

ISWAR: An Imaging System with Watermarking and Attack Resilience

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Abstract

With the explosive growth of internet technology, easy transfer of digital multimedia is feasible. However, this kind of convenience with which authorized users can access information, turns out to be a mixed blessing due to information piracy. The emerging field of Digital Rights Management (DRM) systems addresses issues related to the intellectual property rights of digital content. In this paper, an object-oriented (OO) DRM system, called “Imaging System with Watermarking and Attack Resilience” (ISWAR), is presented that generates and authenticates color images with embedded mechanisms for protection against infringement of ownership rights as well as security attacks. In addition to the methods, in the object-oriented sense, for performing traditional encryption and decryption, the system implements methods for visible and invisible watermarking. This paper presents one visible and one invisible watermarking algorithm that have been integrated in the system. The qualitative and quantitative results obtained for these two watermarking algorithms with several benchmark images indicate that high-quality watermarked images are produced by the algorithms. With the help of experimental results it is demonstrated that the presented invisible watermarking techniques are resilient to the well known benchmark attacks and hence a fail-safe method for providing constant protection to ownership rights.

Keywords: Software systems, multimedia content protection, digital rights management, image watermarking, invisible watermarking, visible watermarking, discrete cosine transformation (DCT).

1 Introduction

The Internet revolution towards the end of the last millennium, has ushered in a new era of information technology. There has been an explosive growth in multimedia applications including video-on-demand, and distant education. An interesting trend of this new era is to move from conventional to digital libraries. This, in turn, provides tremendous opportunities for scholarly research and education because of the ease with which images and texts can be availed through the internet. However, this kind of ultimate flexibility to avail digital content, particularly that of images, has also its negative side. Easy access facilitates information piracy through unauthorized replication and manipulation of digital content with the help of inexpensive tools. Hence, of late, concerns about protection and enforcement of intellectual property (IP) rights of the digital content involved in these transactions, have also been mounting. The emerging field of digital rights

management (DRM) systems [6, 17, 22] addresses these issues related to ownership rights of digital content. Specifically, issues addressed by DRM systems encompass various aspects of content management, namely content identification, storage, representation, distribution and intellectual property rights management. Two basic goals of DRM systems that can be met with digital watermarking are: (1) preventing unauthorized use of the images (in general, any digital information), particularly for commercial purposes and (2) providing visibility to the authentic source or the owner of the information on a continuous basis.

Digital watermarking, in essence, is the process of embedding into a multimedia object a digital signature or data that is variously known as watermark, tag or label. Detection or extraction of this watermark at a later juncture enables assertions about the authenticity and ownership of the object [16]. Hence, watermarking is one of the key technologies that can be used for establishing ownership rights, tracking usage, ensuring authorized access, preventing illegal replication, and facilitating content authentication [1, 20, 30, 5, 6, 16, 22]. In general, a watermarking scheme consists of three parts, namely: (1) creation or procurement (say, from a library) of the watermark, (2) insertion or encoding of the watermark, and (3) detection or extraction and verification of the watermark. The insertion algorithm incorporates the watermark into the object, whereas the verification algorithm authenticates the object, determining both the owner and the integrity of the object. Our **Imaging System with Watermarking and Attack Resilience (ISWAR)** has class methods to perform all these tasks.

When encryption technologies are used in conjunction with watermarking [7, 22], full protection from unauthorized access of digital content can be achieved. Our ISWAR precisely uses this two-tier protection mechanism with methods for traditional encryption and decryption as well as others for visible and invisible watermarking. The watermarking methods use the novel algorithms developed by us for this purpose. Unlike many other secure systems, our system prevents even authorized users from illegally replicating the decrypted content. Since it is difficult to alter an image without damaging the watermark, image integrity can be protected by watermarking—visible or invisible.

The **novel contributions of this paper** are as follows:

1. An object-oriented DRM system, called “**Imaging System with Watermarking and Attack Resilience**” (ISWAR) is presented. The system generates watermarked color images and authenticates color images for protection against infringement of ownership rights and security attacks.
2. A visible watermarking algorithm is presented that adaptively inserts a watermark on the host color image such that high-quality watermarked color images are produced from ISWAR.
3. An invisible watermarking algorithm that uses both encryption and watermarking for dual-layer protection of the watermark.
4. Complete implementation of ISAWR imaging system as a user-friendly software.
5. Exhaustive validation the ISWAR imaging system.
6. Exhaustive experiments of the visible and invisible watermarking algorithms with benchmark color images.

The organization of the rest of the paper is as follows. Section 2 presents the state of the art in digital watermarking. Against this backdrop, a high-level view of ISWAR is presented in Section 3. Sections 4 and 5 present our visible and invisible watermarking algorithms, respectively. System implementation, usage and validation are detailed in section 6. Section 7 presents performance analysis of the watermarking algorithms. Summary and conclusions are presented in Section 8.

2 State of the Art of Digital Watermarking

Research on watermarking has matured over the last decade and hence the current literature abounds with techniques in this area. Various published works discuss the desired characteristics of various types of watermarks from the research point of view as well as from the users' perspective [2, 20, 41, 16]. The categorization of the watermarking schemes under various criteria is presented in Figure 1. At the same time hardware-assisted watermarking approaches are presented [27, 28].

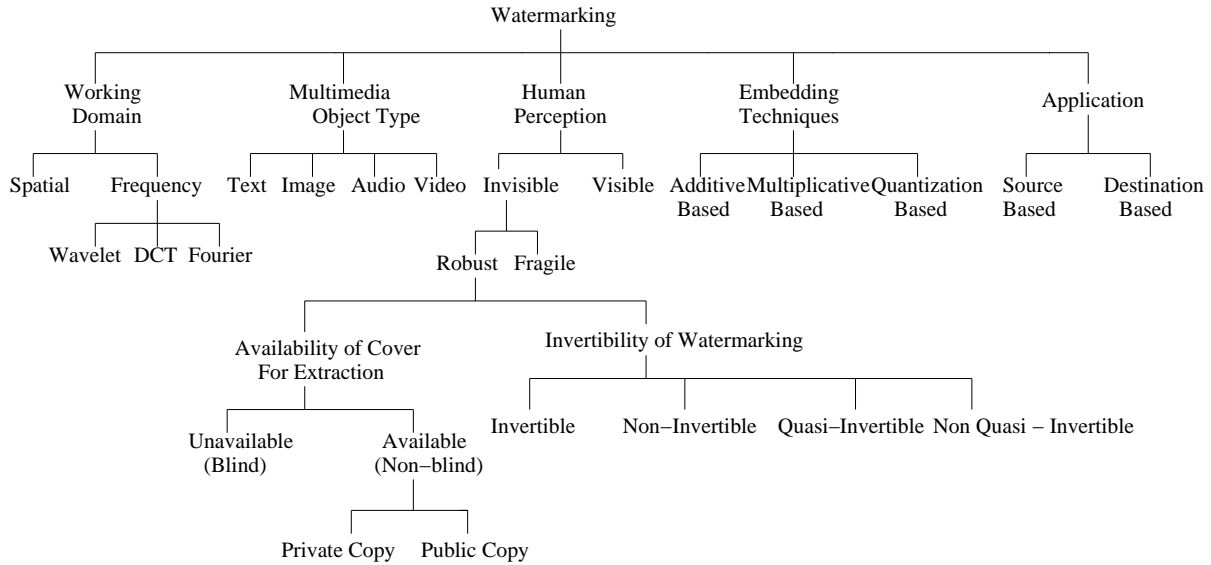


Figure 1: Types of watermarking techniques.

Based on the domain of the cover object used for embedding tokens, watermarking methods may be classified as spatial domain or frequency (or transform) domain methods. Watermarking techniques can be divided into four categories according to the type of multimedia object to be used, namely, image, video, audio, or text watermarking. Based on human perception, digital watermarks can be divided into visible and invisible types. In visible watermarking, which is analogous to watermarking on paper currency, a secondary translucent image is overlaid on the primary (cover) image [29]. The invisible-robust watermark is one that is embedded in such a way that alterations made to the pixel value are not perceptually noticed and it can be recovered only with the appropriate decoding mechanism. Invisible robust watermarks may be further classified on two criteria — (1) availability of the original cover image for extraction/detection purposes and (2) invertibility of the watermarking scheme. In addition to the above, several hybrid watermarking algorithms have been proposed in the literature for different purposes [24, 13, 34, 11]. Based on the embedding techniques used, watermarking schemes can be categorized as additive, multiplicative, or quantization [38]. From the application point of view, digital watermarks could be classified as source or destination based [39] watermarks. In summary, there are various currently available watermarking techniques tailored for the needs of different applications.

Selected literature in watermarking research, whose scope is more close to the research presented in this paper, is discussed now. In [35, 9, 18], several software-based DRM and watermarking systems are proposed which are more or less ready-to-use. Visible watermarking algorithms which are absolutely essential for many applications, including protection of publicly available images and video broadcasting, are presented in [2, 21, 15, 25, 19, 12, 36, 14, 37, 4, 42, 8]. Invisible-robust watermarking algorithms presented in [3, 40, 31, 33, 32] hide a binary image inside the host image and hence are well positioned to provide the highest level of image security.

3 ISWAR – A High Level View

This section introduces a full-fledged software system called ISWAR that we developed for secure imaging applications. It seeks to provide the user with controlled access and data security via data encryption, good network bandwidth utilization via frequency domain techniques for data reduction, and copyright protection via watermarking. It can perform both visible and invisible watermarking of color as well as monochrome images. This system provides information privacy and resilience to security attacks by a two layer protection mechanism that is built upon traditional encryption schemes as well as the novel invisible and visible watermarking schemes proposed here. Explicitly, the system was designed to fulfill the following requirements:

1. Simplicity with flexibility and extensibility—With our system, it is possible to generate images with varied levels of resilience to attack with visible (e.g., registered company seals) or robust invisible watermarking with encryption.
2. Ease in extraction of watermarks from the images for the purpose of proving ownership.
3. No degradation in the cover images due to watermarking.
4. High-level of information hiding, i.e., the presence of an invisible watermark should not be inferrable from the statistics of the watermarked image.
5. Robustness to common signal attacks such as filtering and lossy compression.
6. Lossless retrieval of embedded watermarks.
7. User-friendly graphical interface for easy insertion and extraction of watermarks.

The first requirement above translates into an object-oriented (OO) architecture with a simple class hierarchy depicted in Figure 2 for ISWAR. In the OO analysis for ISWAR, the following three main scenarios are considered: (1) Visible Watermarking, (2) Invisible Watermarking with encryption, and (3) Extraction of encrypted invisible watermark. The sequence diagrams corresponding to these 3 scenarios are presented in Figures 3(a), 3(b), and 3(c), respectively. The OO architecture facilitates easy handling of new scenarios and extensibility of the system with new types of watermarks and watermarking or encryption algorithms.

The above analysis leads to the design of the algorithms for the “Embed” method that needs to be executed polymorphically for the two types (*i. e.*, visible and invisible) watermarks. The crux of our design is in the two algorithms that we originally developed for visible and invisible watermarking of monochrome images and extended later for color images. The algorithms are presented in the following sections. The watermark extraction method for images embedded with invisible watermarks uses a process that is an inverse of our invisible watermarking algorithm. It is described in a subsequent section.

4 Image Adaptable Visible Watermarking in ISWAR

Considering the robustness and data reduction requirements of ISWAR, this paper focusses on the area of transform domain (particularly the Discrete Cosine Transform, DCT, as it is omnipresent in major compression standards) watermarking for the design of our visible watermarking algorithm. For ISWAR, this paper introduces a novel approach to visible watermarking which is image-adaptable and robust. In this algorithm, unlike in other methods, the classification of image blocks into 8 perceptual classes for the purpose of adaptable embedding is not performed. Rather, the parameters involved in the watermark embedding for individual blocks are computed using a mathematical model explicitly introduced for this purpose. This model, based on a sensitivity analysis of the Human Visual System (HVS), utilizes the

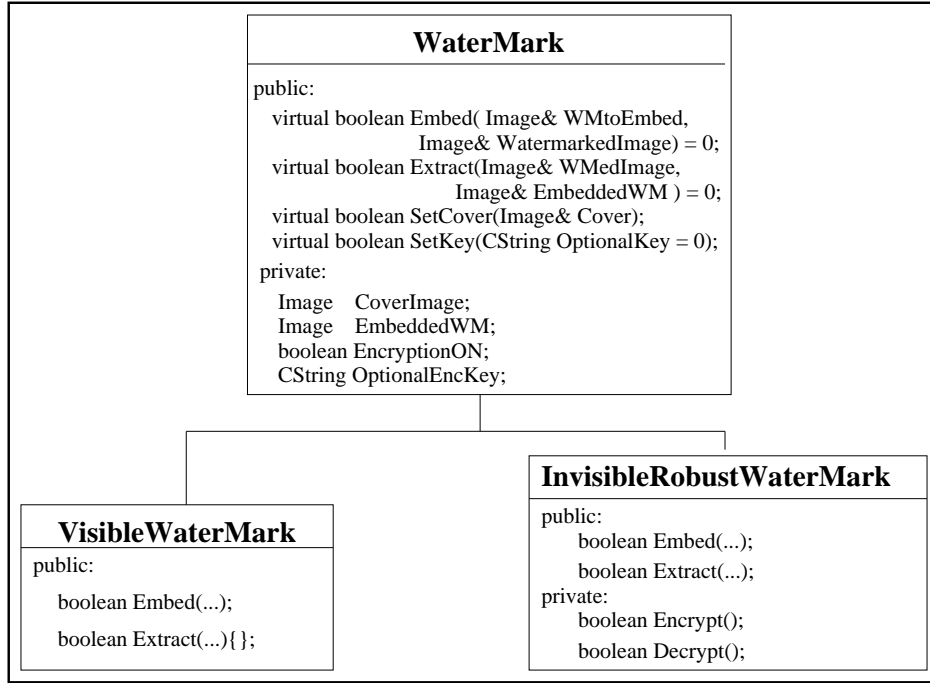
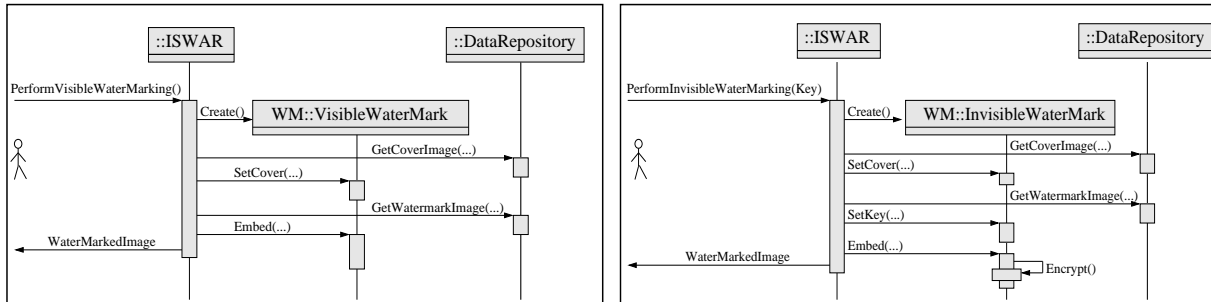
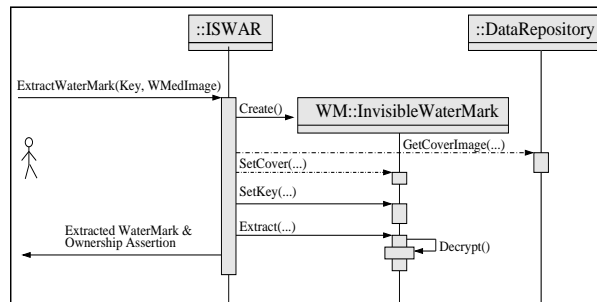


Figure 2: Class hierarchy in ISWAR (default constructors and destructors are not explicitly shown in diagram for brevity.)



(a) Visible watermark embedding.

(b) Invisible watermark embedding.



(c) Invisible watermark extraction and authentication. The dotted arrows indicate optional operations required for non-blind extraction.

Figure 3: Sequence diagrams for different operations.

statistics of the cover and watermark image blocks to calculate, for each block, embedding parameter values that do not distort the cover image.

4.1 Visible Watermark Embedding

The activity diagram for the visible watermark embedding process is shown in Figure 4. Essential inputs to the process are the cover and watermark image objects including their sizes as well as the watermark's target size (i.e., after embedding) and position for embedding. These are provided through the “Embed” method of the watermark class. The process can also be provisioned with four optional inputs, the maximum and minimum values of the scaling and embedding parameters (α_{max} , α_{min} , β_{max} , and β_{min}) that determine the relative proportions of the cover and watermark contents in the embedding process. If these values are not provided, pre-configured default values (presented in the implementation section) are used by the system.

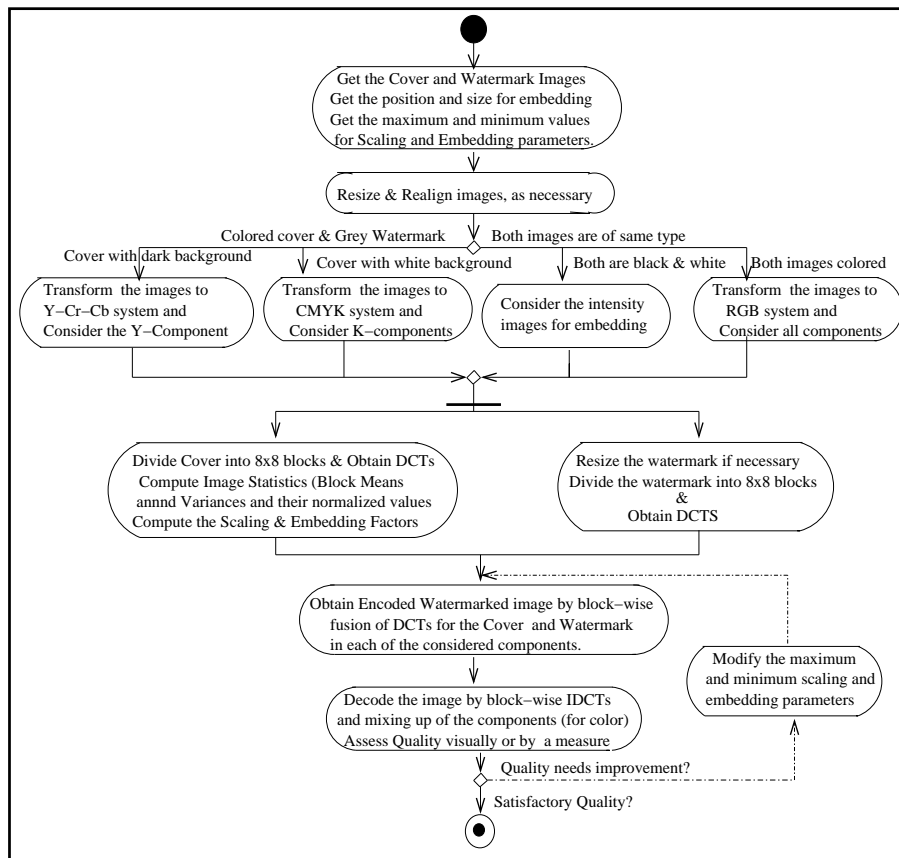


Figure 4: Activity diagram for visible watermark embedding method.

The algorithm assumes that the target size of the watermark (i.e., the size after embedding) is equal to, or smaller than that of the cover image in both dimensions. Hence if the specified target size of the watermark violates this stipulation, the size should be properly reduced to bring in the watermark within the bounds of the cover. Resizing is also required if the target size is different from the original size of the watermark. Further, since the algorithm works on 8×8 size image blocks, the images need to be extended using standard image extrapolation techniques, as necessary, to facilitate division of the original images into an integral number of 8×8 blocks. The first step of the algorithm is proper resizing of the images. Apart from the image sizes, the watermark-position parameter may also require adjustment. In the algorithm, this

parameter is specified as the number of the cover image block (in a system of successive numbering with raster scanning) to which the watermark image is aligned. Alignment involves positioning of the top-left corner of the watermark image and the same corner of the specified block of the image. However, if the specified position of the watermark is such that a part of it falls outside the cover, the position is to be readjusted to bring in the watermark totally into the range of the cover. Thus, resizing and realignment are the operations in the initial step of the algorithm. The next step is to select the suitable components of the image for the embedding operation. In case of grey level images, there is no choice; the algorithm has only the intensity component. Similarly, when both cover and watermark are colored, all three (R, G and B) components of the images are considered and component by component embedding is performed. In the case of colored cover and grey watermark, it is advantageous to embed the watermark in the Y-component (i.e., the luminance component in the Y-Cr-Cb coordinate system) of the cover. More aesthetic watermarked images may be obtained for grey watermarks and colored covers with predominantly white background by using the K-components of the CMYK color map of the cover [36]. Thus, the characteristics of the cover and watermark images determine the image coordinate space for embedding. These characteristics may be assessed using a simple analysis of the image pixels and a decision regarding the image components required for the embedding operation may be taken as shown in Figure 4.

Once the component(s) is (are) are obtained, each component of the cover and the watermark is divided into blocks of size 8×8 . For each block of the cover and the watermark images, the DCT is obtained, if possible, by parallel processing. Let us denote by c_n , w_n , and c'_n the n -th blocks, in the DCT domain, of the cover, the watermark, and the watermarked images, respectively. We also denote by $c_{ij}(n)$, $w_{ij}(n)$, and $c'_{ij}(n)$, the (i, j) -th DCT coefficient of the n -th block of the respective images; when $i = j = 0$, the corresponding coefficient is DC.

The next step of the algorithm is to gather image statistics for the cover. This information is useful for computation, as shown in the following subsection, of the scaling and embedding parameters necessary for block-by-block fusion of the cover and the watermark images. The statistics comprise of the block mean intensities and log variances (AC DCT coefficients) of individual blocks. The mean values of individual blocks are given by the DC DCT coefficients of the blocks. These values are scaled in the range $[0.1 - 1.0]$ and normalized block means (μ'_n s) are obtained using the following expression:

$$\mu'_n = 0.1 + 0.9 \left(\frac{c_{00}(n) - c_{00min}}{c_{00max} - c_{00min}} \right), \quad (1)$$

where, c_{00max} and c_{00min} are the maximum and minimum values, respectively, among the DC DCT coefficients of different blocks of the cover. Assuming the number of blocks in the image is N , the normalized mean gray value of the image I is calculated using the following expression:

$$\mu' = \frac{1}{N} \sum_{n=1}^N \mu'_n. \quad (2)$$

The log variances for the AC DCT coefficients of individual blocks are obtained using the formula:

$$\sigma_n = \log_e \left(\frac{1}{63} \sum_i \sum_{j|i+j \neq 0} (c_{ij}(n) - \mu_n^{ac})^2 \right), \quad (3)$$

where μ_n^{ac} is the average of the AC DCT terms of the n -th block obtained by the following expression:

$$\mu_n^{ac} = \frac{1}{63} \sum_i \sum_{j|i+j \neq 0} c_{ij}(n). \quad (4)$$

These log variances are scaled in the range $[0.1 - 1.0]$ and normalized block log variances are obtained by the following expression:

$$\sigma'_n = 0.1 + 0.9 \left(\frac{\sigma_n - \sigma_{min}}{\sigma_{max} - \sigma_{min}} \right). \quad (5)$$

Here, σ_{max} and σ_{min} are the maximum and minimum values, respectively, of the log variances for different blocks of the cover. In addition to gathering these image statistics, further image analysis to identify edge blocks in the cover is required for the purpose of computing the scaling and embedding parameters as indicated in the following subsection.

The final step in visible watermarking is the embedding operation itself. For this, the watermark is positioned on the cover at the specified position (after all adjustments in the initial step of the algorithm). For portions of the cover image not covered by such a superposition of the watermark, the watermark pixel values (hence the corresponding block DCT coefficients) are assumed to be zero. Now, the watermarked image may be conceived as the one obtained by fusing the original watermark, so augmented with zero pixel values, into the cover. The DCT domain block-wise fusion operation may now be defined by the following equation:

$$c'_{ij}(n) = \alpha_n \times c_{ij}(n) + \beta_n \times w_{ij}(n). \quad (6)$$

α_n and β_n are the scaling and embedding parameters that need to be chosen on a per block basis in such a way as to yield a watermarked image that is appealing to the HVS [10]. In the following subsection, we develop mathematical formulae for these parameters based on the information available in the literature on visual perception regarding the contextual sensitivity of HVS to distortions. By juxtaposition of the $c'_{ij}(n)$ blocks obtained as above, we obtain the encoded image I' . The watermarked image in spatial form may be obtained from I' by block-wise decoding the individual $c'_{ij}(n)$ s with IDCTs (Inverse DCTs). Hence, an important consideration in the choice of the above scaling and embedding parameters is to contain, to imperceptible levels, the degradation in the resultant image due to blocking (or tiling) effects in the inverse transform process and other distortions. Another consideration is to make the watermark more robust in the sense that removal or destruction of the watermark will result in a degraded image that cannot be reused. The watermarked image is expected to be of good quality for the proper choice of the scaling and embedding parameters. The visual quality may be assessed by either visual inspection or any application-specific quality measures. The optional feedback loop (dashed line) in the activity diagram suggests that this information regarding image quality may be used to tune up the image quality by tuning either manually or automatically the parameters α_{max} , α_{min} , β_{max} , and β_{min} and, through them, the computations of the α_n and β_n values for different blocks.

4.2 Determining Scaling and Embedding Factors - A Mathematical Model

Our mathematical model for determination of the scaling and embedding factors, α_n and β_n , is based on the following psycho-visual considerations that help to preserve the perceptual quality of the watermarked images despite distortions:

- The edge blocks should be least altered to avoid significant distortion of the image and hence the relative intensity of the watermark should be low in any block containing edges of the cover image. This, in turn, means that α_n and β_n should be set to values close to α_{max} and β_{min} (the user-configured maximum and minimum value of the scaling and the embedding factors), respectively.
- The distortion visibility is low when the background has strong texture. The higher the texture of a block, the lower the variance of its AC DCT coefficients due to more evenly distributed energy among these coefficients. This suggests that proportionately larger information content of the watermark can be fused into those blocks without adversely affecting the distortion visibility. Hence, we assume that

a choice of α_n directly proportional to the variance σ_n of the AC DCT coefficients of $c_{ij}(n)$, and a choice of β_n inversely proportional to the same would be ideal.

- The blocks with mid-intensity are more sensitive to noise than those of low and high intensities. This suggests a bell-shaped Gaussian distribution for α_n values; they should increase with the mean intensity values (μ_n s) of their respective blocks up to a mid intensity value (say, the mean intensity μ of the whole cover image) and then start decreasing with the block mean intensities. As usual, the variation of the β_n s should be exactly the reverse. The μ_n s are given by the DC DCT coefficients of the corresponding blocks.

Figure 5 depicts the variation of the scaling and embedding factors based on these theoretical considerations. Mathematical formulation of these relationships yields the following equations for the scaling and embedding parameters:

$$\alpha_n = \begin{cases} \alpha_{max} & \text{For Edge Blocks} \\ \alpha_{min} + (\alpha_{max} - \alpha_{min}) \times [\sigma'_n \exp\{-(\mu'_n - \mu')^2\}] & \text{For Other Blocks} \end{cases} \quad (7)$$

$$\beta_n = \begin{cases} \beta_{min} & \text{Edge Blocks} \\ \beta_{min} + (\beta_{max} - \beta_{min}) \times \left[\left(\frac{1}{\sigma'_n} \right) \{1 - \exp\{-(\mu'_n - \mu')^2\}\} \right] & \text{Other Blocks} \end{cases} \quad (8)$$

The parameters α_{max} , α_{min} , β_{max} and β_{min} could be specified by the user. If they are not specified, pre-defined default values may be used. On experimentation with a large number of images, the above expressions have been found to conform to the patterns of the theoretical relationship discussed earlier.

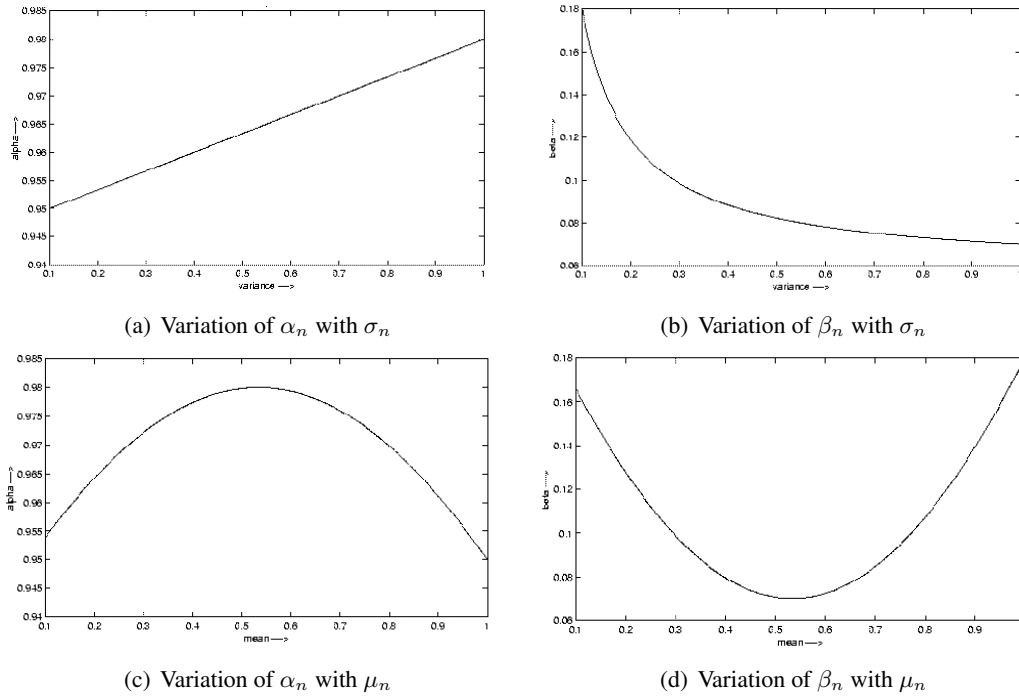


Figure 5: Variation of scaling and embedding factors with respect to cover image statistics.

5 Secure Invisible Watermarking in ISWAR

Because of the data compression and fusion robustness aspects of the transform domain methods, we focus here also on the transform domain approach to invisible watermarking. For this initial version of ISWAR, a simple but effective invisible watermarking algorithm is introduced that uses a binary watermark which is described in the following subsections.

5.1 Invisible Watermark Embedding

Figure 6 shows the UML activity diagram for our invisible watermark insertion process. To achieve two levels of protection as indicated earlier, the algorithm first encrypts the watermark and then fuses it into the intensity image of the cover in the case of a black and white cover, and into the Y-component (in the Y-Cr-Cb coordinate system) of a colored cover. In the sequel, the relevant component of the cover is referred as I . Decomposition of the image to obtain the required component is done in the preprocessing stage of the algorithm. Encryption and hashing of the binary watermark using a user-supplied key is also performed in this preprocessing step. Further, just as in the visible watermarking algorithm, any image extension necessary to facilitate the division of the image into integral number of blocks is performed in this stage.

After preprocessing, the cover image I is divided into 8×8 blocks and each block is transformed into the DCT domain. Let us denote the “ (i, j) ”-th DCT coefficient of the k -th block by $c_{ij}(k)$. Assuming that the image has M blocks overall, each block can be numbered uniquely with a number in the range $[1, M_{block}]$ based on its position in the raster scanning of the image. M_{block} is given by $(M \times N)/64$, where M is the number of image pixels row-wise, and N , the number of pixels column-wise. The number of DCT components to be considered for obtaining good quality watermarked images is a tradeoff of quality and robustness. In this algorithm, the DC component c_{00} and the three 3 low frequency components c_{01}, c_{10} and c_{11} are considered. In this case, the size of the encoded and hashed watermark should be such that it can be partitioned into the same number of blocks as the cover, but with a block size of 2×2 . It cannot be bigger, but, if it is smaller, it can be padded with zeros. Using the same notation as before, the watermark’s binary value at position (i, j) in block k is denoted as $w_{ij}(k)$. This watermark is embedded in the cover image using the following expression:

$$\forall i, j, \text{ and } k, \quad c'_{ij}(k) = \begin{cases} c_{ij}(k)(1 + \alpha_{ij}) & \text{if } w_{ij}(k) = 1, \\ c_{ij}(k)(1 - \alpha_{ij}) & \text{if } w_{ij}(k) = 0. \end{cases} \quad (9)$$

In this algorithm, the watermark is not always added to the significant frequency components. Instead, the watermark is added to some components and subtracted from others. This satisfies the system requirement that a statistical analysis of watermarked image should not reveal the presence of an invisible watermark. Another feature of the proposed method is that two different scaling factors (α s) are used for different frequency components: α_{dc} for DC components and α_{ac} for AC components. Thus, the algorithm has the following: $\alpha_{00} = \alpha_{dc}$ and $\alpha_{01} = \alpha_{10} = \alpha_{11} = \alpha_{ac}$. Since choosing so many scaling factors (one for each frequency component) is a problem by itself, the algorithm is confined to only two values that may be so chosen so as not to degrade the quality of the watermarked image. Image quality can be assessed either qualitatively by visual inspection or quantitatively by measuring its Peak Signal-to-Noise Ratio (PSNR).

In the case of black and white covers, the watermarked image I' can be obtained by performing block-wise IDCTs (Inverse Discrete Transforms) on the coefficients modified as above. However, in the case of colored

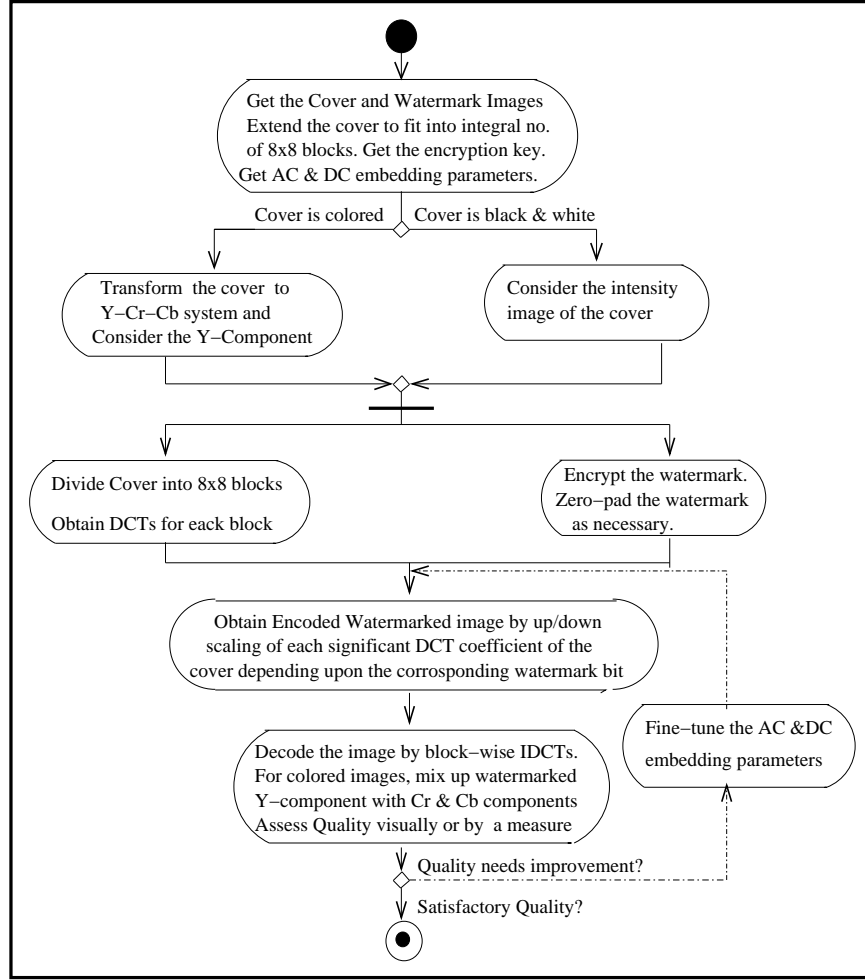


Figure 6: Activity diagram for invisible watermark embedding method.

images, we get only the Y-component of I' by the above process. This should be clubbed with the Cr and Cb components of the cover to get I' . At this point, as in the visible watermarking case, the algorithm has an optional step (dashed line) of assessing quality of the watermarked image by either visual inspection or a computational measure and fine-tuning of the parameters α_{ac} and α_{dc} .

5.2 Invisible Watermark Extraction and Authentication Method of ISWAR

Figure 7 depicts the activity diagram for the invisible watermark extraction process in ISWAR. The extraction algorithm involves many steps which are reversals of the insertion process. The algorithm first gets the watermarked (possibly suspect) image I' and the original cover image I . The watermark image and key that is to be tested are also gathered. The algorithm divides both I' and I into 8×8 blocks as in the insertion process. Both the cover and watermark images are converted from RGB space to YCbCr representation if they are color. DCT transformation is performed for the blocks from both images. The algorithm at this point compares corresponding image blocks. If a DCT coefficient in a block of I' is larger than the corresponding coefficient in the original image block then the watermark bit is 1, else it is 0. The algorithm compares the extracted sequence with the binary watermark (encrypted with the key) to make a decision whether the image is authentic or not.

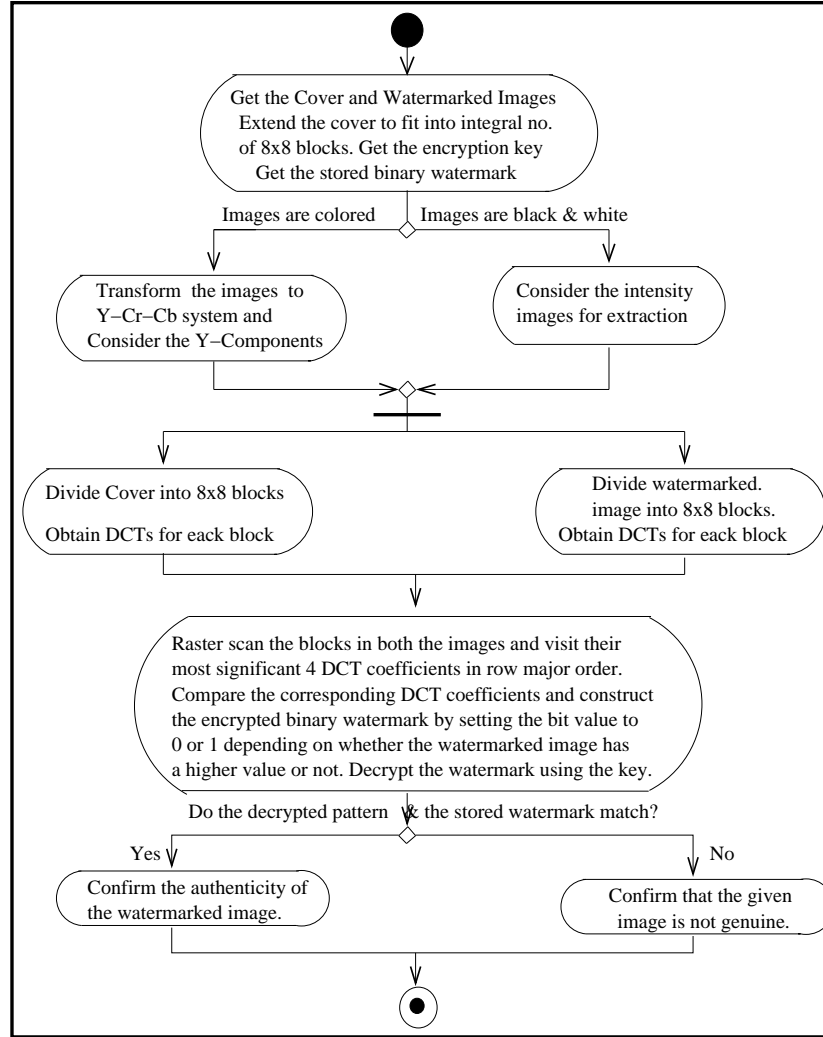


Figure 7: Activity diagram for the invisible watermark extraction and authentication method.

6 Implementation, Usage and Validation of ISWAR

ISWAR is implemented using the VC++.NET platform [26]. In order to be able to view an image in the document window, it should be saved in one of the standard image formats such as jpeg (.jpg), bit-map (.bmp), portable network graphics (.png), or graphics interchange format (.gif). The system defaults for α_{max} , α_{min} , β_{max} and β_{min} are set to 0.95, 0.98, 0.05 and 0.17, respectively. These values have been found to yield good results and hence have been incorporated into the system as defaults. For the same reason, the system has been provisioned with the default values of 0.1 and 0.02 for the parameters α_{ac} and α_{dc} used in the invisible watermarking algorithm. For identifying edge blocks in the visible watermarking case, the Sobel edge operator is used because of its simplicity. It could be replaced by more sophisticated operators in later versions of ISWAR. The encryption algorithm used in our secure invisible watermarking was blow-fish. Any other encryption algorithm, e.g. Advanced Encryption Standard (AES) can be easily integrated in the future. ISWAR has a user-friendly interface through which choice of the algorithms and the specification of parameters can be performed.

The visible watermark embedding can be initiated as shown in Figure 8 using a file menu for selecting

and opening a cover image and watermark menu for selecting the required operation. Once the cover and watermark images are stored, visible watermarking may be performed using the following steps, shown in Figure 8:

- Open the host (cover) image by “Click File —> Open” or the Shortcut “.”
- Select “Apply Visible Watermark” from the Watermark menu. This will open up a new screen (dialog box) with the same name.
- Select the watermark file by either typing the path to the file in the list box on the screen, or browsing using the “Browse” button. The size (height and width) of the watermark image should be less than that of the host image that was selected.
- Specify the watermark position using the “Combo” (combination) box on the same screen. The 9 choices available for selection are as follows: (1) Top Left, (2) Top Center, (3) Top Right, (4) Middle Left, (5) Middle Center, (6) Middle Right, (7) Bottom Left, (8) Bottom Center, and (9) Bottom Right. These positions are relative to the host image.
- Specify the Intensity of the watermark image to be embedded in the host image using the slider control available on the screen. The intensity values range from 10 to 100 and the selected value will be displayed on the sliding bar.
- Click the “Embed” button. This button click will generate the event trigger to run the algorithm to insert the visible watermark. After the algorithm is executed, the dialog box for Visible Watermark will close and the watermarked image will be opened in the document window.

The invisible watermark embedding operation steps are presented in Figure 9. Here, after opening up, in the same way as above, a host image that is stored in one of the standard formats, the operation “Embed a Non-blind Watermark” is selected from the “Watermark” menu. This opens up a screen for selecting the watermark image in the same way as above. This screen has also a provision for typing in a key of 6-56 characters. This key can contain any text. It is used for authentication as well as for extraction at the receiver end. After specifying these two parameters required for invisible watermark embedding, the “Embed” button on the screen may be clicked. This will trigger execution of the algorithm and the watermarked image will be opened in the document window. Simultaneously, the dialog box for embedding invisible watermark will close.

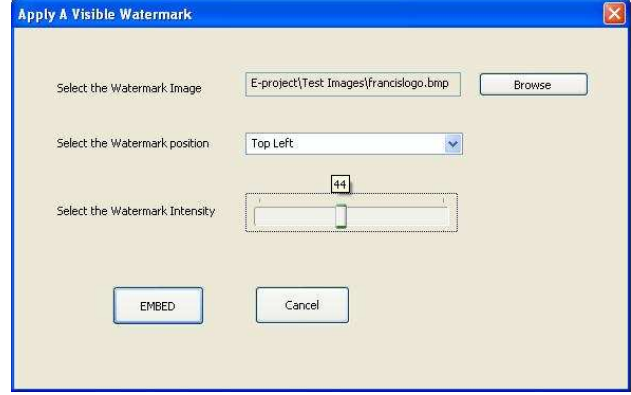
The process for invisible watermark extraction and image authentication is depicted in Figure 10. In a watermark extraction operation, the watermarked image is first opened as in the previous two operations. Selection of the operation “Extract an Invisible Watermark” from “Watermark” menu then opens up a screen for specification of the required parameters. On this screen, the user can specify the original host image, original binary watermark image that was embedded, and the key that was used during the embedding process. After these parameters are specified correctly, clicking of the “Extract” button on the screen will initiate the extraction and authentication process that would produce a message indicating whether the image is authenticated or not.

7 Performance of ISWAR’s Algorithms

The visible and invisible watermarking algorithms are tested for several benchmark images and different watermarks. For brevity, the consolidated results of our visible and invisible watermarking algorithms on the selected benchmark images (Lena, F16, mandrill and pepper) are presented in Figures 11 and 12. The visible watermark embedding was tested for various intensity levels of the watermark. The colored watermark



(a) Open an image.



(b) Select position, size and intensity.



(c) Insert the watermark.

Figure 8: Performing visible watermarking using ISWAR.

image used for testing of our visible watermarking algorithm is presented in Figure 13(a). The binary image used for invisible watermark embedding and extraction is depicted in Figure 13(b).

The quality of the images obtained using our visible and invisible watermarking algorithm may be assessed by visual inspection of the watermarked images in Figures 11 and 12. In addition, the PSNR of the watermarked images provides a quantitative assessment of the quality of those images. Image quality metrics such as Mean Square Error (MSE) and PSNR [22, 23] are applied to quantify the performance of the algorithms. The MSE and PSNR [22, 23] are expressed by the following equations:

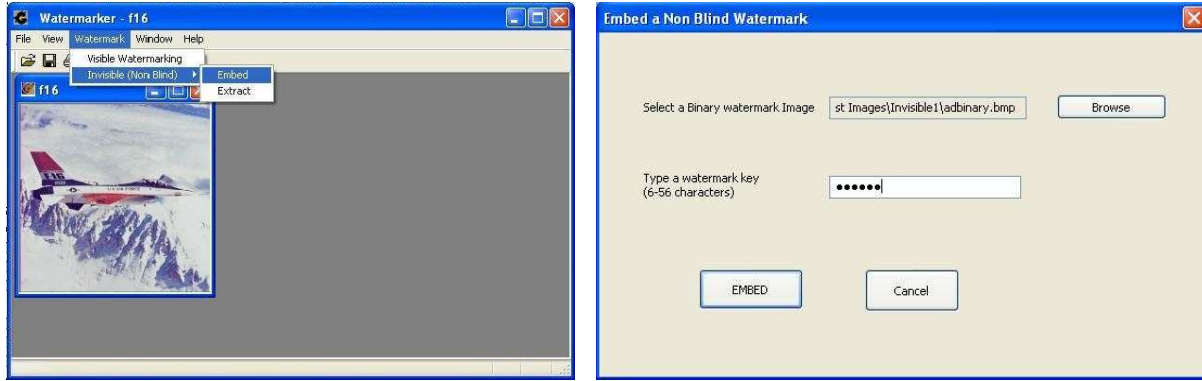
$$PSNR = 10 \log_{10} \left(\frac{(2^i - 1)^2}{MSE} \right). \quad (10)$$

$$MSE = \left(\frac{\sum_{m=1}^M \sum_{n=1}^N \sum_{k=1}^3 I_E(m, n, k)}{3M \times N} \right). \quad (11)$$

$$I_E(m, n, k) = |I(m, n, k) - I'(m, n, k)|^2, \quad (12)$$

where m is the image pixel row from 1 to M , n is the image pixel column from 1 to N , and k is the index (1 to 3 for RGB color space) corresponding to the color plane. $p(m, n, k)$ and $q(m, n, k)$ are the images' pixels after and before processing, respectively, and i is the bit length of the image pixel, 8 in RGB systems.

In order to obtain a comparative perspective of the visible watermarking algorithm presented here, other selected algorithms from the current literature are considered [14, 4, 42, 8]. The PSNR for various benchmark



(a) Open an image.

(b) Enter watermarking key.



(c) Insert the watermark.

Figure 9: Performing invisible watermark insertion using ISWAR.

images is reported in Table 1. The image quality improvement resulting by the proposed algorithm, which is quantified as an increase in PSNR, is also reported. As is evident from the Table, the visible watermarking algorithm generates high-quality images with *PSNR* improvement in the range of 32.6 – 87.8% than other state-of-the-art algorithms.

Table 1: Comparative Perspective with Existing Visible Watermarking Algorithm.

Visible Watermarking	PSNR (in dB)	% Improvement by ISWAR Algorithm
ISWAR Algorithm	Lena - 48.2 dB, F16 - 39.5 dB, mandril - 47.5 dB, pepper - 49.4 dB	NA
Huang, et al. [14]	9.7 - 27.6 dB (Avg. 19.3 dB)	58.6%
Chen, et al. [4]	2.4 - 13.2 dB (Avg. 5.6 dB)	87.8%
Yang, et al. [42]	23.4 - 42.0 dB (Avg. 29.8 dB)	35.2%
Farrugia, et al. [8]	22.6 - 36.8 dB (Avg. 31.4 dB)	32.6%

The performance of ISWAR's current invisible watermarking algorithm with respect to attack resilience has been established by the results shown in Table 2 for the well-known Stirmark attack against the algorithm. In the table, we reported only the binary outcomes of different attacks, that is, whether the watermark extracted has survived in the sense that it is recognizable as a replica of the original watermark, or not. Unlike some earlier reports, a comparative analysis on how well the extracted watermark from the attacked image

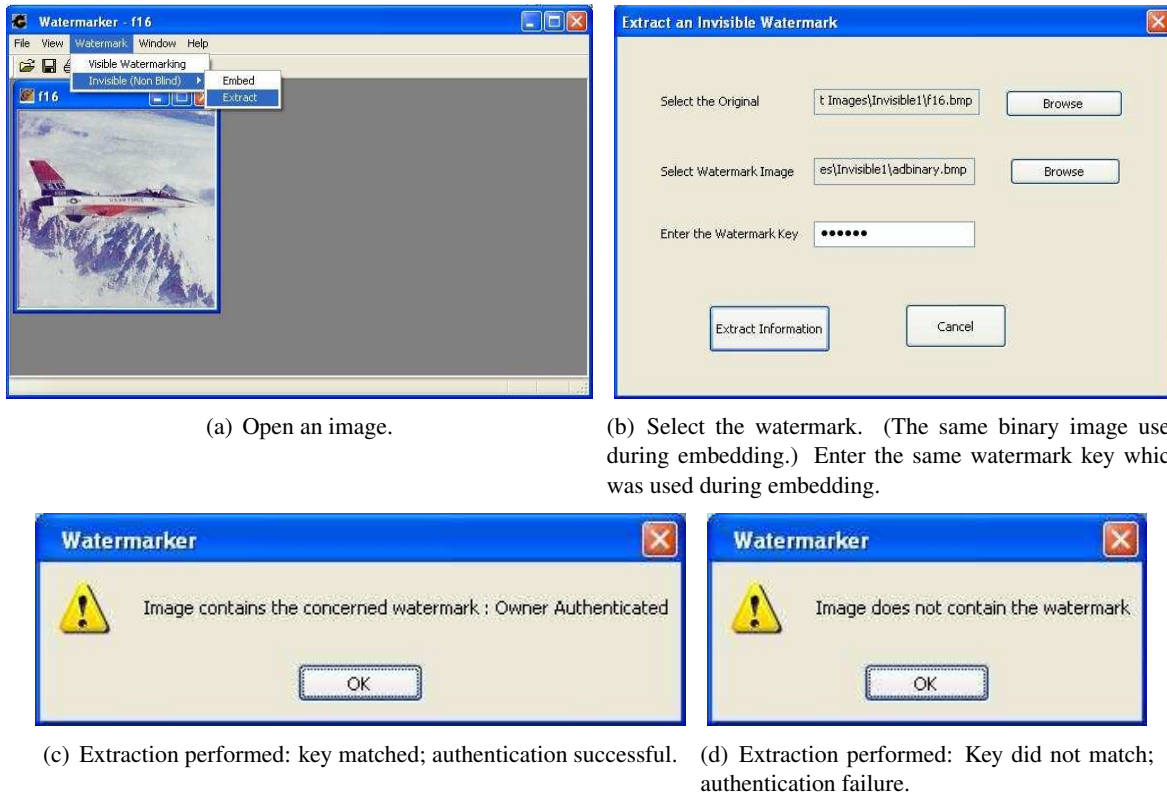


Figure 10: Performing invisible watermark extraction using ISWAR.

correlates with its prototype is not presented for the following three reasons: (1) The paucity of color image watermarking algorithms makes such a comparison infeasible. (2) The very purpose of invisible-robust watermarking is authentication which is a binary decision. Hence, it is more meaningful to investigate the number of difficult attack scenarios the algorithm can handle rather than the accuracy for watermark extraction. As long as the extracted watermark is recognizable, the purpose is served. (3) There is always a tradeoff between the perceptual quality of the watermarked image produced by an algorithm and the quality of the extracted watermark under noise and other degradations. Hence, after establishing with different images and different watermark intensities that the visual quality of our watermarked images are acceptable, the results that are presented help benchmarking our algorithm against the ideal algorithm that survives all the attack types in the Stirmark attack.

In order to obtain a comparative perspective of the performance of the invisible-robust watermarking algorithm, selected watermarking techniques are discussed. The proposed invisible watermarking algorithm is unique in using both AC and DC DCT coefficients for watermarking candidates, encryption in the framework, and hides binary images inside the host image by selective addition and subtraction. Thus, it can allow secure storage of sensitive information including binary fingerprint and hand signature, in a cover image. The results are reported in Table 3. As it is evident from the Table, the invisible-robust watermarking algorithm generates high-quality images with *PSNR* improvement in the range of 56.7 – 76.7% compared to the state-of-the-art.

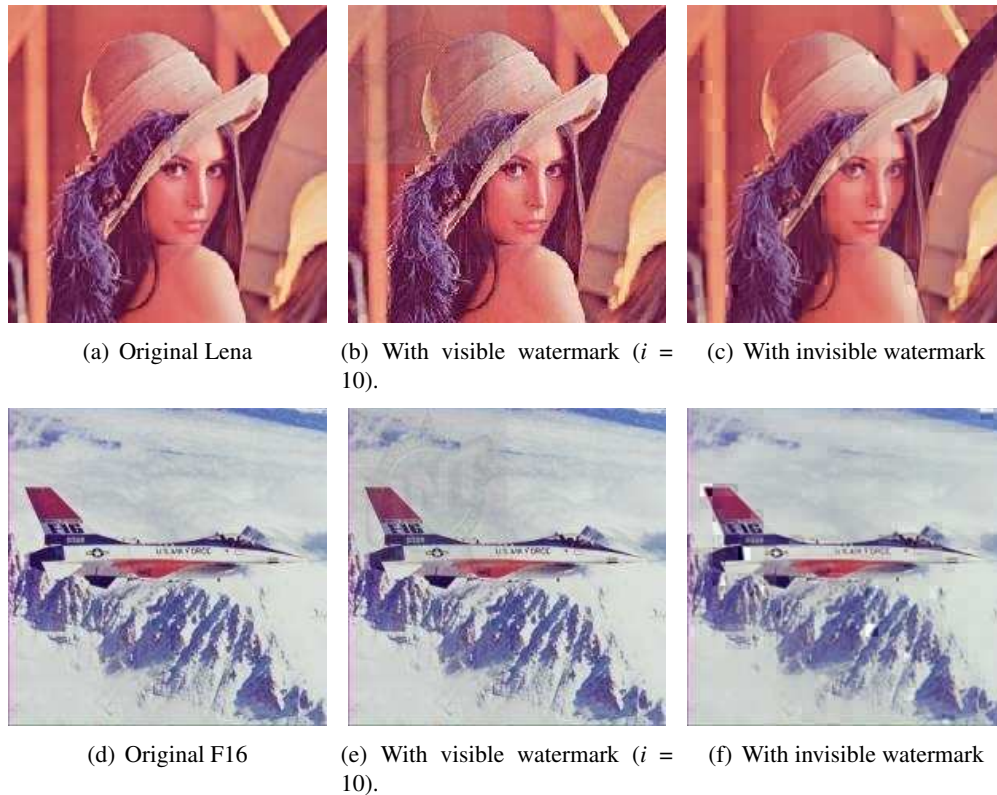


Figure 11: Algorithm evaluation for benchmark image set - 1. The intensity level of the visible watermark is refereed to as i .

8 Summary and Conclusion

In this paper, an object-oriented secure imaging system with watermarking called ISWAR is presented along with novel and effective algorithms for visible and invisible watermarking, extraction and authentication. The system is useful for diverse image security applications. The OO design makes it extensible. Like any active system, ISWAR is evolving and hence many enhancements are underway. For example, an extension that is under consideration for the invisible-robust watermarking is to have two watermarks, a user specific binary watermark and a synthetic watermark generated by the system, and fuse them together into the cover for additional protection and better image quality. Other possible extensions include use of wavelet transforms for embedding of strong watermarks. Here, Daubechies 9/7 filters will be investigated compared to Haar wavelets as the latter may leave out some detail. Blind extraction of invisible watermarks is also a planned extension particularly due to its usefulness in authentication at the receiver end as well as identification of secretive communication among enemies using steganography.

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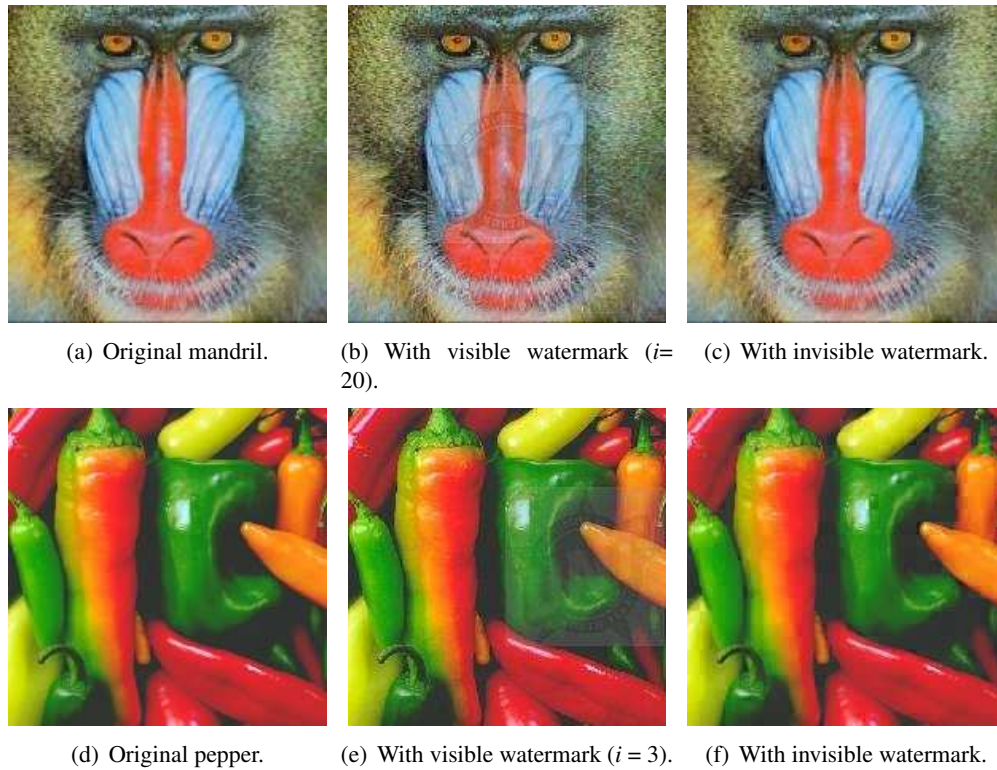


Figure 12: Algorithm evaluation for benchmark image set - 2. The intensity level of the visible watermark is referred to as i .

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Binary Watermark by SPM

(a) Visible watermark. (b) Invisible watermark.

Figure 13: Images used as watermarks.

Table 2: Attacks performed using benchmarks for testing of the invisible-robust algorithm.

Attacks Performed for Testing	For Various Benchmark Images			
	Lena	F16	mandril	pepper
JPEG Compression	Survived	Survived	Survived	Survived
Gray scaling 16 levels	Survived	Survived	Survived	Survived
Gray scaling 256 levels, JPEG	Survived	Survived	Survived	Survived
Blurring, JPEG Compression	Survived	Survived	Survived	Survived
Partial cropping	Survived	Survived	Survived	Survived
Stirmark \tilde{U} Self Similarities	Survived	Survived	Survived	Survived
Stirmark \tilde{U} JPEG compression	Survived	Survived	Survived	Survived
Stirmark \tilde{U} median filtering	Survived	Survived	Survived	Survived
Stirmark \tilde{U} Random Distortions	Survived	Survived	Survived	Survived

Table 3: Comparative perspective with existing invisible-robust watermarking algorithm.

Invisible Watermarking	PSNR (in dB)	% Improvement by ISWAR Algorithm
ISWAR Algorithm	Lena - 105 dB, F16 - 99 dB, mandril -101 dB, pepper - 108 dB	NA
Wu, et al. [40]	24.9 - 47.9 dB (Avg. 38.3 dB)	62.4 %
Pai, et al. [31]	29.1 - 39.6 dB (Avg. 34.7 dB)	65.9 %
Saxena, et al. [33]	23.67 - 23.73 dB (Avg. 23.7 dB)	76.7 %
Rao, et al. [32]	42.9 - 45.8 dB (Avg. of 44.1 dB)	56.7 %

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