A Second Order Spread Spectrum Watermarking Scheme Using Multi-Threshold Wavelet Codec

Imran Khan¹, Syed Wajahat Raza¹, Dimitrios A. Karras², Mussarat Abdullah¹, Faisal Shafique Butt¹
¹Department of Computer Science, COMSATS Institute of Information Technology, Quaid Avenue, The Mall, Wah Cantt 47040 Pakistan.
²Chalkis Institute of Technology, Automation Dept, Greece
E-mail: dakarras@teihal.gr, dakarras@ieee.org , {imrankhan1984, wajahatraka}@gmail.com, {mussarat, faisal-butt}@cuonline.net.pk

Abstract

In this era of digital communication and technology advancements it is now quite feasible and very economical to store, share and transmit multimedia data like images, audio and video in digital form using computer networks and through the internet (World Wide Web). The commercial applications and e-businesses over the internet are steadily becoming more famous and are highly appreciated when images and other multimedia data is involved in these applications. With the distribution of multimedia content like movies, banners, CD labels and personal documents so easily it becomes more crucial to stamp your proof of ownership if it is misused by someone else. However if all these possibilities are to be realized, an integrated technique or approach is required (for the security and duplication issue of the multimedia data) that is robust, secure, and easy to use. Distribution and copy of multimedia data in its exact original form is a reality and poses a great threat. To avoid this threat we need such a tool which is helpful in distribution/duplication issue. The idea of using reliable/permanent watermark to identify uniquely both the source (owner) of an image and an intended recipient has much importance in the electronic publishing and printing industries as well as production houses and movie studios. Because of these challenges and possible applications it is necessary for a watermark to be visually imperceptible, secure, reliable and resistant to attacks (intentional, unintentional, geometric attacks and attacks during the transmission). The main requirements for a robust watermark are as follows

1. Imperceptibility: The watermarked content and the original one should look the same or identical.
2. Robustness: The embedded data or watermark should be capable to survive against signal attacks.
3. Capacity: What is the maximum capacity of data that can be embedded into a digital image, and can it be increased using specialized techniques.
4. Security: No one should be able to access or remove the watermark embedded.
5. Low Complexity of Embedding and Detection System: The process of embedding and extracting the watermark should be simple and less complex.
6. Reliability: The owner of the content should be identifiable, despite hostile attacks on the content.

The main techniques are at the center of attention of research formations. Because of their robustness the Transform domain watermarking technique. The classification of the digital watermarking can be done into two classes depending on the domain of watermark insertion i.e. the spatial and the frequency domain or Transform domain watermarking.

A. Spatial Domain Watermarking: easy to implement hence proves useful to understand the watermarking process. In spatial domain the watermark is embedded by transforming the pixel values directly to an extent that the change is minimal. However it fails under signal processing attacks such as low pass filtering and compression. Because in the spatial domain technique the Least Significant Bit LSB of the pixel is modified to have as minimum color distortion as possible and the compression techniques also discard the LSB to achieve better compression rate.

B. Frequency Domain or Transform Domain Watermarking: on the other hand provides more protection under most of the signal processing attacks. Much of the research work has been done in modifying the data into the Transform domain. These include FFT [1], DCT [2] and DWT [3] domain transformations. Because of their robustness the Transform domain techniques are at the center of attention of research community.

The work presented in this research paper is also based on the Transform domain wavelet watermarking technique. The
proposed method searches significant coefficients across subbands to embed the watermark as proposed in [4]. It is imperative for the imperceptibility of the watermark that the minimum distortion is produced in the host image. There are number of ways which deal with the imperceptibility of the watermarked image. A lot of research has been made on how to do this namely [5] [6] and [7].

The author in [8] proposed a low error probability watermarking scheme using second order spread spectrum technique to empower the watermark to be more resilient to communication errors and other image manipulations. A detail of such technique is presented in next section.

After the process of watermark sequence generation, its time to determine the locations of the host image, to place the watermark bits. The author in [9] has suggested a DWT based decomposition of the image before embedding the watermark. After the decomposition the coefficients that are determined can be classified into two types the low energy coefficients and the high energy coefficients.

The watermark placed in high energy coefficients ensures more visual imperceptibility but is less likely to withstand the image compression and other attacks like low pass filtering. While watermark placed at low energy coefficients are more resilient to image compression and other operations but affect the image perceptibility to a great extent.

One needs to select the respective coefficients according to the nature of the image and most importantly purpose of the application. If the watermark security is of more concern than its visual presence then the watermark should be placed in the lower energy coefficients, otherwise in higher energy coefficients. But correct selection of either type of coefficients is still a challenge. A technique for searching the significant coefficients based on the Multi-Threshold Wavelet Codec (MTWC) technique is proposed in [10] in detail.

The rest of the paper is organized as follows; the procedure of second order spread spectrum is described in section 2. The multi-threshold wavelet codec technique is explained in section 3. Embedding and Detecting processes are illustrated in Section 4. Finally the concluding remarks are presented in section 5.

II. SECOND ORDER SPREAD SPECTRUM

As mentioned before the main purpose of this work is to make watermark more error resistant and robust under high transmission error rates. Our idea of second order spread spectrum arises from the concept of [8]. Figure 1 below shows the basic structure of a general watermark scheme.

This approach deals with the watermark sequence. In our solution the watermark sequence is a Gaussian Pseudo Random Number Sequence that is generated from the Key obtained after hashing the original image. The process of hashing an image is described in [11]. The length of the watermark is an issue. If the block based approach is used then [12] proposed embedding 3 watermark bits per 64 bits of the original image. Otherwise our approach is to restrict the user to usually 8, 16, 32 or 48 bit long watermark.

After the watermark is generated then its time to use the error correcting codes ECC to make sure that the watermark is recovered even under severe distortions. Work in [8] proposed Reed Solomon Encoding to be used for the watermark bits before embedding but we suggest the use of Viterbi Encoding because of less complexity of the later. The details of the Viterbi encoding for digital communications can be found in [13].

The watermark sequence is modulated using Viterbi encoding to correct errors. Now it is followed by the DSSS process (Direct Sequence Spread Spectrum). The advantage of DSSS is that if we embedded a watermark sequence without the DSSS, then it is quite possible for the noise to destroy the watermark sequence. However, the DSSS protects the signature from any kind of damages since it is spread over the selected transform domain coefficients not as originally existing but encoded through Viterbi encoding technique and twice modulated through DSSS, following the above mentioned second order modulation approach. Because the watermark sequence is spread across the whole signal, hence noise resistance would be increased provided that the stored information in the image blocks could be retrieved even after reasonable perturbation of the image block coefficients. In other words, it could be said that the proposed methodology is related to how the watermark signature could be stably stored in image block coefficients. The whole process is illustrated in figure 2 below. After this process the watermark sequence is ready to be embedded.

III. MULTI-THRESHOLD WAVELET CODEC (MTWC)

In section 2 we described the process of watermark sequence generation and presented the use of spread spectrum technique. Now the problem arises where to put the watermark in the host image. We proposed to decompose the host image using Discrete Wavelet Transform. There are many DWT techniques that can be used for image transformation like Haar wavelet transform, Daubechies D4 wavelet transform etc. usually transformation is done up to 4 levels.

The new method of selecting the significant coefficients is described in [9] and [10]. The main process of selection of wavelet coefficients lies on a single initial threshold that is used in all wavelet codec like EZW, LZC. This initial threshold is applied to wavelet coefficients of all sub bands and refined as the process proceeds. The successive subband quantization (SSQ) scheme was adopted in MTWC to choose perceptually significant coefficients for watermark casting. Before embedding these coefficients are sorted according to their perceptual importance.

Our approach differs from the one proposed in [9] that in the mentioned solution the selection of those coefficients is done which are higher energy ones. But our approach requires the coefficients to be selected from the lower energy coefficients for higher robustness.
In our procedure after the wavelet transform, the wavelet coefficients in each subband has a Gaussian distribution with zero mean and variance $\sigma^2$, the simplified rate distortion model is

$$ D = \begin{cases} \frac{T}{12} & \sigma^2 > \frac{T}{12}, \\ \sigma^2 & \sigma^2 \leq \frac{T}{12} \end{cases} $$

As in (1), $D$ is proportional to the square of the current threshold $T$ if the corresponding variance $\sigma$ is large. A larger $D$ implies that this subband contains more energy and should not be treated as a significant subband in comparison with other subbands. Hence we can search for the significant subbands based on their minimum thresholds.

The threshold $T$ is the initial threshold of the subband under consideration and is calculated as

$$ T = \frac{C_{\text{min}}}{2} \cdot s $$

Where $C_{\text{min}}$ is the minimum absolute coefficient value in the subband $s$. The significant coefficient searching procedure can be described as.

1. Set the initial threshold $T$, of each subband to two times of its minimum absolute value of coefficient inside the subband. Set all coefficients un-selected.

2. Select the subband (Except DC term) with the minimum value of $\beta_sT_s$, where $\beta$ is the weighting factor of subband $s$. For the selected subband, we examine all un-selected coefficients $C_s$ and choose coefficient less than the current threshold $T_s$ as significant coefficient. Cast the watermark in these selected significant coefficient.

3. Update the new threshold in subband $s$ as $T_{\text{new}} = \frac{T_s}{2}$.

4. Repeat Step 2 to Step 3 until all watermark symbols are cast.

This modified MTWC technique ensures the selection of proper and deserving significant coefficient for the process of watermarking and is illustrated in Figure 3.

IV. WATERMARK EMBEDDING AND DETECTION PROCESS USING PROPOSED METHODS

The watermark embedding function is illustrated in Figure 3. The watermark and the selected coefficients are used to embed the watermark and then replace the modified coefficients back to their respective places. The [14] describes the overall embedding and detection process as follows

$$ C = T(I) \cdot C = e \cup \bar{e} \cdot I = T^{-1}(C) \cdot \bar{e} = \hat{I} + N \cdot \bar{s} = \mathcal{D}(e) \cdot s_d = \frac{\sigma^2_0}{\sigma^2_0} $$

The embedder $e$ characterized by a period $\Delta$ and a threshold $\beta$ is as follows

$$ p = D(e) $$

$$ e(k) = s(k) - p(k) $$

$$ e(k) = (|e(k)| > \beta) \cdot \text{sign}(e(k)) \cdot \frac{\beta}{2} : e(k) $$

$$ c(k) = (c(k) \geq 0) \cdot c(k) + c(k) : c(k) - e(k) $$

Similarly the algorithm for the detector is as follows

$$ g(k) = \text{rem}(\frac{|c(k)|}{\Delta}), \quad k = 1 \cdots D $$

$$ \hat{c}(k) = (g(k) \geq \frac{\Delta}{2}) \cdot \left(\frac{3\Delta}{4} - g(k) : \frac{\Delta}{4} - g(k)\right) $$

A reasonable choice of values for period $\Delta$ and threshold $\beta$ is about 100 and 12 respectively. But other values of $\beta$ can also be used. Small values of $\beta$ can be used for smooth images, while large values of $\beta$ can be chosen for highly textured images.

The process of detecting a watermark is shown in Figure 4. The most difficult problem, that is faced when the watermarked image is used for the watermark detection in the frequency domain, is to identify coefficients with the embedded watermark values.

From section 3 we can say that each coefficient $C_s(x, y)$ in subband $s$ can be represented by

$$ C_s(x, y) = \text{sign} \cdot a_b (T/2^n + a_{b+1} (T/2^n + \cdots + a_n (T/2^n)) $$

Where $\text{sign}$ is the $\cdot + $ sign value, $b$ is the bit-plane layer number, $a_b$ is the binary bit at the $b$th bit plane and $T$ is the initial threshold of subband $s$. For the purpose of detecting a selected significant coefficient in the $b$th bit plane of subband $s$, i.e. $T_{s,b} < C_s(x, y) < T_{s,b+1}$, then the watermarked version of $C_{s,b}(x, y)$ is

$$ C^w_{s,b}(x, y) = \text{sign} \cdot \Delta_b (C_{s,b}(x, y)) + a_b, T_{s,b}W_b $$

$$ C_{s,b}(x, y) = \text{sign} \cdot a_b (T/2^n + a_{b+1} (T/2^n + \cdots + a_n (T/2^n))$$

Where $\text{sign}$ is the $\cdot + $ sign value, $b$ is the bit-plane layer number, $a_b$ is the binary bit at the $b$th bit plane and $T$ is the initial threshold of subband $s$. For the purpose of detecting a selected significant coefficient in the $b$th bit plane of subband $s$, i.e. $T_{s,b} < C_s(x, y) < T_{s,b+1}$, then the watermarked version of $C_{s,b}(x, y)$ is

$$ C^w_{s,b}(x, y) = \text{sign} \cdot \Delta_b (C_{s,b}(x, y)) + a_b, T_{s,b}W_b $$
Where sign is the sign value of $C_s(x, y)$ the operation $\Delta_p$ is defined as

$$\Delta_p(C_s(x, y)) = (1+2^p \alpha_s) T_{s,b}$$

Then, we can obtain $p$ by

$$p = \arg \min \text{DIS}_{s,b,p}(x, y)$$

After $p$ is selected, we have

$$\text{DIS}_{s,b,p}(x, y) \leq 2^p \alpha_s$$

The watermark detection formula is as follows

$$E^*_{s,b}(x, y) = C^*_{s,b}(x, y) - \text{sign} \times \Delta_p(C^*_{s,b}(x, y))$$

Now after that we have the coefficients in which water-mark was embedded, its time to apply the detector function as in (5). After this Viterbi Decoding is performed to extract the watermark sequence.

If the Original Image is present then the watermark sequence extracted from the Watermarked Image can be used to find the similarity between the original watermark sequence and the one that is extracted.

$$\text{SIM}(I^*, I) = \sum_{k=1}^{Nw} \frac{|E^*_s(x,y) \cdot E_s(x,y)|}{||E^*_s(x,y)|| \cdot ||E_s(x,y)||}$$

V. PROPOSED SOLUTION SIMULATED OBSERVATIONS AND RESULTS

<table>
<thead>
<tr>
<th>#</th>
<th>Image Size</th>
<th>Delta</th>
<th>Total Bits</th>
<th>Detected Bits</th>
<th>Watermark Detected?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>100x75</td>
<td>24</td>
<td>8</td>
<td>7</td>
<td>Yes</td>
</tr>
<tr>
<td>2.</td>
<td>153x110</td>
<td>20</td>
<td>8</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>3.</td>
<td>158x162</td>
<td>28</td>
<td>16</td>
<td>12</td>
<td>Yes</td>
</tr>
<tr>
<td>4.</td>
<td>120x75</td>
<td>28</td>
<td>32</td>
<td>23</td>
<td>Yes</td>
</tr>
<tr>
<td>5.</td>
<td>178x114</td>
<td>28</td>
<td>8</td>
<td>6</td>
<td>Yes</td>
</tr>
<tr>
<td>6.</td>
<td>138x100</td>
<td>32</td>
<td>32</td>
<td>17</td>
<td>No</td>
</tr>
</tbody>
</table>

A set of images has been involved in testing the above proposed methodology. A sample of the results is shown in the previous table. All the above images were in JPEG format and after watermarking them they were converted to PNG format as a test. The total bits are the ones that were embedded as watermark, and the detected bits are the bits detected after the conversion. The proposed Scheme promises to be robust in nature and quite efficient. Other experiments are being carried out to further evaluate the performance of the proposed scheme.

VI. CONCLUSION

In this paper we have presented a novel approach based on the idea of Spread Spectrum Communication and Multi-Threshold Wavelet Codec. The watermark is a pseudo random sequence twice modulated using DSSS technique. To make the process more error resistant we applied Viterbi Encoding for the Watermark Sequence. The significant coefficients of the host image were found after the MTWC technique which is used to identify the wavelet coefficients that are more suitable for the watermark casting. A blind watermark recovering technique was also presented to retrieve the watermark.
REFERENCES


[2] N. Kaewkamne, K. K. Rao “Multi Resolution based Image Adaptive Watermarking Scheme Dept. of EE, Chulachomklao Royal Military Academy Thailand, Dept of EE, University of Texas, TX 76019 USA


[7] Tzung Her Che, Gwoboa Horng and Sang Hao Wang “A Robust Wavelet based Watermarking Scheme using Quantization and Human Visual Model”, Institute of Computer Science National Chung Hsing University 250 Kuo Kiang Road, Taichung 40227 Taiwan ROC


