distributed without the owner's consent. Digital watermarks have been proposed as a way to tackle this tough issue. This digital signature could discourage copyright violation, and may help determine the authenticity and ownership of an image.

In general, a digital watermark is a code that is embedded inside an image. It acts as a digital signature, giving the image a sense of ownership or authenticity. Ideal properties of a digital watermark have been stated in many articles and papers [13-15].

These properties include:

1. A digital watermark should be perceptually invisible to prevent obstruction of the original image.

2. A digital watermark should be statistically invisible so it cannot be detected or erased. Watermark extraction should be fairly simple. Otherwise, the detection process requires too much time or computation.

3. Watermark detection should be accurate. False positives, the detection of a non-marked image, and false negatives, the non-detection of a marked image, should be few.

4. Numerous watermarks can be produced. Otherwise, only a limited number of images may be marked.

5. Watermarks should be robust to filtering, additive noise, compression, and other forms of image manipulation.

6. The watermark should be able to determine the true owner of the image.

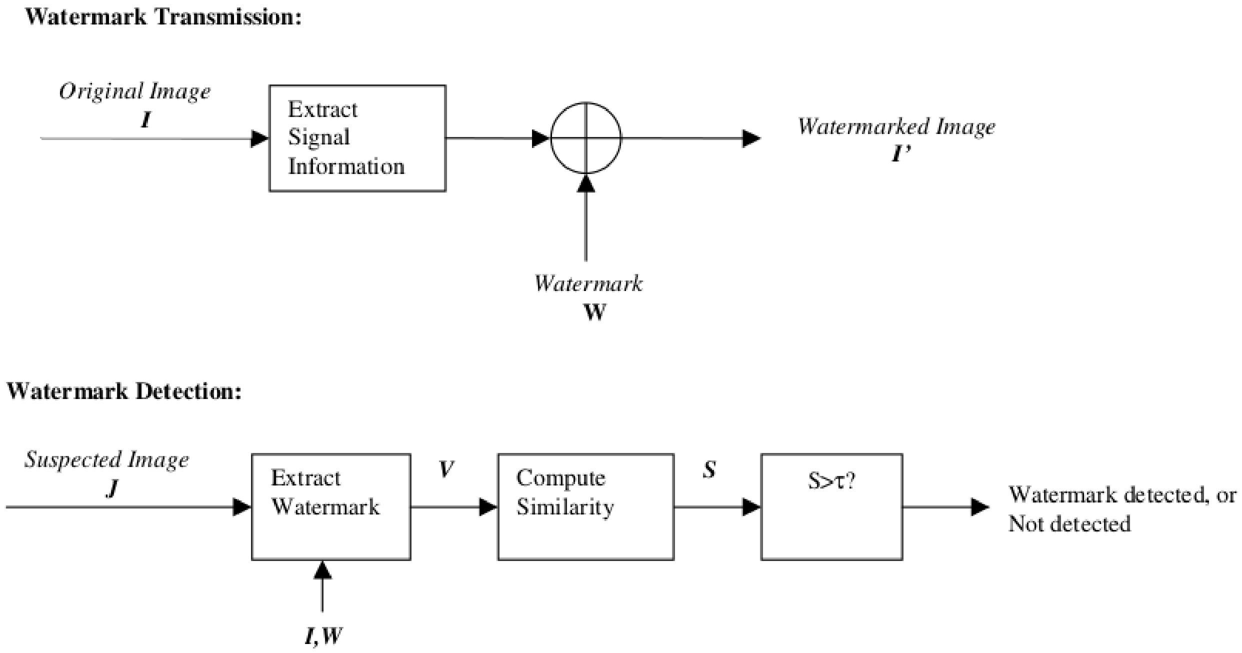


Figure 1.

Figure 1 shows a general watermarking scheme. For transmission, the watermark W is generated as a pseudo-random sequence to ensure statistical invisibility. Signal information, such as DCT coefficients, are extracted from the original image I and embedded into the information. The watermarked image I’ is formed with no visible differences between I and I’. For watermark detection, a suspected image J is taken and its signal information is obtained. A suspected watermark V is extracted based on knowledge of the original image I and the watermark W. A similarity measure S is performed on V and W. Popular measures include the cross-correlation and correlation coefficient. Finally, S is compared to a threshold τ. If S is larger than the threshold, then the watermark W is detected. Otherwise, no watermark is detected.

Security in Multimedia Communications

Steganography

Steganography is the science of hiding information. Whereas the goal of cryptography is to make data unreadable by a third party, the goal of steganography is to hide the data from a third party.

There are a large number of stenographic methods that most of us are familiar with, ranging from invisible ink and microdots to secreting a hidden message in the second letter of each word of a large body of text and spread spectrum radio communication. With computers and networks, there are many other ways of hiding information, such as:

- Covert channels (e.g., Loki and some distributed denial-of-service tools use the Internet Control Message Protocol, or ICMP, as the communications channel between the "bad guy" and a compromised system)

- Hidden text within Web pages

- Hiding files in "plain sight" (e.g., what better place to "hide" a file than with an important sounding name in the c:\winnt\system32 directory?)

- Null ciphers (e.g., using the first letter of each word to form a hidden message in an otherwise innocuous text)

Steganography today, however, is significantly more sophisticated than the examples above suggest, allowing a user to hide large amounts of information within image and audio files. These forms of steganography often are used in conjunction with cryptography so that the information is doubly protected; first it is encrypted and then hidden so that an adversary has to first find the information (an often difficult task in and of itself) and then decrypt it.

Digital Watermarking

A Digital Watermark is a pattern of bits inserted into a digital image, audio or video file that identifies the file's copyright information (author, rights, etc.). The name comes from the faintly visible watermarks imprinted on stationery that identify the manufacturer of the stationery. The purpose of digital watermarks is to provide copyright protection for intellectual property that's in digital format.
Unlike printed watermarks, which are intended to be somewhat visible, digital watermarks are designed to be completely invisible, or in the case of audio clips, inaudible. Moreover, the actual bits representing the watermark must be scattered throughout the file in such a way that they cannot be identified and manipulated. And finally, the digital watermark must be robust enough so that it can withstand normal changes to the file, such as reductions from lossy compression algorithms. Satisfying all these requirements is no easy feat, but there are a number of companies offering competing technologies. All of them work by making the watermark appear as noise - that is, random data that exists in most digital files anyway. To view a watermark, you need a special program that knows how to extract the watermark data.

Image Watermarking

Fidelity

Classification of Watermarking

Robustness

A digital watermark is called "fragile" if it fails to be detectable after the slightest modification. Fragile watermarks are commonly used for tamper detection (integrity proof). Modifications to an original work that clearly are noticeable commonly are not referred to as watermarks, but as generalized barcodes.

A digital watermark is called semi-fragile if it resists benign transformations, but fails detection after malignant transformations. Semi-fragile watermarks commonly are used to detect malignant transformations.

A digital watermark is called robust if it resists a designated class of transformations. Robust watermarks may be used in copy protection applications to carry copy and no access control information.

Perceptibility

A digital watermark is called imperceptible if the original cover signal and the marked signal are perceptually indistinguishable.

A digital watermark is called perceptible if its presence in the marked signal is noticeable (e.g. Network Logo, Content Bug, Codes, and Opaque images.)

This should not be confused with perceptual, that is, watermarking which uses the limitations of human perception to be imperceptible.

Capacity

The length of the embedded message determines two different main classes of digital watermarking schemes:

- The message is conceptually zero-bit long and the system is designed in order to detect the presence or the absence of the watermark in the marked object. This kind of watermarking scheme is usually referred to as zero-bit or presence watermarking schemes. Sometimes, this type of watermarking scheme is called 1-bit watermark, because a 1 denotes the presence (and a 0 the absence) of a watermark.

- The message is an n-bit-long stream $(m = m_1 \ldots m_n,\ n \in N \text{ with } n=|m|)$ *or* $M = \{0, 1\}^n$ and is modulated in the watermark. These kinds of schemes usually are referred to as multiple-bit watermarking or non-zero-bit watermarking schemes.

Statistical Imperceptibility

Low Error Probability

Real-time Detector Complexity

Reviews on Image Watermarking Techniques

Spatial Domain Watermarks

Modification of the Less-Significant-Bit (LSB): It is a simple approach to superimpose the watermark logo on the Least Significant Bit of the host image. It involves replacing **n** LSB of host image with data of the message to hide.

Statistical Approximation: It deals with the modification of some statistics of the image to keep information. A simple example would be the increase and decrease of brightness of certain pixels of the image. The pixel selection is determined by a pseudorandom number generator. In this way, the statistic of the difference between two pixels from the image taken randomly is altered.

Texture Block Encoding: It consist on selecting and copying a portion of the image determined by texture (herbs, asphalt, etc.) in other area of the image with similar characteristics. In this way two zones with identical textures can be obtained from the image. To detect these regions in a watermarked image it will suffice to calculate the image self-correlation to detect the position, and subtract the image itself but shifted to the position indicated by the self-correlation. After this process, zones where the difference is 0 can be appreciated. The geometrical form described by the profile of the copied zone may be the watermark (industry name, geometrical figure, etc). If the entire image suffers a uniform transformation, both regions will be affected in the same way and it will be possible to detect these two equal parts. However, this method requires a visual inspection to detect possible zones to copy, and the visual impact that the process produces.

Frequency Domain Watermarks

These schemes hide information in frequencies domain of the images, changing the value of the spectral coefficients. Most of these approaches are inspired in coding and compression methods (DCT, DFT and DWT).

Discrete Fourier Transform

Discrete Fourier transform (DFT) converts a finite list of equally spaced samples of a function into the list of coefficients of a finite combination of complex sinusoids, ordered by their frequencies, that has those same sample values. It can be said to convert the sampled function from its original domain (often time or position along a line) to the frequency domain.

The DFT is the sampled Fourier Transform and therefore does not contain all frequencies forming an image, but only a set of samples which is large enough to fully describe the spatial domain image. The number of frequencies corresponds to the number of pixels in the spatial domain image, *i.e.* the image in the spatial and Fourier domains are of the same size.

For a square image of size N×N, the two-dimensional DFT is given by:

$$F(k,l) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} f(i,j)\; e^{-\iota 2\pi \left(\frac{ki}{N} + \frac{lj}{N}\right)}$$

where *f(a,b)* is the image in the spatial domain and the exponential term is the basis function corresponding to each point *F(k,l)* in the Fourier space. The equation can be interpreted as: the value of each point *F(k,l)* is obtained by multiplying the spatial image with the corresponding base function and summing the result.

The basis functions are sine and cosine waves with increasing frequencies, *i.e. F(0,0)* represents the DC-component of the image which corresponds to the average brightness and *F(N-1,N-1)* represents the highest frequency.

In a similar way, the Fourier image can be re-transformed to the spatial domain. The inverse Fourier transform is given by:

$$f(a,b) = \frac{1}{N^2} \sum_{k=0}^{N-1} \sum_{l=0}^{N-1} F(k,l)\; e^{\iota 2\pi \left(\frac{ka}{N} + \frac{lb}{N}\right)}$$

Note the $\frac{1}{N^2}$ normalization term in the inverse transformation. This normalization is sometimes applied to the forward transform instead of the inverse transform, but it should not be used for both.$$

To obtain the result for the above equations, a double sum has to be calculated for each image point. However, because the Fourier Transform is *separable*, it can be written as

$$F(k,l) = \frac{1}{N} \sum_{b=0}^{N-1} P(k,b)\, e^{-\iota 2\pi \frac{lb}{N}}$$

where

$$P(k,b) = \frac{1}{N} \sum_{a=0}^{N-1} f(a,b)\, e^{-\iota 2\pi \frac{ka}{N}}$$

Discrete Cosine Transform

A discrete cosine transform (DCT) expresses a finite sequence of data points in terms of a sum of cosine functions oscillating at different frequencies. The most common variant of discrete cosine transform is the type-II DCT, which is often called simply "the DCT", its inverse, the type-III DCT, is correspondingly often called simply "the inverse DCT" or "the IDCT". The discrete cosine transform (DCT) helps separate the image into parts (or spectral sub-bands) of differing importance (with respect to the image's visual quality). The DCT is similar to the discrete Fourier transform: it transforms a signal or image from the spatial domain to the frequency domain. The general equation for a 1D (N data items) DCT is defined by the following equation:

$$F(u) = \left(\frac{2}{N}\right)^{\frac{1}{2}} \sum_{i=0}^{N-1} \Lambda(i).cos\left[\frac{\pi.u}{2.N}(2i+1)\right] f(i)$$

Where

$$\Lambda(i) = \begin{cases} \frac{1}{\sqrt{2}} & \text{for} \xi = 0 \\ 1 & \text{otherwise} \end{cases}$$

The general equation for a 2D (*N* by *M* image) DCT is defined by the following equation:

$$F(u,v) = \left(\frac{2}{N}\right)^{\frac{1}{2}} \left(\frac{2}{M}\right)^{\frac{1}{2}} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \Lambda(i).\Lambda(j).cos\left[\frac{\pi.u}{2.N}(2i+1)\right] cos\left[\frac{\pi.v}{2.M}(2j+1)\right].f(i,j)$$

and the corresponding ***inverse*** 2D DCT transform is simple $F^{-1}(u,v)$, i.e.:

where

$$\Lambda(\xi) = \begin{cases} \frac{1}{\sqrt{2}} & \text{for} \xi = 0 \\ 1 & \text{otherwise} \end{cases}$$

The basic operation of the DCT is as follows:

- The input image is N by M;
- f(i,j) is the intensity of the pixel in row i and column j;
- F(u,v) is the DCT coefficient in row k1 and column k2 of the DCT matrix.
- For most images, much of the signal energy lies at low frequencies; these appear in the upper left corner of the DCT.
- Compression is achieved since the lower right values represent higher frequencies, and are often small - small enough to be neglected with little visible distortion.

- The DCT input is an 8 by 8 array of integers. This array contains each pixel's gray scale level;
- 8 bit pixels have levels from 0 to 255.

The DCT is used in JPEG image compression, MJPEG, MPEG, DV, Daala, and Theora video compression. There, the two-dimensional DCT-II of N \times N blocks are computed and the results are quantized and entropy coded. In this case, N is typically 8 and the DCT-II formula is applied to each row and column of the block.

Discrete Wavelet Transform

Discrete wavelet transform (DWT) is any wavelet transform for which the wavelets are discretely sampled. As with other wavelet transforms, a key advantage it has over Fourier transforms is temporal resolution: it captures both frequency and location information (location in time).

Chapter 3

Discrete Cosine Transform based schemes:

Discrete Wavelet Transform based schemes:

In [15] a novel method is presented for audio watermarking. In this method the host signal in transform domains is modified with respect to the binary watermark signal (0 or 1). The embedding processes used in this method can be summarized as follows:

1. Windowing the host signal.

2. Applying the wavelet transform to each frame.

3. Embedding the watermark bit of 1 or 0 to a number of wavelet coefficients, W(i), of each frame based on the following equations:

   $W'(i) = W(i).\alpha$ For embedding 1 (1)
   $W'(i) = W(i)/\alpha$ For embedding 0 (2)

   where α is the strength factor.

4. Inverse wavelet transforming the resulted coefficients of each frame.

In the detection process, the embedded data is detected by the following process:

1. Windowing the original and received signal and Applying the wavelet transform to each frame of them.

2. Calculating a compare vector by dividing the wavelet coefficients of the received signal to the original one.

3. Detecting the embedded bit by comparing the vector which is calculated in the second step with a threshold level. If the majority of the vector components is larger than the threshold level, the embedded bit would be 1, otherwise 0 is detected It is proved in [16] that as the embedding process is symmetrical, the best threshold value is $(\alpha + 1/\alpha)$. 1/2

Watermark embedding

The embedding processes used in this method can be summarized as:

- Segmenting the original image to small non-overlapping blocks and then applying the wavelet transforming to each block.

- In each block, the wavelet coefficients in the last low pass scale are modified for embedding

1 or 0 based on (1) and (2).

- Applying the inverse wavelet transform to the obtained wavelet coefficients.

Watermark detection

The detection process can be described as follows:

- Block segmenting of the received and the original image and applying the wavelet transform to each block for the both images.
- Calculating the comparing matrix by dividing the wavelet coefficients of the received image to the original one.
- Detecting the embedded bit by comparing the matrix which is calculated in the second step with a threshold level. If the majority of the matrix components is larger than the threshold level, the embedded bit would be 1, otherwise 0 is detected.

We use the threshold level of ($\alpha + 1/\alpha$). 1/2, same as [16].

Hybrid Watermarking Schemes

In this proposed scheme we convert the image into DWT domain followed by a 1D – DCT. This watermarking scheme is blind in nature meaning that it does not require the original Cover Image or even the watermark logo to recover the watermark.

Watermark embedding

The embedding processes used in this method can be summarized as:

- Wavelet transform the cover image to two levels
- In each block, the wavelet coefficients in the last low pass scale are modified for embedding 1 or 0 based on (1) and (2).
- Applying the inverse wavelet transform to the obtained wavelet coefficients.

Watermark detection

The detection process can be described as follows:

- Block segmenting of the received and the original image and applying the wavelet transform to each block for the both images.
- Calculating the comparing matrix by dividing the wavelet coefficients of the received image to the original one.

- Detecting the embedded bit by comparing the matrix which is calculated in the second step with a threshold level. If the majority of the matrix components is larger than the threshold level, the embedded bit would be 1, otherwise 0 is detected.

Chapter 4

Experimental Results

We considered Normalized Cross Correlation (NCC) and Bit Error Rate (BER) as a parameter to test our results. GIMP Image editor is used for our tests during JPEG compression, adding Blur filter, sharpening filter, cropping, rotation, equalization etc.
Normalized Cross Correlation (NCC) is done by subtracting the mean at every step from the two waveforms and calculating their product, finally dividing by the standard deviation.

$$\text{Normalized Cross Correlation } \textbf{(NCC)} = \frac{\sum_{(i,j)\in W} I_1(i,j).I_2(x+i,y+j)}{\sqrt[2]{\sum_{(i,j)\in W} I_1^2(i,j).\sum_{(i,j)\in W} I_2^2(x+i,y+j)}}$$

A Bit Error Rate (BER) is defined as the rate at which errors occur in a transmission system, in our case in the extracted watermark.

$$\boldsymbol{BER} = (\text{Number of Bit Errors})/(\text{total number of bits in extracted image})$$

For each image we conducted the following tests:

1. *JPEG Image Compression*: The Watermarked Image is compressed at different JPEG compression Levels from 100 to 10. Then the watermarks are extracted and their NCC and BER are calculated and plotted against compression level.

2. *Image Blurring*: Blur Filter is added to watermarked images with Blur radius varying from 1 to 5. Then the watermarks are extracted and their NCC and BER are calculated and plotted against blur radius.

3. *Image Sharpening*: Sharpen filter is added to the Watermarked image with sharpening radius varying from 4 to 20 at an interval of 4. Then the watermarks are extracted and their NCC and BER are calculated and plotted against sharpening radius.

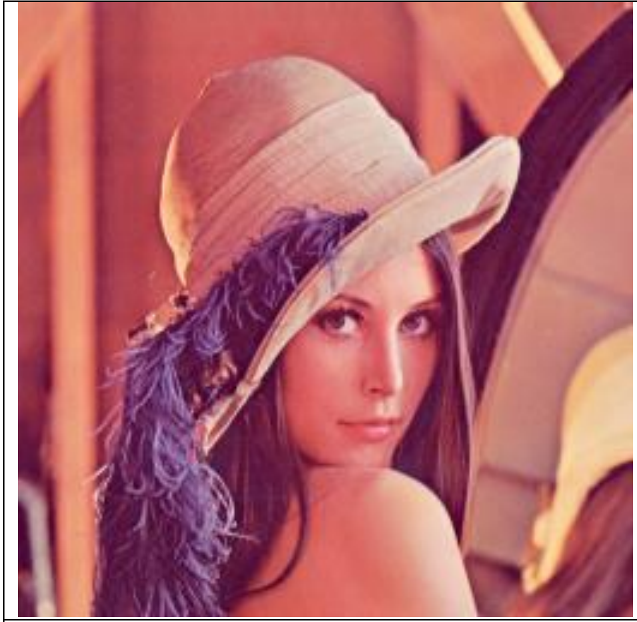
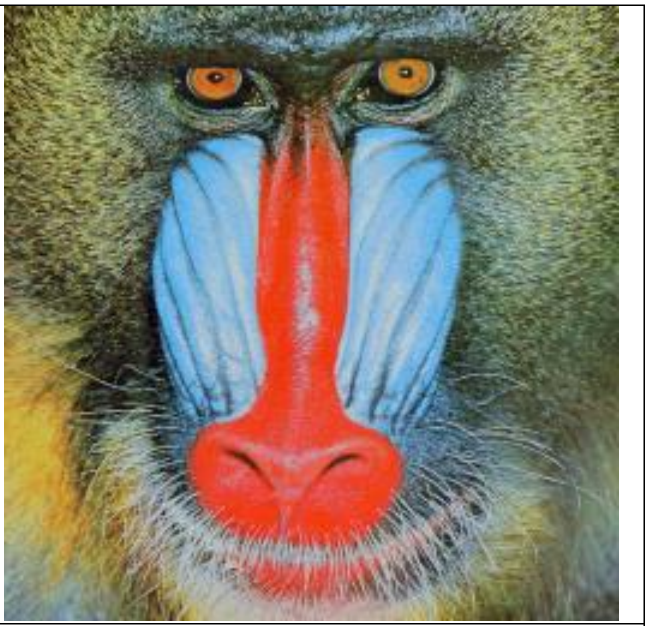
4. *Hurl Noise Addition*: Hurl noise is added to the Watermarked image to test their robustness against random noise which might occur during transmission or even by an attacker. Hurl Randomization value is varied from 5 to 25 at an interval of 5 each step.

5. *Histogram Equalization*: The Watermarked image is passed through Histogram Equalization filter and the Watermark is extracted. The NCC and BER are calculated and plotted.

6. *Image Rotation*: The Watermarked image is rotated from -7 degree to +7 degree to test the watermark's robustness against geometrical attacks and also against the interpolation of pixel values. The rotated image is first recovered to its initial position and the Watermark is extracted. Finally the NCC and BER are calculated and plotted against the rotation angles.

7. *Image Cropping*: The Watermarked Image is slightly cropped and the watermark is extracted. The NCC and BER value for the corresponding image is calculated.

Our tested included 4 popular test images –

	
Lena Figure 2a (Cover Image)	Mandrill Figure 2b (Cover Image)
Barbara Figure 2c (Cover Image)	Goldhill Figure 2d (Cover Image)

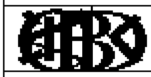



Figure 2e (Watermark Logo)	

A. Results of DWT Watermarking scheme:

In this section we perform several experiments to test the proposed algorithms and evaluated its performance against various kinds of attacks. Throughout our experiments we choose the strength factor of α = 1.025. These factors are selected to maximize the robustness of this approach, while the modifications introduced by the watermarking process are imperceptible. We use Normalized Cross Correlation (NCC) to measure the performance of the watermarking scheme against attacks. A set of four common images were tested for our experiments. The images are illustrated in Figure 2a, 2b, 2c and 2d. Watermark Logo to embed is shown in Figure 2e.

These two are 512×512 standard images: Lena and Mandrill

Their watermarked versions are shown in Figures 2f and 2g. As we see the imperceptibility of the watermarked images are satisfied, the mean PSNR (peak-signal-to-noise-ratio) of the watermarked images are **71.91 dB**, **80.19 dB, 77.81 and 76.46** respectively.

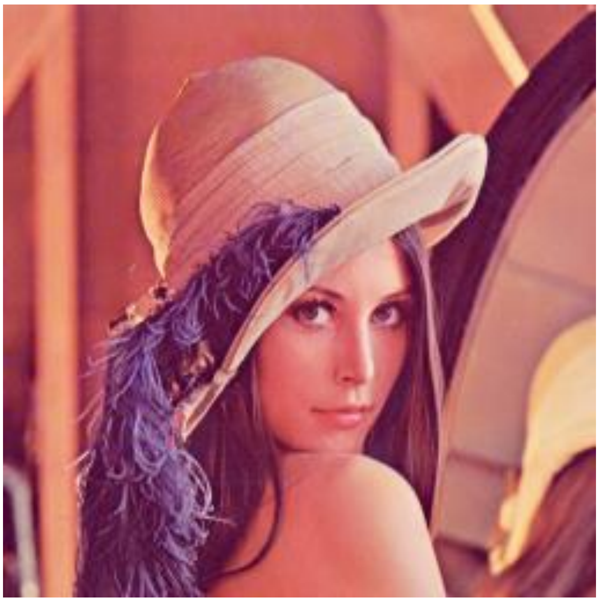
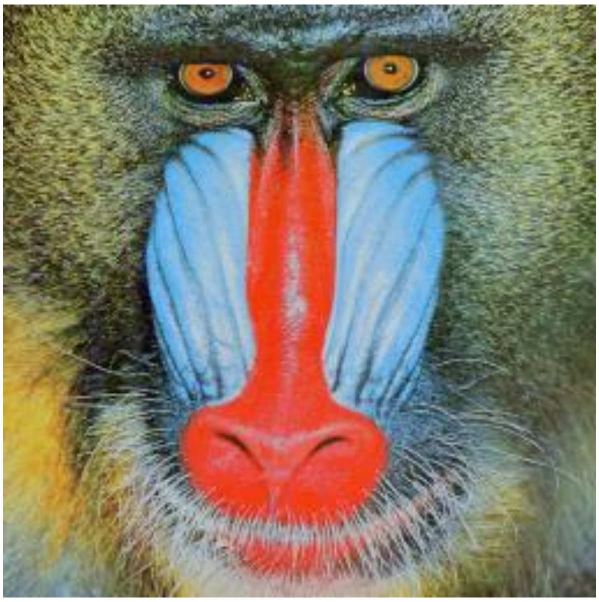
	

Figure 2f (After Watermarking)	Figure 2g (After Watermarking)
NCC: 1 mse=0, psnr=71.91, psnrMax=71.01, snr=66.01 ber: 0	NCC: 1 mse=0, psnr=80.19, psnrMax=77.5, snr=74.1 ber: 0

Figure 2h (After Watermarking)	Figure 2i (After Watermarking)
NCC: 1 mse=0, psnr=77.81, psnrMax=76.53, snr=71.22 ber: 0	NCC: 1 mse=0, psnr=76.46, psnrMax=75.75, snr=70.4 ber: 0

In the second experiment, we test the robustness of this watermarking method against JPEG compression attacks. Figure 2e shows the resulted NCC for different images. As we see, the DWT method is highly robust against JPEG attacks.

JPEG Compression/Metrics	Image Name	NCC	MSE	PSNR	PSNR Max	SNR	BER
100%	Lena	1.0	0.0	Infinity	Infinity	Infinity	0.0
90%	Lena	1.0	0.0	Infinity	Infinity	Infinity	0.0
80%	Lena	0.98	889.9	18.64	17.93	14.61	0.02
70%	Lena	0.97	1686.13	15.86	15.15	11.83	0.04
60%	Lena	0.96	2154.5	14.8	14.09	10.77	0.04
50%	Lena	0.93	3372.26	12.85	12.14	8.82	0.07
40%	Lena	0.89	5292.57	10.89	10.18	6.86	0.11
30%	Lena	0.85	7306.56	9.49	8.78	5.46	0.15
20%	Lena	0.76	0866.16	7.77	7.06	3.74	0.23
10%	Lena	0.61	18594.25	5.44	4.73	1.41	0.39

JPEG	Image	NCC	MSE	PSNR	PSNR	SNR	BER

Compression/Metrics	Name				Max		
100%	Mandrill	1	46.84	31.42	30.72	27.39	0
90%	Mandrill	0.99	702.55	19.66	18.95	15.63	0.01
80%	Mandrill	0.97	1358.27	16.8	16.09	12.77	0.03
70%	Mandrill	0.92	3840.63	12.29	11.58	8.26	0.08
60%	Mandrill	0.91	4636.85	11.47	10.76	7.44	0.1
50%	Mandrill	0.88	5807.78	10.49	9.78	6.46	0.12
40%	Mandrill	0.84	7681.25	9.28	8.57	5.25	0.16
30%	Mandrill	0.84	7587.58	9.33	8.62	5.3	0.16
20%	Mandrill	0.77	10866.16	7.77	7.06	3.74	0.23
10%	Mandrill	0.63	16954.96	5.84	5.13	1.81	0.35

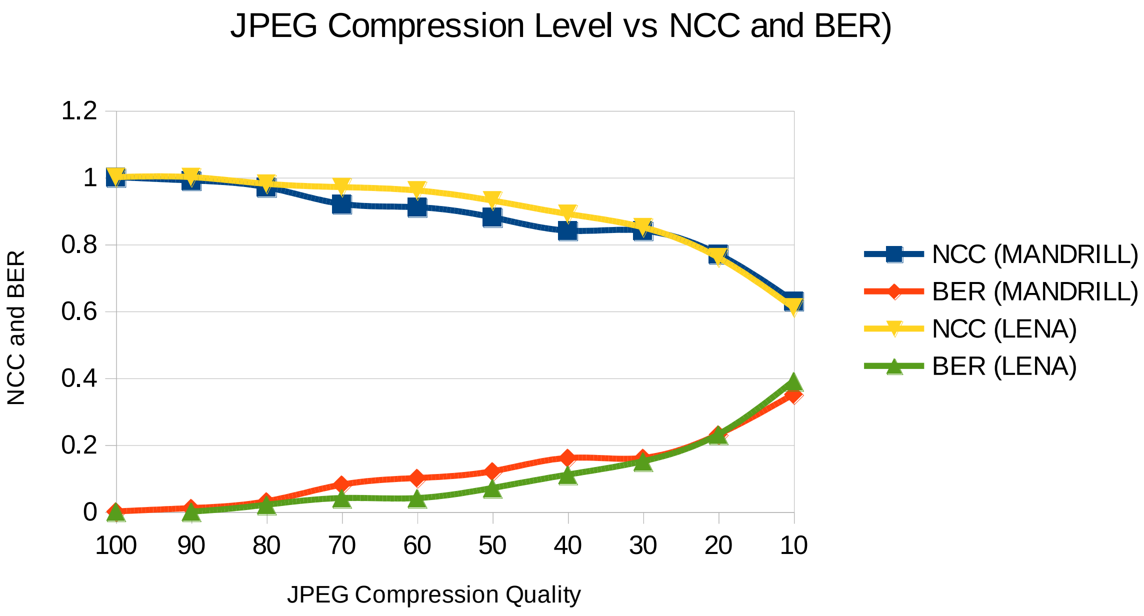
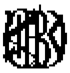
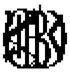
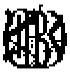
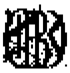
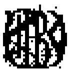
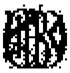
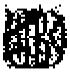
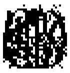


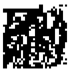
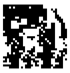
Figure 2e (Line Graph – JPEG Compression Level vs NCC and BER)

NCC: Normalized Cross Correlation | BER: Bit Error Rate

JPEG Compression Level	JPEG Compressed Image	Extracted Watermark

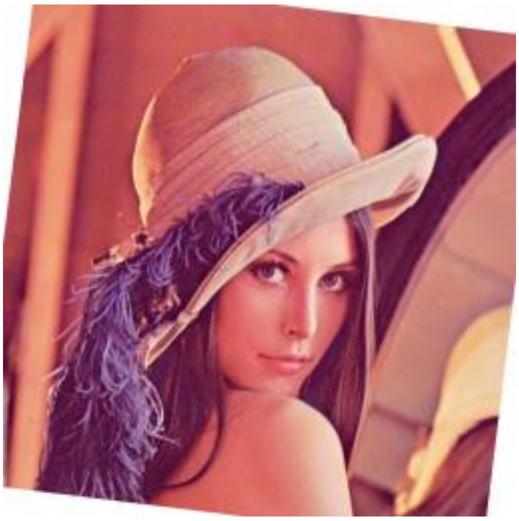
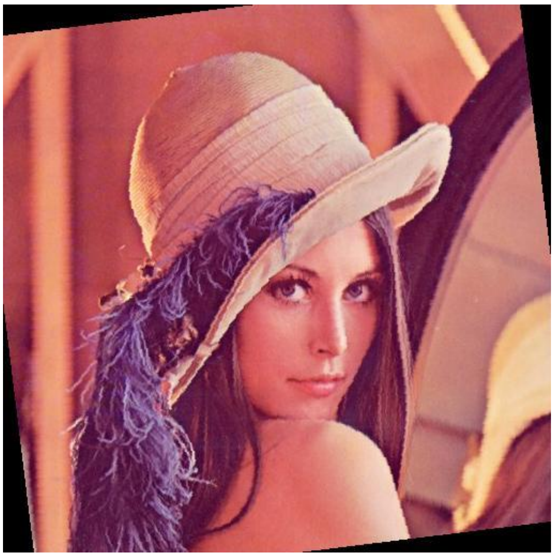
JPEG Compressed Image with quality factor of 100%		
JPEG Compressed Image with quality factor of 90%		
JPEG Compressed Image with quality factor of 80%		
JPEG Compressed Image with quality factor of 70%		

JPEG Compressed Image with quality factor of 60%		
JPEG Compressed Image with quality factor of 50%		
JPEG Compressed Image with quality factor of 40%		
JPEG Compressed Image with quality factor of 30%		

JPEG Compressed Image with quality factor of 20%		
JPEG Compressed Image with quality factor of 10%		

In the third experiment, the watermarks are tested against additive white Gaussian noise attack with different noise levels. The NCC results are shown in Figure 2f. Again, we see that the proposed watermarking schemes are robust against even high variance noise attack.

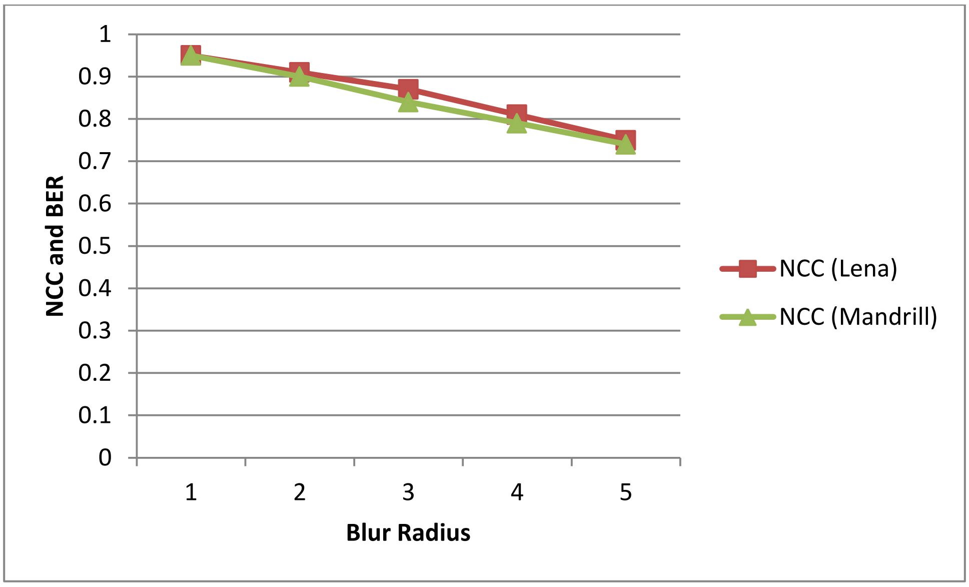
Robustness against rotation is the concept of the fourth experiment. Using template matching the rotation attack can be compensated by identifying the rotation angle and then rotating the image back. Therefore, the introduced distortion only comes from the interpolation due to image rotation. The NCC results are shown in Table 1. As we see even for large rotation angles our watermarking methods are still robust.

 Watermarked Image rotated 7 degrees to right with respect to center.	 Recovered Image	 Extracted Watermark

We test the robustness against blurring in the fifth experiment. Here we introduce Gaussian Blur into the watermarked image with blur radius varying from 1 to 5.

Image	**Blur Radius**	**NCC**	**Recovered Image**
Lena	1	0.95	
Lena	2	0.91	
Lena	3	0.87	
Lena	4	0.81	
Lena	5	0.75	
Mandrill	1	0.95	
Mandrill	2	0.90	
Mandrill	3	0.84	
Mandrill	4	0.79	
Mandrill	5	0.74	

Table showing NCC values corresponding to Blur Radius.

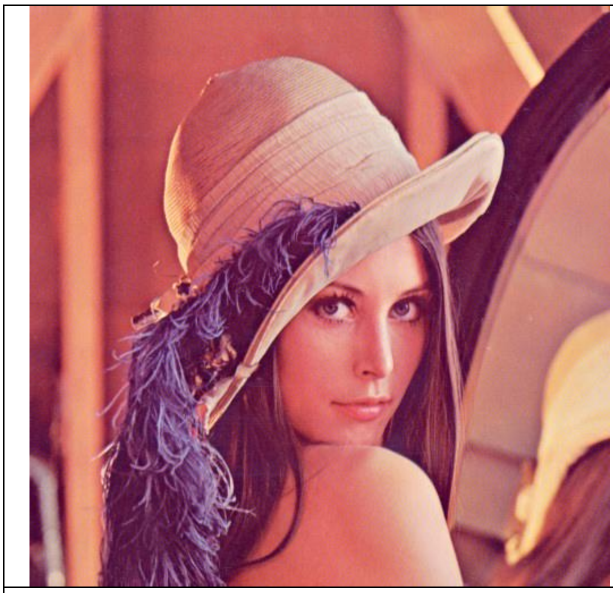
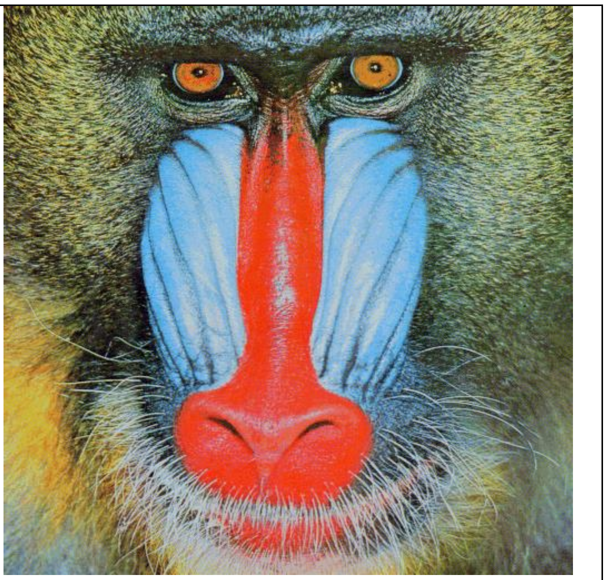
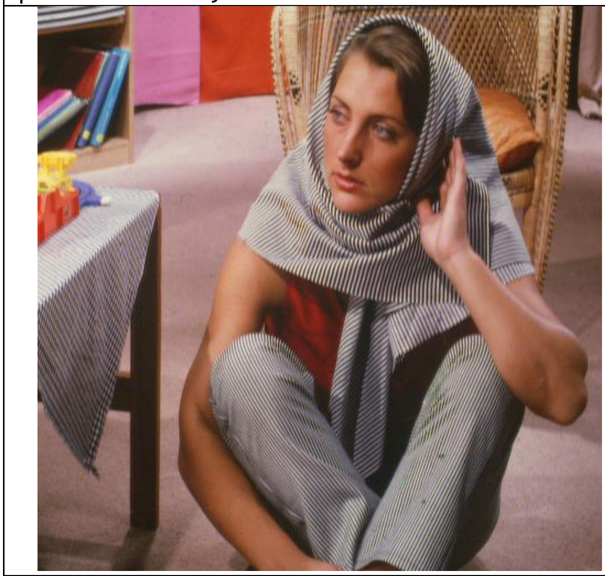


Graphical representation of NCC values vs Blur Radius

Clearly we can see that this proposed scheme is robust against Blurring Attacks.

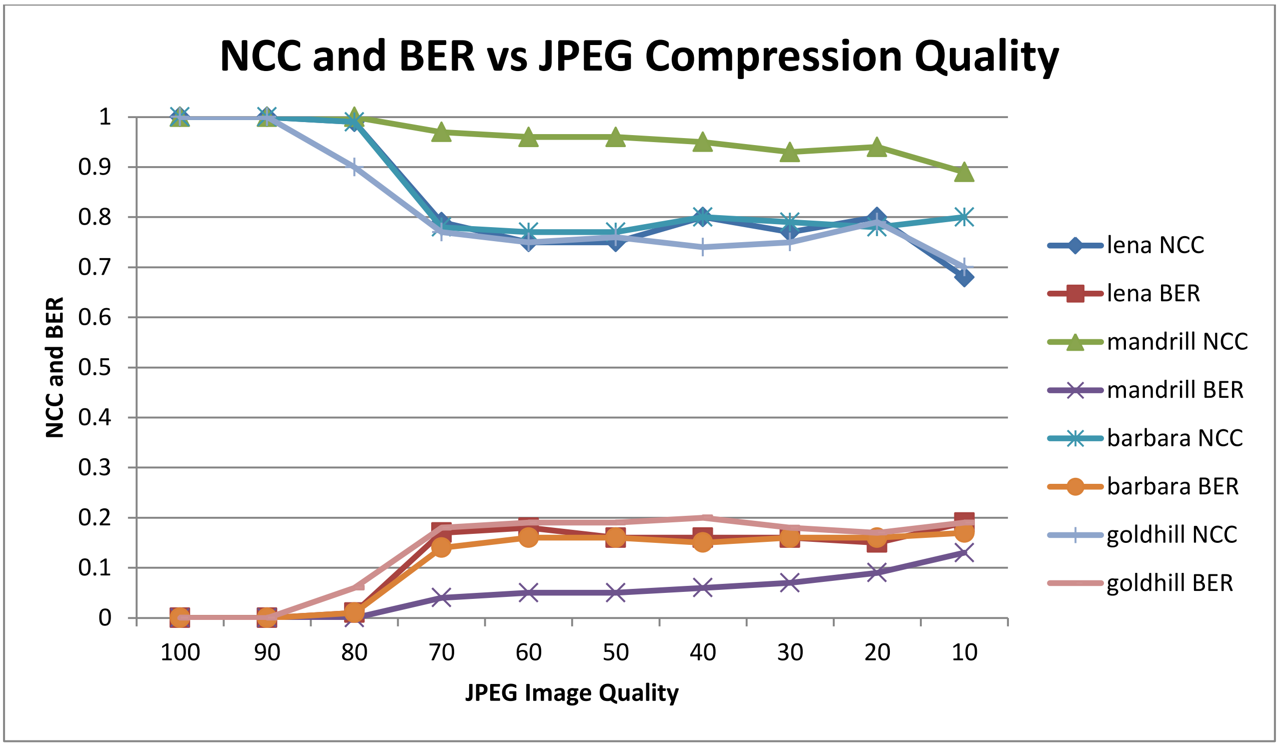
In the seventh experiment we test the watermarked image against Noise Attacks.

B. Results of DCT Watermarking scheme:

	
Lena Figure 4B(i) (After DCT Watermarking)	Mandrill Figure 4B (ii) (After DCT Watermarking)
`NCC: 1 mse=0.01, psnr=68.59, psnrMax=67.69, snr=62.69 ber: 0.01`	`NCC: 1 mse=0.1, psnr=58.05, psnrMax=55.36, snr=51.96 ber: 0.02`
	
`NCC: 1 mse=0.07, psnr=59.68, psnrMax=58.39, snr=53.09 ber: 0.01`	`NCC: 1 mse=0.17, psnr=55.91, psnrMax=55.2, snr=49.84 ber: 0.03`

In the second experiment, we test the robustness of this watermarking method against JPEG compression attacks. Figure 2e shows the resulted NCC for different images. As we see, the DWT method is highly robust against JPEG attacks.

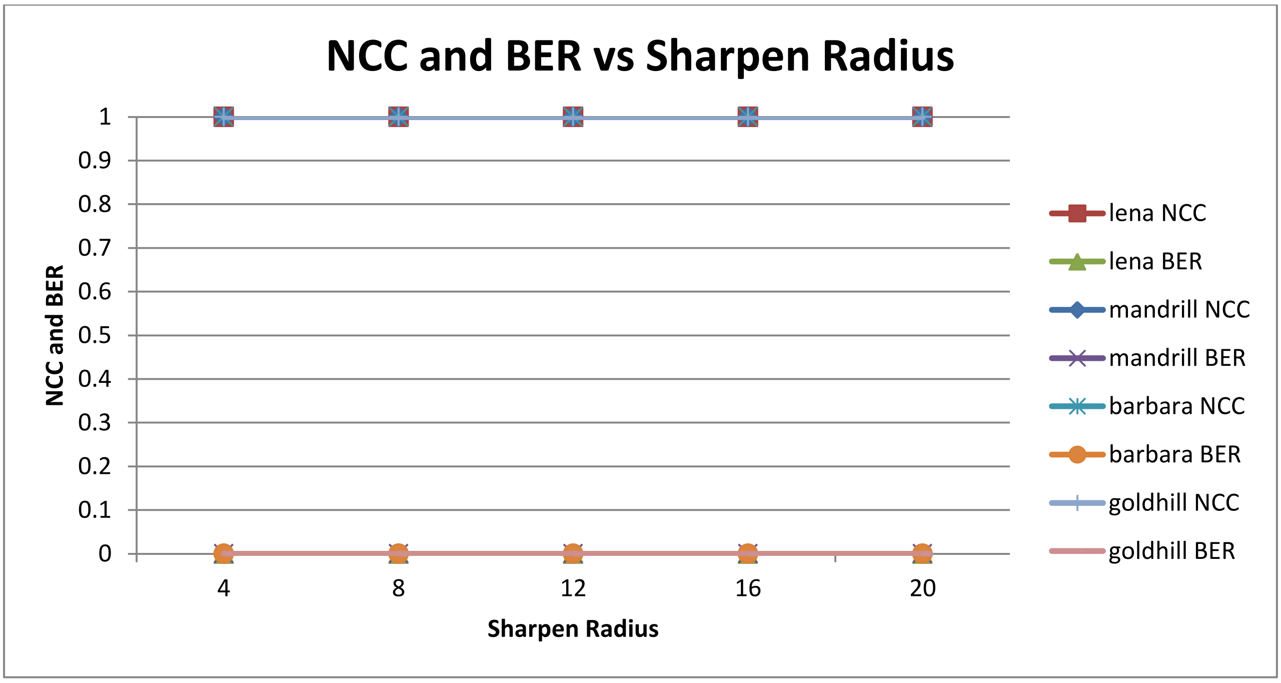
	lena		mandrill		barbara		goldhill	
JPEG Quality	NCC	BER	NCC	BER	NCC	BER	NCC	BER
100	1.00	.00	1.00	.00	1.00	.00	1.00	.00
90	1.00	.00	1.00	.00	1.00	.00	1.00	.00
80	.99	.01	1.00	.00	.99	.01	.90	.06
70	.79	.17	.97	.04	.78	.14	.77	.18
60	.75	.18	.96	.05	.77	.16	.75	.19
50	.75	.16	.96	.05	.77	.16	.76	.19
40	.80	.16	.95	.06	.80	.15	.74	.20
30	.77	.16	.93	.07	.79	.16	.75	.18
20	.80	.15	.94	.09	.78	.16	.79	.17
10	.68	.19	.89	.13	.80	.17	.70	.19



Sharpen Attack Results

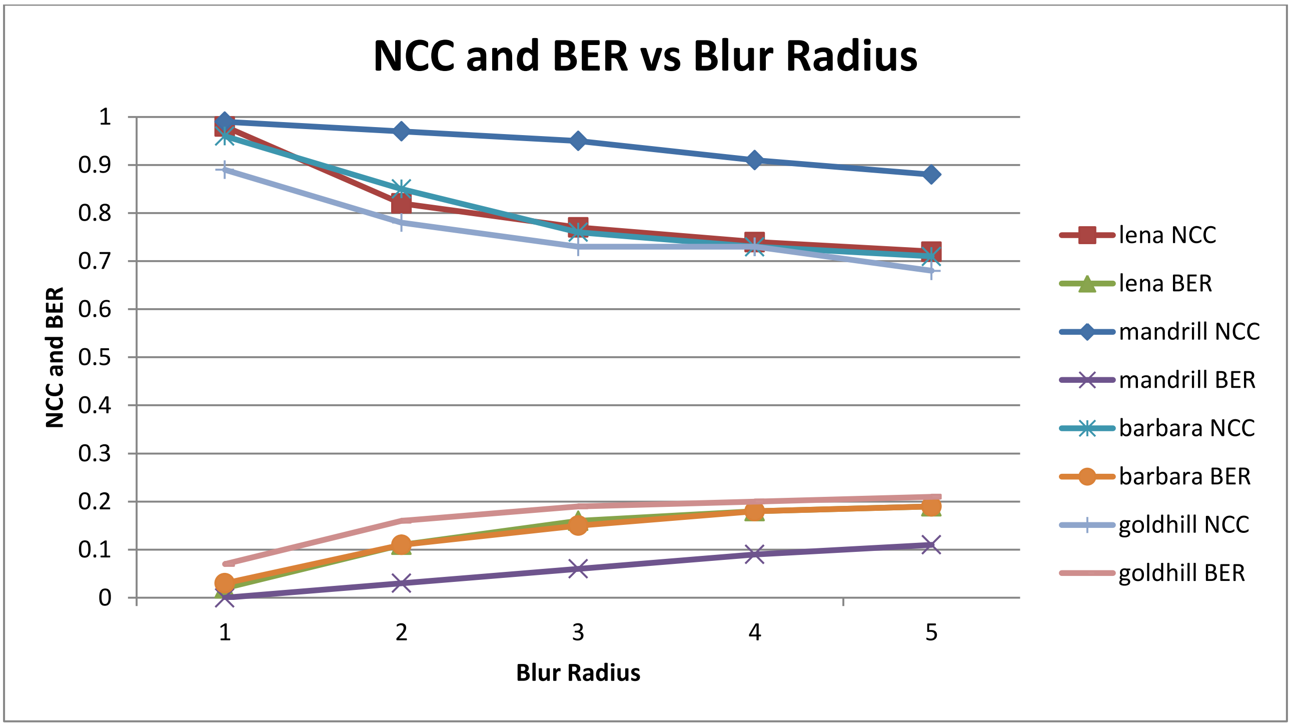
	lena		mandrill		barbara		goldhill	
Sharpen Radius	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**
4	1.00	.00	1.00	.00	1.00	.00	1.00	.00

	lena		mandrill		barbara		goldhill	
Sharpen Radius	NCC	BER	NCC	BER	NCC	BER	NCC	BER
8	1.00	.00	1.00	.00	1.00	.00	1.00	.00
12	1.00	.00	1.00	.00	1.00	.00	1.00	.00
16	1.00	.00	1.00	.00	1.00	.00	1.00	.00
20	1.00	.00	1.00	.00	1.00	.00	1.00	.00



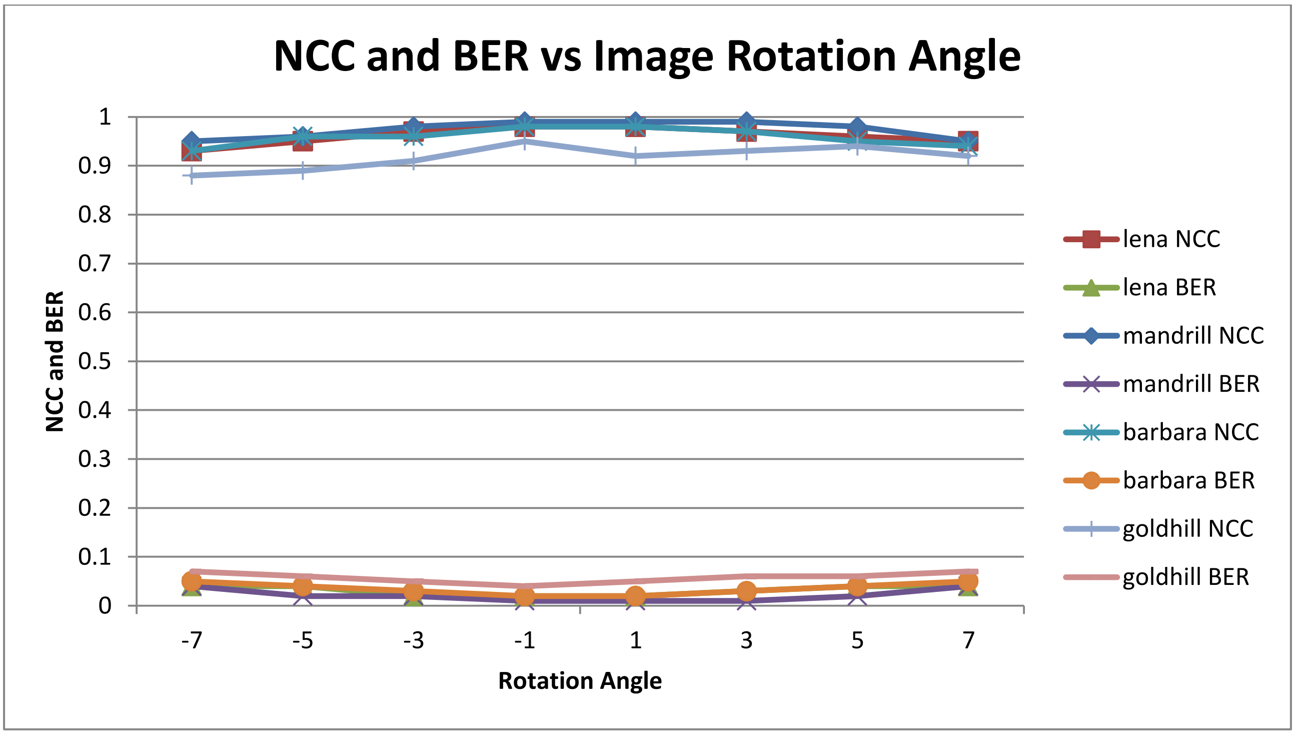
Blur Attack Results

	lena		mandrill		barbara		goldhill	
Blur Radius	NCC	BER	NCC	BER	NCC	BER	NCC	BER
1	.98	.02	.99	.00	.96	.03	.89	.07
2	.82	.11	.97	.03	.85	.11	.78	.16
3	.77	.16	.95	.06	.76	.15	.73	.19
4	.74	.18	.91	.09	.73	.18	.73	.20
5	.72	.19	.88	.11	.71	.19	.68	.21



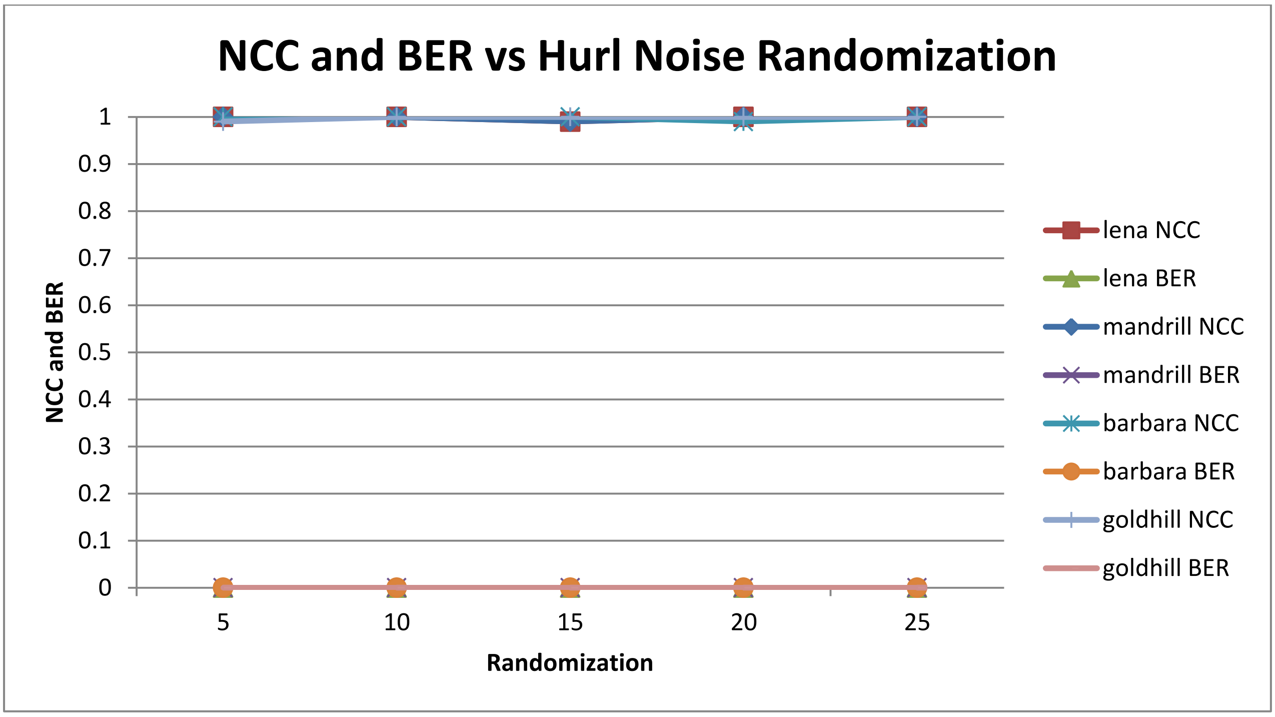
Rotation Attack Results

	lena		mandrill		barbara		goldhill	
Rotation Angle	NCC	BER	NCC	BER	NCC	BER	NCC	BER
-7	.93	.04	.95	.04	.93	.05	.88	.07
-5	.95	.04	.96	.02	.96	.04	.89	.06
-3	.97	.02	.98	.02	.96	.03	.91	.05
-1	.98	.02	.99	.01	.98	.02	.95	.04
1	.98	.02	.99	.01	.98	.02	.92	.05
3	.97	.03	.99	.01	.97	.03	.93	.06
5	.96	.04	.98	.02	.95	.04	.94	.06
7	.95	.04	.95	.04	.94	.05	.92	.07



Hurl Noise Attack Results

	lena		mandrill		barbara		goldhill	
Randomization	NCC	BER	NCC	BER	NCC	BER	NCC	BER
5	1.00	.00	1.00	.00	1.00	.00	.99	.00
10	1.00	.00	1.00	.00	1.00	.00	1.00	.00
15	.99	.00	.99	.00	1.00	.00	1.00	.00
20	1.00	.00	1.00	.00	.99	.00	1.00	.00
25	1.00	.00	1.00	.00	1.00	.00	1.00	.00



Equalization Attack Results

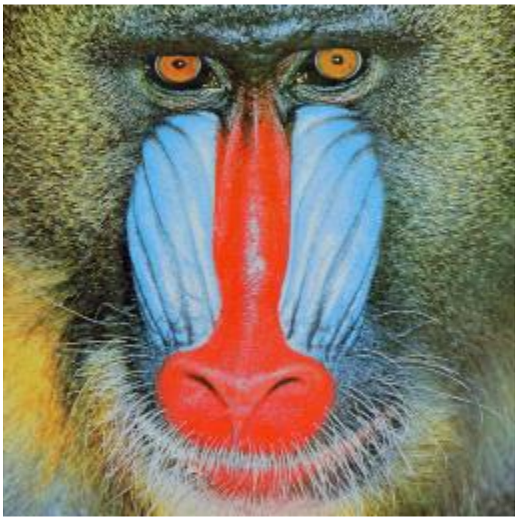
	lena		mandrill		barbara		goldhill	
Equalize	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**
	1.00	.00	1.00	.00	.98	.01	.91	.08

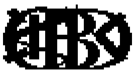
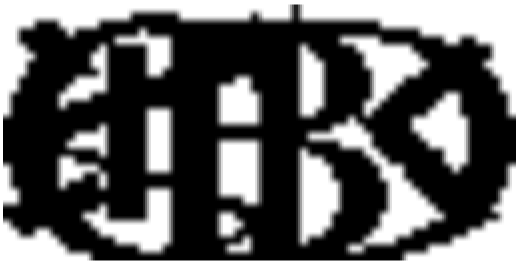
Cropping Attack Results

	lena		mandrill		barbara		goldhill	
Cropped	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**	**NCC**	**BER**
	1.00	.00	1.00	.00	.99	.01	1.00	.00

C. Results of Hybrid Watermarking scheme:

In this section we perform the above set of experiments to test our proposed algorithm and evaluate its performance against various kinds of attacks. Throughout our experiments we choose the strength factor of $\alpha = 10$. These factors are selected to maximize the robustness of this approach, while the modifications introduced by the watermarking process are imperceptible. We use Normalized Cross Correlation (NCC) to measure the performance of the watermarking scheme against attacks. A set of two common images were tested for our experiments. The images are illustrated in Figure 2a and 2b. Watermark Logo to embed is shown in Figure 2c.

 Figure 2a (Cover Image)	 Figure 2b (Cover Image)

The Logo used for watermarking is shown here. It is a 64x32 pixel logo. Logo scaled to 400%	 Figure 2c  Figure 2d

Here also we have used the same set of images standard images: Lena and Mandrill

Their watermarked versions are shown in Figures 2b and 2c. As we see the imperceptibility of the watermarked images are satisfied, the mean PSNR (peak-signal-to-noise-ratio) of the watermarked images are 71.03 dB, 72.06 dB

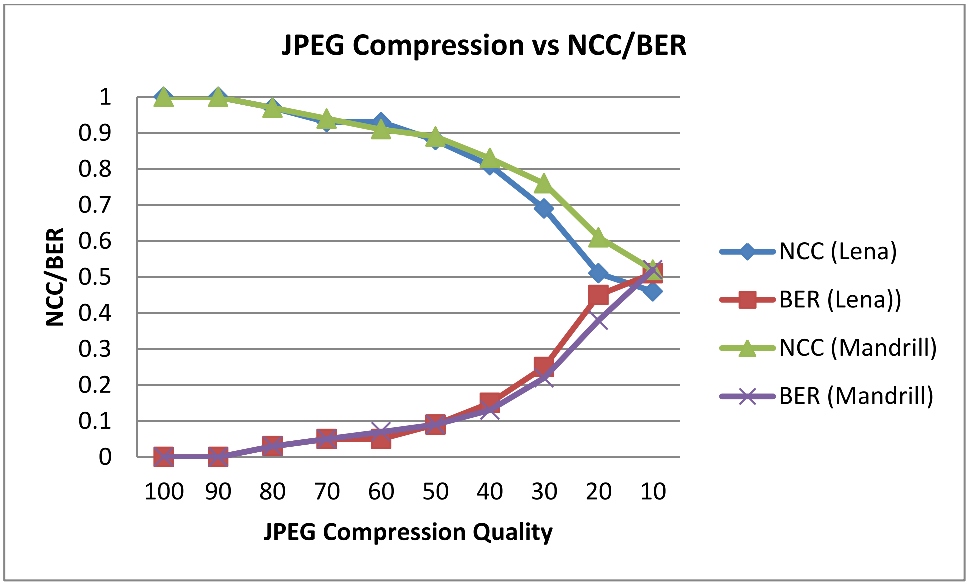
Figure 2c (After Watermarking)	Figure 2d (After Watermarking)
NCC: 1 mse=0.01, psnr=71.03, psnrMax=70.14, snr=65.14 ber: 0.01	NCC: 1 mse=0, psnr=72.06, psnrMax=69.37, snr=65.96 ber: 0

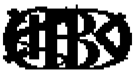
In the second experiment, we test the robustness of this watermarking method against JPEG compression attacks. Figure 2e shows the resulted NCC for different images. As we see, this scheme is highly robust against JPEG attacks.

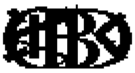
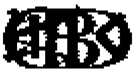
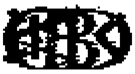
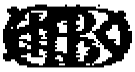
JPEG Compression/Metrics	**Image Name**	**NCC**	**MSE**	**PSNR**	**PSNR Max**	**SNR**	**BER**
100%	Lena	1	0	∞	∞	∞	0
90%	Lena	1	46.84	31.42	30.72	26.28	0
80%	Lena	0.97	1264.6	17.11	16.4	11.96	0.03
70%	Lena	0.93	2177.92	14.75	14.04	9.6	0.05
60%	Lena	0.93	2599.45	13.98	13.27	8.83	0.05
50%	Lena	0.88	4145.07	11.96	11.25	6.81	0.09
40%	Lena	0.81	7142.63	9.59	8.88	4.44	0.15
30%	Lena	0.69	11802.9	7.41	6.7	2.26	0.25
20%	Lena	0.51	21591.82	4.79	4.08	-0.36	0.45
10%	Lena	0.46	24308.36	4.27	3.56	-0.87	0.51

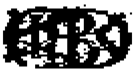
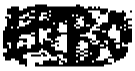
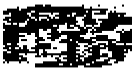
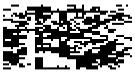
JPEG Compression/Metrics	**Image Name**	**NCC**	**MSE**	**PSNR**	**PSNR Max**	**SNR**	**BER**
100%	Mandrill	1	0	∞	∞	∞	0
90%	Mandrill	1	23.42	34.44	33.73	29.29	0

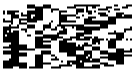
80%	Mandrill	0.97	1358.27	16.8	16.09	11.65	0.03
70%	Mandrill	0.94	2295.01	14.52	13.81	9.38	0.05
60%	Mandrill	0.91	3395.68	12.82	12.11	7.67	0.07
50%	Mandrill	0.89	4472.93	11.62	10.92	6.48	0.09
40%	Mandrill	0.83	6463.49	10.03	9.32	4.88	0.13
30%	Mandrill	0.76	10468.05	7.93	7.22	2.78	0.22
20%	Mandrill	0.61	18383.49	5.49	4.78	0.34	0.38
10%	Mandrill	0.52	25081.17	4.14	3.43	-1.01	0.52



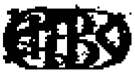
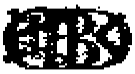
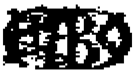
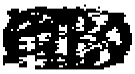
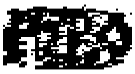
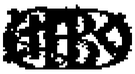
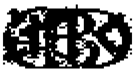
JPEG Compression Level	**JPEG Compressed Image**	**Extracted Watermark**
JPEG Compressed Image with quality factor of 100%		

JPEG Compressed Image with quality factor of 90%		
JPEG Compressed Image with quality factor of 80%		
JPEG Compressed Image with quality factor of 70%		
JPEG Compressed Image with quality factor of 60%		

JPEG Compressed Image with quality factor of 50%		
JPEG Compressed Image with quality factor of 40%		
JPEG Compressed Image with quality factor of 30%		
JPEG Compressed Image with quality factor of 20%		

JPEG Compressed Image with quality factor of 10%		

The third experiment is on Blurring attack. Here we test the robustness of this watermarking method against Gaussian Blur attacks. We introduce blurring in the image using Gaussian Blur technique with blur radius of 1 to 5. We get satisfactory results till blur radius of 3 but at blur radius of 5 the Cover Image as well as the extracted watermark starts detoriating. Figure 2e shows the resulted NCC/BER for different blur radii. This scheme is robust against blurring attacks as well.

Gaussian Blur Radius/ Metrics	**Image Name**	**NCC**	**MSE**	**PSNR**	**PSNR Max**	**SNR**	**BER**	**Recovered Watermark**
1	Lena	0.95	1967.15	15.19	14.48	10.04	0.04	
2	Lena	0.91	2880.47	13.54	12.83	8.39	0.06	
3	Lena	0.87	4168.49	11.93	11.22	6.78	0.09	
4	Lena	0.81	6205.89	10.2	9.49	5.06	0.13	
5	Lena	0.75	8009.11	9.09	8.39	3.95	0.17	
1	Mandrill	0.95	1896.9	15.35	14.64	10.2	0.04	
2	Mandrill	0.9	3302	12.94	12.23	7.8	0.07	

Gaussian Blur Radius/ Metrics	Image Name	NCC	MSE	PSNR	PSNR Max	SNR	BER	Recovered Watermark
3	Mandrill	0.84	4941.29	11.19	10.48	6.04	0.1	
4	Mandrill	0.79	6510.33	9.99	9.29	4.85	0.14	
5	Mandrill	0.74	8641.41	8.76	8.06	3.62	0.18	

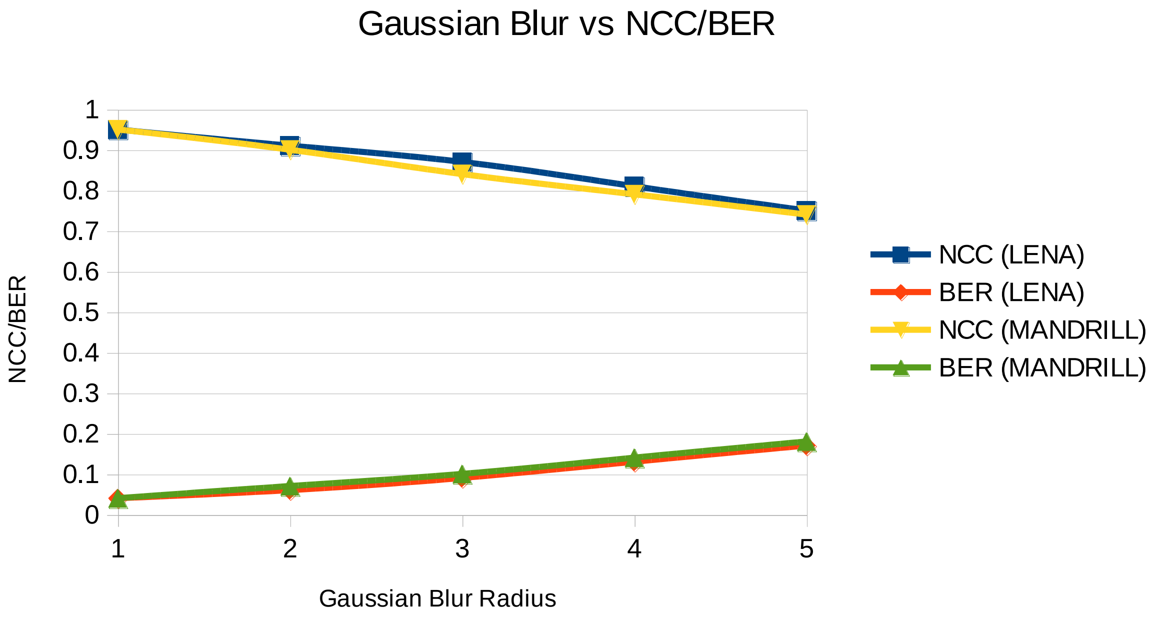
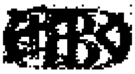
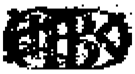
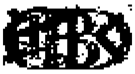
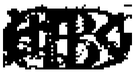
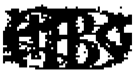
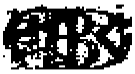
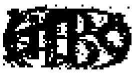
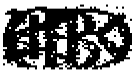
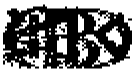
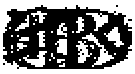
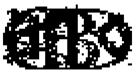
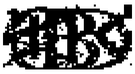
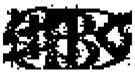
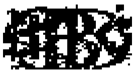


Figure showing results of NCC and BER on Gaussian Blur

In the fourth experiment, we test the robustness of this watermarking method against Image Rotation attacks. We rotate the image by some small degrees and then try to recover it to it's original position. Then we try to extract the watermark. Figure 2e shows the resulted NCC for different rotation angles. As we see, this scheme is highly robust against Image Rotation attacks.

Rotation Angle	Image Name	NCC	MSE	PSNR	PSNR Max	SNR	BER	Recovered Watermark
-7	Lena	0.88	4074.81	12.03	11.32	6.88	0.08	
-5	Lena	0.89	3302	12.94	12.23	7.8	0.07	

Rotation Angle	**Image Name**	**NCC**	**MSE**	**PSNR**	**PSNR Max**	**SNR**	**BER**	**Recovered Watermark**
-3	Lena	0.91	3091.24	13.23	12.52	8.08	0.06	
-1	Lena	0.92	2927.31	13.47	12.76	8.32	0.06	
1	Lena	0.91	2927.31	13.47	12.76	8.32	0.06	
3	Lena	0.91	3419.09	12.79	12.08	7.64	0.07	
5	Lena	0.9	3770.37	12.37	11.66	7.22	0.08	
7	Lena	0.87	4355.83	11.74	11.03	6.59	0.09	
-7	Mandrill	0.9	3559.61	12.62	11.91	7.47	0.07	
-5	Mandrill	0.91	3700.12	12.45	11.74	7.3	0.08	
-3	Mandrill	0.9	3208.33	13.07	12.36	7.92	0.07	
-1	Mandrill	0.92	2903.89	13.5	12.79	8.35	0.06	
1	Mandrill	0.92	2997.56	13.36	12.65	8.22	0.06	
3	Mandrill	0.9	4262.16	11.83	11.13	6.69	0.09	
5	Mandrill	0.89	3746.95	12.39	11.68	7.25	0.08	
7	Mandrill	0.89	4379.25	11.72	11.01	6.57	0.09	

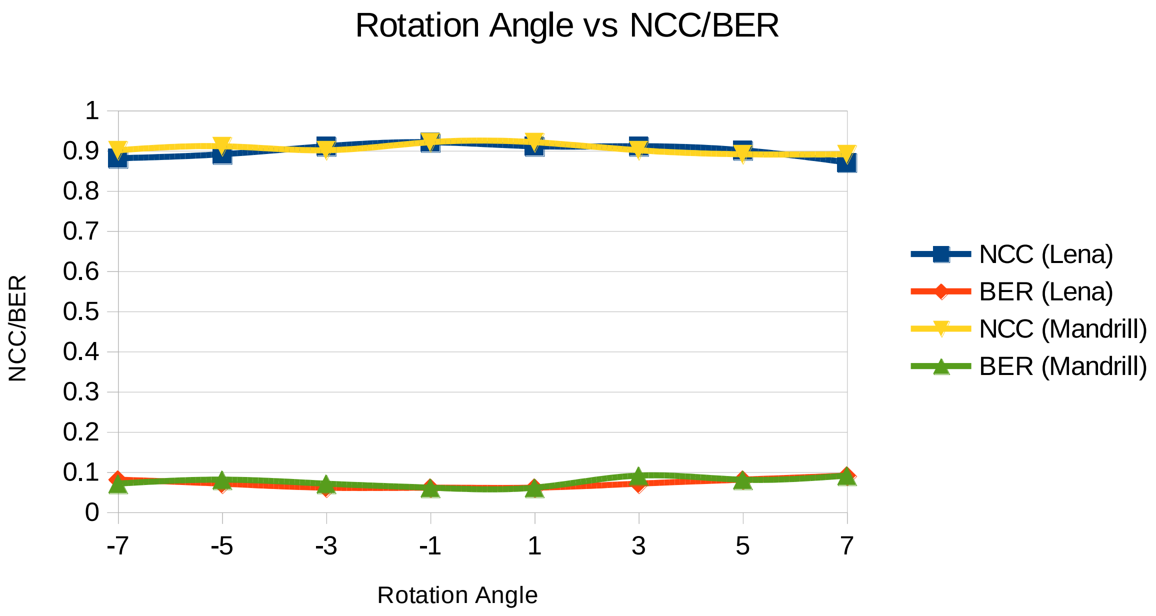


Figure showing results of NCC and BER on Rotation Angle

In the fifth experiment we try to introduce random noise into the Watermarked image and then try to extract the watermark.

In the sixth experiment we crop the cover image slightly and try to recover the watermark. Before watermark extraction the cropped location is recovered and the recovery algorithm is adjusted accordingly. Here also we observe that this scheme is robust against minor cropping attacks.

Cropping Attack Results

	lena		mandrill		barbara		goldhill	
Cropped	NCC	BER	NCC	BER	NCC	BER	NCC	BER
	0.94	0.04	0.94	0.04	0.95	0.03	0.9	0.06

Tests on Robustness

Tests on Fidelity

Chapter 5

Conclusion

In the previous chapters, we provided 3 watermarking schemes for watermarking still images. The first scheme is DCT based semi-blind Watermarking scheme, second one is DWT based Watermarking scheme which requires the original cover image for watermark detection and the third one is a Hybrid Blind Watermarking scheme having a DWT followed by a 1D DCT watermarking which does not require the original cover image or the logo. All these schemes are very robust especially against JPEG compression and other common image manipulation and attacks. All the schemes also achieve a very good balance in “Image-imperceptibility vs. Robustness” trade-off and are ICAR in nature.

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