

Feature Image Watermarking Based on Bicubic Interpolation of Wavelet Coefficients Using CRT

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Abstract—The main objective of watermarking method is to improve the robustness and imperceptibility. This paper introduces an improved CRT watermarking method using absolute value of interpolated wavelet coefficients aiming to improve the imperceptibility and robustness. The standard CRT method embeds the watermark bits on the blocks of pixels evenly. Hence, it can significantly reduce the quality of watermarked images when the watermark lies on the homogeneous area. Otherwise, the proposed method is embedding the watermark bits on the heterogeneous area by sorting the absolute magnitude of wavelet coefficients descending. The wavelet coefficients are selected from high frequency wavelet sub band HH. This scheme is able to determine the appropriate embedding location in certain range of value. The watermark bits are then embedding on the selected pixel value using CRT scheme. The result shows that the average imperceptibility value the CRT is 0.9980 while the proposed method has average value of 0.9993. On robustness against compression, the proposed method achieves better result compared to the CRT with the average NC values of 0.7916 higher than the CRT value of 0.7530. These prove that the proposed method has better performance in term of imperceptibility and robustness against compression than the CRT method.

Index Terms—Watermarking, CRT, Bicubic Interpolation, Wavelet

I. INTRODUCTION

IN computer science, watermarking is a popular method that is used to protect the copyright of digital medium [1]. Watermarking can solve the problem of illegal copying of media [2]. The ownership information is embedded into the medium using certain algorithm. Then, it can be extracted to be used as proof of ownership. Watermarking can be implemented on most of the digital media such audio, image, or video. In current trends of digital watermarking, image becomes the most used medium.

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Generally, watermarking is a process of embedding the proprietary information called watermark into a host image which can be further extracted if it is necessary. Watermarking methods are classified by several criteria such as domain, data type, application area, and visibility [3]. Nowadays, most of watermarking algorithms are classified by the domain consisting of spatial and transform domain. The transform domain methods have complex computation which causes slower process. However, it has better robustness that can preserve the watermark. On the other hand, the spatial domain algorithms have lower computational cost, but the robustness and the imperceptibility are inversely proportional. In the last decade, the Chinese Remainder Theorem (CRT) algorithm [4] became one of the popular methods in watermarking. The CRT is able to withstand against light compression and good robustness in additive noise. Moreover, it can be advanced into Discrete Cosine Transform method [5]. Nevertheless, the CRT can cause significant degradation on homogeneous area of the image due to its spread embedding scheme.

This paper proposes a new embedding scenario using wavelet coefficient to determine the optimum location for embedding. Wavelet coefficient is a frequency magnitudes based on wavelet transformation [1, 6, 7] which can represent the heterogeneity of image area within certain range of value. The down sampled wavelet coefficients are further expanded using bicubic interpolation to get same resolution as the host image. The interpolation of wavelet coefficients are then used to embed the watermark according to its absolute magnitude. This scheme is able to improve the imperceptibility and preserve the robustness as well.

II. RESEARCH METHOD

A. Conventional CRT

In theory and cryptography, the fundamental of CRT is the ability to reconstruct a certain range of integers from their modular residues within pair-wise coprime integer [8]. In field of watermarking, this algorithm is further developed by Ref. [4] to embed the watermark into 6-bit of pixel value Z . We let

$$Z \equiv r_i \cdot \text{mod } m_i \quad (1)$$

where r_i is the i -th residue and Z is 6-bit integer value that can be expressed as

$$Z \equiv \left(\sum_{i=1}^s r_i \frac{M}{m_i} k_i \right) \text{mod } M \quad (2)$$

m_i is a pair-wise coprime integer of s set integers, and M is the modulo which is

$$M = \prod_{i=1}^s m_i \quad (3)$$

and it finds k_i until it has fulfilled followed condition

$$\left(k_i \frac{M}{m_i} \right) \text{mod } m_i = 1. \quad (4)$$

The embedding scheme is to adjust the value of Z that r_i fulfills the condition that is determined by the bits value of watermark. The modulo are resulted from the number of s and the values of r_i as shown in Eq. (3) until Eq. (5). The M value should close to the largest value of 6-bit integer which represents the pixel value. The CRT is embedding the watermark bits evenly on the block of pixels. It causes significant degradation when the watermark bits are embedded on small difference region or in the homogeneous area. Therefore, the authors propose a method to embed the watermark using the interpolation of wavelet coefficients to determine the embedding location of the watermark according to its absolute magnitude.

B. Discrete Wavelet Transform (DWT)

In image processing, the DWT is a two-dimensional transformation which works in multilevel resolution. Spatial image pixels are decomposed into four groups of wavelet coefficients called as sub bands as shown in Fig. 1. The first sub band, LL, is generated from Low Pass Filter (LPF) in row and column order. The next sub band is HL as a result from High Pass Filter (HPF) in row, followed by LPF in column direction. Moreover, the LH sub band is coming from LPF in row and HPF in column direction. The last sub band, HH, is generated from two HPF in both row and column order. The LL is a low frequency sub band which represents the homogeneous area of image. The HL and LH are

middle frequency areas that consist of horizontal and vertical feature. The HH is a high frequency sub band which contains most heterogeneous area of the image. These wavelet coefficients are most suitably used to determine the embedding location due to the capability of determining the image features in multiple representations.

C. Bicubic Interpolation

Bicubic interpolation is an algorithm developed from cubic interpolation to interpolate two-dimensional data [9]. Interpolation algorithms are rapidly developed and applied in fundamental fields of image processing such as image correlation [10], medical image processing [11], detection and estimation [12], and edge interpolation [13]. Bicubic interpolation generates smoother than the other corresponding interpolation algorithms such as bilinear and nearest-neighbor.

In this paper, the bicubic interpolation is used to expand the down sampled wavelet coefficient to get the embedding location within the resolution of the host image using 16 adjacent pixels as follows:

$$h_c(s) = \begin{cases} 1 - (c+3)s^2 + (c+2)s^3, & \text{for } 0 \leq s < 1 \\ -4c + 8cs - 5cs^2 + cs^3, & \text{for } 1 \leq s < 2 \\ 0 & \text{for } 2 \leq s. \end{cases} \quad (5)$$

where s is the distance from reference pixel to interpolated pixel, and c is a constant. The best approximation is achieved by using the constant $c = -0.5$ of the original equation that is given by

$$h_c(s) = \begin{cases} 1 - 2.5s^2 + 1.5s^3, & \text{for } 0 \leq s < 1 \\ 2 + 4s + 2.5s^2 - 0.5s^3, & \text{for } 1 \leq s < 2 \\ 0 & \text{for } 2 \leq s. \end{cases} \quad (6)$$

D. Proposed Embedding

The embedding scheme starts with decomposing host image into wavelet sub band as shown in Fig. 2. The absolute wavelet coefficients are then sorted to determine the proper embedding location based on the magnitude. The pair-wise coprime integer is determined from the previous research by Ref. [4] that can handle value of 2^6 . The detailed process is as follows:

- 1) Decompose host image to get high frequency wavelet sub band HH
- 2) Apply bicubic interpolation using Eq. (5) on the wavelet coefficients to get full resolution of HH'
- 3) Sort the absolute magnitude of wavelet coefficients descending to determine the embedding locations that further are used as a key

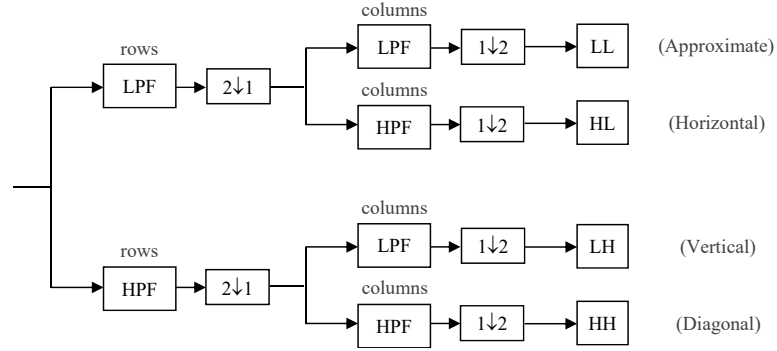


Fig. 1. The wavelet decomposition process

- 4) Get 6 least significant bit value of the selected pixels Z
- 5) Define the pair-wise coprime value of 6 and 11 as m_1 and m_2
- 6) Apply CRT on Z to get the pair-wise residue r_1 and r_2 :

$$r_1 = Z \bmod m_1 \quad (7)$$

$$r_2 = Z \bmod m_2 \quad (8)$$

- 7) Embed the bits of watermark w by modifying Z until fulfilled these conditions:

$$\begin{aligned} r_1 &\geq r_2, & w &= 1 \\ r_2 &< r_2, & w &= 0. \end{aligned} \quad (9)$$

Z is modified based on watermark bits value using the procedure described in Alg. 1.

- 8) Repeat the process until all of watermark bits are embedded.

E. Proposed Extraction

The sorted absolute wavelet magnitude is used as a key to extract the watermark bits as follows:

- 1) Use the absolute magnitude to determine the embedded pixels
- 2) Get 6 least significant bit value of the embedded pixels Z
- 3) Apply CRT on 6-bit value of embedded pixel Z to get r_1 and r_2 using Eq. (7) and Eq. (8), respectively
- 4) Extract the watermark bits w based on the following condition:

$$w = \begin{cases} 1, & r_1 \geq r_2 \\ 0, & r_1 < r_2 \end{cases} \quad (10)$$

- 5) Repeat the process until all of watermark bits are extracted.

Algorithm 1:

```

if ( $w = 1$ ) then
  for ( $j = 1; j < 64; j++$ ) do
    if ( $Z - j \geq 0$ ) then
       $r_1 = (Z - j) \bmod m_1$ 
       $r_2 = (Z - j) \bmod m_2$ 
      if ( $r_1 \geq r_2$ ) then
        return  $Z - j$ ;
      end
    end
  if ( $Z + j < 64$ ) then
     $r_1 = (Z + j) \bmod m_1$ 
     $r_2 = (Z + j) \bmod m_2$ 
    if ( $r_1 \geq r_2$ ) then
      return  $Z - j$ ;
    end
  end
end
if ( $w = 0$ ) then
  for ( $j = 0; j < 64; j++$ ) do
    if ( $Z - j \geq 0$ ) then
       $r_1 = (Z - j) \bmod m_1$ 
       $r_2 = (Z - j) \bmod m_2$ 
      if ( $r_1 < r_2$ ) then
        return  $Z - j$ ;
      end
    end
  if ( $Z + j < 64$ ) then
     $r_1 = (Z + j) \bmod m_1$ 
     $r_2 = (Z + j) \bmod m_2$ 
    if ( $r_1 < r_2$ ) then
      return  $Z - j$ ;
    end
  end
end

```

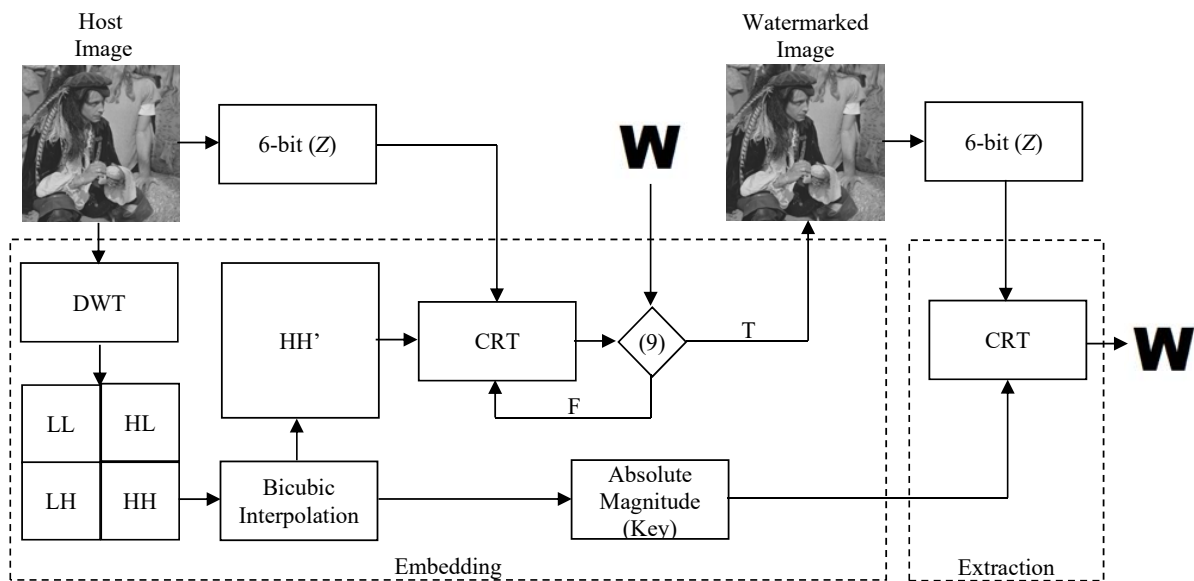


Fig. 2. The Proposed Method.

III. RESULTS AND DISCUSSIONS

The experiments are conducted to compare the proposed method with the standard CRT method by Ref. [4] in term of imperceptibility and robustness against image compression and additive noise. Ten standard images within size of 512×512 , and grayscale format are used as host images. These images will be embedded with a 128×128 binary watermark image. They are shown in Fig. 3.

To get the stable result, the seed value of 0 until 9 are used on host images from the aerial until woman image respectively. The seed is used on the most significant absolute magnitude to scramble the selected embedding location and to generate the additive noise location as well.

A. Imperceptibility

The imperceptibility of the CRT and the proposed method are measured using the Structural Similarity (SSIM) [14] due to its capability to measure the quality according to human vision. The result shows that the proposed method has outperform the CRT in term of imperceptibility. The average imperceptibility value of the CRT is 0.9980, while the proposed method has value of 0.9993. The proposed method has outperformed the CRT as presented in Table I and Fig. 4.

On the CRT method, the watermark bits are embedded evenly on the blocks of pixels. This scheme causes significant degradation when the watermark bits are embedded on small difference region or in the



Fig. 3. The host images: (a) Aerial, (b) Airplane, (c) Apc, (d) Cameraman, (e) House, (f) Livingroom, (g) Pirate, (h) Tank, (i) Tiffany, (j) Woman, and (k) the watermark image.

TABLE I
IMPERCEPTIBILITY OF WATERMARKED IMAGES.

Images	CRT	Proposed
Aerial	0.9987	0.9998
Airplane	0.9978	0.9989
Apc	0.9990	0.9994
Cameraman	0.9973	0.9997
House	0.9975	0.9990
Livingroom	0.9986	0.9996
Pirate	0.9982	0.9996
Tank	0.9978	0.9989
Tiffany	0.9979	0.9996
Woman	0.9975	0.9982
Average	0.9980	0.9993

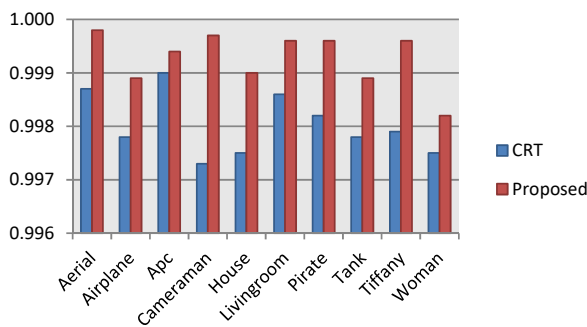


Fig. 4. Imperceptibility of watermarked image.

homogeneous area. On the other hand, this paper uses the absolute value of interpolated wavelet coefficients on high frequency sub band to determine the appropriate embedding location. The high frequency wavelet coefficients are able to represent the heterogeneous image area to be embedded with the watermark bits. This scheme has effectively reduced image degradation to improve the image quality.

B. Robustness

The robustness of watermark images are tested using common JPEG2000 compression and salt and pepper noise with the compression ratio and density of 3% and 5% respectively. They are applied on all of watermarked image. Then, the watermarks are extracted and measured using the standard Normalized Correlation (NC) to get the value and visual representation as well. Table II and Fig. 5 show that the proposed method achieves better result compared to the CRT method in term of robustness against JPEG2000 compression. The proposed method has higher NC value of 0.7916 than the CRT value of 0.7530.

The proposed method embeds the watermark bits on the significant change regions which have high frequency. This area is very suitable for preserving the watermark against such compression. Generally,

TABLE II
ROBUSTNESS AGAINST COMPRESSION AND ADDITIVE NOISE.

Images	Compression		Additive Noise	
	CRT	Proposed	CRT	Proposed
Aerial	0.6570	0.7159	0.9849	0.9819
Airplane	0.8807	0.8819	0.9821	0.9845
Apc	0.6439	0.6484	0.9822	0.9830
Cameraman	0.8579	0.9125	0.9847	0.9841
House	0.6798	0.9054	0.9823	0.9834
Livingroom	0.7459	0.7380	0.9837	0.9848
Pirate	0.7380	0.7600	0.9822	0.9823
Tank	0.6925	0.7079	0.9838	0.9848
Tiffany	0.7481	0.7558	0.9817	0.9829
Woman	0.8857	0.8900	0.9826	0.9818
Average	0.7530	0.7916	0.9830	0.9834

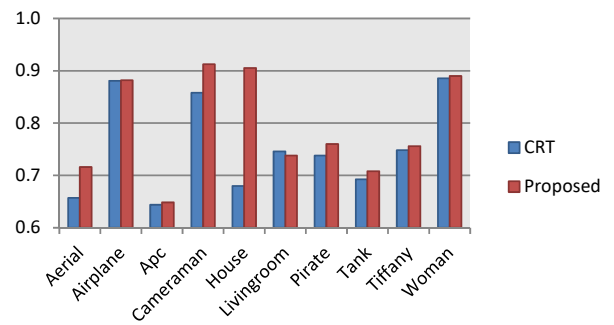


Fig. 5. Robustness against compression.

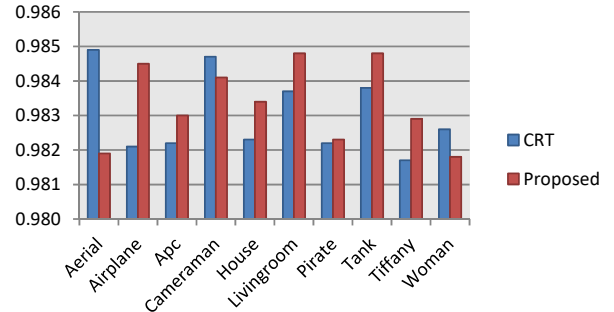


Fig. 6. Robustness against additive noise.

the compression algorithms have major impact on homogeneous area of the compressed image and minor effect on heterogeneous area.

Meanwhile, in term of robustness against 'salt and pepper' noise, both methods have similar result as shown in Fig. 6. The CRT results in NC value of 0.9830 while the proposed method has NC value of 0.9834. In robustness test, the proposed method has higher performance than the CRT method in term of robustness against JPEG2000 compression. In additive noise, both methods have similar robustness. The extracted watermark images under compression and additive noise are depicted in Table III.

TABLE III
EXTRACTED WATERMARK IMAGES.

Images	Compression		Additive Noise	
	CRT	Proposed	CRT	Proposed
Aerial				
Airplane				
Apc				
Cameraman				
House				
Livingroom				
Pirate				
Tank				
Tiffany				
Woman				

IV. CONCLUSIONS

This paper presents an improved CRT watermarking method using interpolated wavelet coefficient to determine the proper embedding location on host image. The standard CRT method embeds the watermark bits on the blocks of pixels evenly. Hence, it can significantly reduce the quality of watermarked images when the watermark lies on the homogeneous area. Otherwise, the proposed method embeds the watermark bits on the heterogeneous area by sorting the absolute magnitude of wavelet coefficients descending. This scheme can determine the appropriate embedding location in certain range of value. The proposed method is intended to produce better embedding process than

the previous method.

The result shows that the proposed method has better performance than CRT method in term of imperceptibility and robustness against compression. The average imperceptibility value of the CRT is 0.9980 while the proposed method has average value of 0.9993. On robustness test, the proposed method achieves better result compared to the CRT with the average NC values of 0.7916 than the CRT value of 0.7530. The robustness is increasing significantly by 0.04 which can improve the visual representation of extracted watermark. Meanwhile, in robustness against additive noise, both methods have similar result with NC values of 0.9830 and 0.9834 respectively. The result proves that the proposed method has better performance in imperceptibility and robustness against compression than the CRT method.

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