Robust IHWT- CRT Image Watermarking using YCbCr Color Space

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Abstract. This research proposes a watermarking method that combines Integer Haar Wavelet Transform (IHWT) and Chinese Remainder Theorem (CRT) algorithms on RGB images that are converted to YCbCr color space. The goal is to get a watermarking method that is robust, imperceptible and secure. Robust because with IHWT done on component Y as a place to insert a watermark done on the frequency domain that is resistant to attack. Whereas CRT is an insertion method in a spatial domain that is relatively more imperceptible to human vision, CRT also more secure because CRT is a cryptographic algorithm. Based on the results of the test and bookkeeping of the imperceptibility quality, the average PSNR value is above 48dB and the average SSIM is above 0.99. Whereas the robustness test proves that by using the YCbCr color space the increase in resistance occurs in Gaussian noise, JPEG compression and JPEG 2000 compression with an average NC value above 0.8.

1. Introduction
Digitalization has an influence on all aspects of human life, it causes an increase in the quality and quantity of digital data distributed through internet media. The ease and speed of distribution, manipulation, and duplication causes high violations of copyright in digital works. For example digital images, it is necessary to check the authenticity for proof of ownership[1]. One way to get proof of ownership is by watermarking [1–3].

Watermarking is a technique of hiding information into an object so it is not detected by the human eye [4] with the aim of protecting the copyright and authenticity of data, data authentication and others[5]. Watermarking should meet the criteria of imperceptibility, robustness, and security. Where imperceptibility means that the existence of an image that has a watermark is not permitted to be seen by human vision, nor can it cause image degradation. Robustness means the watermark must be able to withstand various attacks. Whereas security means that the watermark that is inserted in the image cannot be detected or known using general statistical analysis methods or other methods. Watermarking techniques have two categories, namely spatial domain techniques and frequency domain techniques[6]. In the spatial domain, the technique is done by inserting a watermark directly into the image pixel. Spatial domain watermarking has the advantage of low complexity and easy implementation. However, this spatial domain watermarking is vulnerable to image processing operations[7]. Whereas in the frequency domain it is preferred because with this scheme the watermark is implanted with modulation of the magnitude of the coefficients in the transformation domain which allows stronger resistance to image processing operations, for example, JPEG compression, noise attack, and rotation[7].
Wavelet Transform is a transformation method that is used to convert images from spatial shapes into the frequency domain. This transformation is popular and is widely used in image watermarking. There are various derivatives of wavelet transform such as discrete (DWT), redundant discrete (RDWT), integer (IWT) and lifting (LWT). IWT is commonly referred to as the second generation of wavelets. IWT is more flexible and is able to define wavelet bases on grids or irregular intervals[8]. The coefficient on IWT is represented as a finite precision number that maps integers to integers. This avoids the problem of floating-point precision from DWT[9]. One simple type of IWT is the Haar type developed by Xu, et al. in 2004. Integer Wavelet Transform works through a rounding down operation scheme in the decomposition process and adding a value of 1 to the reconstruction. The floor and lifting scheme aims to avoid loss of information after the reconstruction process. IHWT, also known as Lossless Wavelet Transform, is capable of producing a perfect reconstruction process. Basically, wavelet transforms in digital images are used to divide images of size m x n into four groups of wavelet coefficients of size m / 2 x n / 2, which are named LL, HL, LH, and HH and the wavelet coefficients are known as subbands[10].

One algorithm in the spatial domain is the Chinese Remainder Theorem (CRT). CRT can be used for data security such as watermarking, steganography and cryptography, but it is also used for image coding, authentication and image sharing schemes. This theorem utilizes residual values[2,11]. In addition, this algorithm also has a relatively short processing time with minimal distortion. But because the CRT algorithm works in the spatial domain, the resulting watermarking becomes vulnerable to attack. Some previous research addresses this problem by combining it with wavelet transforms [2,6]. But from the research results, resilience can still be optimized again if implemented in color imagery. In research conducted by Koju and Joshi [1] tested the effect of color space such as YUV, YCbCr, and RGB on watermark resistance, where the YCbCr color space is proven to be more resistant to attack. The YCbCr color space is also applied in other watermarking researches such as [12–15], from these studies this color space was chosen to increase the durability of the watermark.

2. Related Work
Koju dan Joshi[1] propose the DWT-SVD watermarking method on the true color host image. In his research, the performance of the method was tested and analyzed on three kinds of color spaces namely RGB, YUV, and YCbCr. The host image used has a dimension of 512x512 pixels. In the initial stage, the image is transformed and decomposed using DWT to produce four subbands, LL, LH, HL, and HH. Insertion is done in the LL subband combined with the SVD algorithm. Based on the image imperceptibility test color spaces RGB has the best performance based on the calculation of PSNR values, followed by YUV, and YCbCr color spaces. But the robustness test of the YCbCr color space has the best performance, based on the calculation of the NCC value, followed by the RGB and YUV color space.

Hajiramezan et al. [16] published a watermarking technique using the non-blind IWT method on grayscale images. The host image used in the test is a 512x512 pixel image while for a watermark image using a 64x64 pixel binary image. The insertion process is carried out in the LL subband, by first doing the IWT transformation. The insertion technique is done by PRNG and factor scale values. The study produced PSNR 44.6157 dB. In the robustness test, the NC results are also higher than the insertion in the LH subband.

Sari et al[12] propose a combination of DCT and SVD methods to insert a watermark in a color image. The host image used is 512x512 pixels and the watermark image is 32x32 pixels. Before inserting, the RGB image is converted to the YCbCr image color model. Insertion is done in room Y. Room Y was chosen because Y is the part that has most of the image information, if the information embedded in this section, it can increase the message of invisibility and durability from various attacks. The study produced a PSNR value of 41.5dB to 42.3 dB. In the endurance test, the majority of NC values were above 0.7 in JPEG compression, salt & pepper, Gaussian filter, median filter, blurring and rotate attacks.

Sudibyo et al [2], combining the CRT algorithm with the Haar Wavelet Transform (HWT) method. The host image used in the test is a grayscale image measuring 512x512 pixels, whereas for a watermark image using a 32x32 pixel binary image. HWT is performed on the host image first to
decompose to produce four subbands, namely LL, LH, HL, HH. Watermark image insertion is performed on the LL-subband domain using the CRT Algorithm. The results of the test produce PSNR values above 60 dB and NC value without attack is 1.

Adi et al. [6], combined the CRT algorithm with the Integer Wavelet Transform (IWT) method. The host image used in the test is a grayscale image measuring 512x512 pixels, whereas for a watermark image using a 128x128 pixel binary image. The watermark process is first performed by transforming the IWT on the host image to produce an LL, LH, HL, HH subband. The embedding process is carried out on LL and HH subband combined with the CRT algorithm to increase imperceptibility and security. In the endurance test, this method proved to improve robustness performance when compared with only the CRT method. As for the measurement of the quality of imperceptibility measured using SSIM with an average value above 0.99.

Based on some analytical research from previous research, this study aims to propose and analyze watermarking methods using a combination of IWT and CRT algorithms on the YCbCr color space. Before the insertion process is carried out, the color image will be converted to the YCbCr color model. Y is chosen as the color space for watermark insertion. Where before being inserted Y space is transformed by IWT using the Haar filter, then the LL subband is selected, then the insertion is done by the CRT algorithm in the LL subband.

3. Chinese Remainder Theorem (CRT) and Integer Wavelet Transform (IWT)

3.1. Chinese Remainder Theorem (CRT)

Based on number theory, the basis of the CRT algorithm is its ability to reconstruct integers with a certain range of values from the remainder of the quotient on the pair of coprime numbers. Patra et al[17] developed a watermarking method based on the CRT algorithm in digital images. A digital image is represented by pixel values which are generally 8-bit in size [0 255]. The CRT algorithm expressed as μ is a set of integers, μ = {M1,M2,…,Mi}, so Mi is a pair of numbers that are relatively prime {R1,R2,…,Ri}. The CRT formula can be seen in formula (1).

\[ Z \equiv R_i \pmod{M_i} \text{ or } R_i = Z \mod M_i \]  

(1)

The Z value is used in the watermarking field to insert a watermark. The insertion process is done by modifying the Z value so that the conditions are met. The watermark insertion process in detail as below:

1. Determine the location of the X pixel
2. Change the pixel value to an 8-bit binary value [0-255]
3. Take 6-LSB from X, then change it to integer value [0-63] as the Z value
4. Take 2-MSB from X then change it to decimal value [0, 64, 128, 192] as Y value
5. Determine the pair of coprime numbers M1 and M2 (the number are 6 and 11 based on [17])
6. Finding the values of R1 and R2 with the formula (1).
7. Modifying the Z value with the following conditions:
   
   
   ```
   for (j=0; j<64; j++)
   if (Z+j < 0)
   R_j = (Z+j) mod M_j;
   R_j = (Z+j) mod M_j;
   if (R_j < R_j) return Z+j;
   if (Z+j < 64)
   R_j = (Z+j) mod M_j;
   R_j = (Z+j) mod M_j;
   if (R_j < R_j) return Z+j;
   }
   ```

8. Combine the modified value Z’ with Y to get the X’ watermarked pixel
9. Repeat steps 1 - 8 until the entire watermark is inserted into the image.

Whereas the detailed extraction steps are as follows:

![Figure 1. Modifying the Z value.](image)
1. Determine the location of the X pixel
2. Change the pixel value to an 8-bit binary value [0 255]
3. Take 6-LSB from X then change it to decimal value [0 63] as the Z value
4. Find the values of R1 and R2 with the formula (1).
5. Determine the value of the watermark bit, with the provisions of bit 1 if $R_1 \geq R_2$ and bit 0 if $R_1 < R_2$
6. Repeat process 1 - 5 until all watermark images are extracted.

### 3.2 Integer Wavelet Transform (IWT)

Wavelet transform is based on small waves called wavelets with variable frequency and limited duration. The basic thing of Discrete Wavelet Transform or DWT is to differentiate images into sub-images of different spatial domains and independent frequency regions. The DWT method has the advantage of identifying parts of the cover image so that the watermark can be effectively inserted\[3,6,9\]. The DWT method works in multiple resolutions. The performance of the watermarking technique using the DWT method is much better because in this method it can be improved to become level 2, level 3 DWT and so on.

![Figure 2. IWT Decomposition process.](image)

One variation of DWT is IWT. In carrying out the process of decomposition of wavelet transforms using two types of filters, namely low pass, and high pass, where both of these filters are quite a lot of variants. Examples of the results of IWT composition can be seen in Fig. 2. One variant of the filter is Haar, where IWT using Haar filter is often called the Integer Haar Wavelet Transform (IHWT). IHWT works from the rounding down operation scheme and adding 1 (lifting) value to the decomposition and reconstruction process. This floor and lifting scheme aims to avoid loss of information after the reconstruction process. IHWT is a lossless compression. IHWT is faster than floating-point arithmetic because floating-point wavelets transform requests for data sizes that are longer than integer wavelet transforms\[6\]. The advantage of the IHWT method is reversibility, which means that the reconstructed image will not lose anything because the coefficients are integers and can be stored without rounding errors.

IHWT decomposition is done by dividing the image into non-overlapping blocks 2x2 as in formula (2)\[6\].

$$\begin{bmatrix} I_{m,n} & I_{m,n+1} \\ I_{m+1,n} & I_{m+1,n+1} \end{bmatrix} \text{ or } \begin{bmatrix} a & b \\ c & d \end{bmatrix}$$

Where $I_{m,n}$ is the pixel image in rows m and column n, then the decomposition process becomes LL subband according to formula (3), LH with the formula (4), HL with the formula (5) and HH with the formula (6).

$$LL = \left\lfloor \frac{a + b}{2} \right\rfloor + \left\lfloor \frac{c + d}{2} \right\rfloor$$

$$LH = \left\lfloor \frac{a + b}{2} \right\rfloor - \left\lfloor \frac{c + d}{2} \right\rfloor$$
\[ H_L = \left\lfloor \frac{a - b + c - d}{2} \right\rfloor \]  
(5) 

\[ H_H = a - b - c + d \]  
(6)

4. Proposed Method
In general, the watermarking method consists of two main parts, namely the embedding and extraction process. In detail the embed process is as follows:
1. The image to be used must be in accordance with the format, the host image used is a color image of 512x512 pixels and a watermark image of 128x128 pixels with a binary color model.
2. Convert the host image to YCbCr Component form with the formula (7), taking YComponent as host image.

\[
\begin{bmatrix}
  Y \\
  C_b \\
  C_r \\
\end{bmatrix} =
\begin{bmatrix}
  0.299 & 0.587 & 0.114 \\
  -0.1687 & -0.3313 & 0.5 \\
  0.5 & -0.4187 & -0.0813 \\
\end{bmatrix}
\begin{bmatrix}
  R \\
  G \\
  B \\
\end{bmatrix} +
\begin{bmatrix}
  0 \\
  128 \\
  128 \\
\end{bmatrix}
\]  
(7)

3. Y-component images are processed using level 1 IHWT producing four subbands: LL, LH, HL, and HH. The insertion process is carried out in the LL subband.
4. Set the CRT method on the LL subband to insert the watermark image in the following steps:
   a. Divide LL subband into several blocks of 2x2 size.
   b. Select the pixel value (X) of each 2x2 block in the index (1,1). Change the X value to an 8-bit binary.
   c. Take 6 Least Significant Bits (LSBs) from X to determine the value of Z. The residual value from X (MSB) is used for subsequent calculations (Y).
   d. Next, to find the residual values of R1 and R2 by selecting the co-prime values of M1 and M2, the values proposed by Patra et al are 6 and 11.
   e. Modify the Z value by inserting a watermark bit. Bit value ‘1’ condition needed R1 ≥ R2 while for bit value ‘0’ condition required R1 < R2.
   f. Combine the values of Z and Y to get the value of X.
5. Perform inverse IHWT and Y component image which has been inserted with the watermark image will be obtained.
6. Convert YCbCr back to the RGB color space.

\[
\begin{bmatrix}
  R \\
  G \\
  B \\
\end{bmatrix} =
\begin{bmatrix}
  1 & 0 & 1.402 \\
  1 & -0.34414 & -0.7414 \\
  1 & 1.772 & 0 \\
\end{bmatrix}
\begin{bmatrix}
  Y \\
  C_b \\
  C_r \\
\end{bmatrix} -
\begin{bmatrix}
  0 \\
  128 \\
  128 \\
\end{bmatrix}
\]  
(8)

7. Test the imperceptibility aspect by comparing the original image with the watermarked image and then calculating it based on the PSNR and SSIM.
Whereas the extraction stage in detail is as follows:
1. The watermarked image is converted into YCbCr space. Produces 3 components Y, Cr, and Cb.
2. Y component is processed using IHWT to produce four subbands namely: LL, LH, HL, HH. The extraction process is carried out in the LL subband.
3. LL subband is processed using CRT by dividing the image into several blocks of the same size based on the number of watermark images. The CRT process is as follows:
   a. Select the pixel value (X) of each 2x2 block in the index (1,1). Change the X value to an 8-bit binary.
   b. Take 6 Least Significant Bits (LSBs) from X to find the value of Z. The remaining value from X (MSBs) is used for further calculations (Y).
   c. Next look for residual values of R1 and R2 by selecting the co-prime values of M1 and M2 using equation (9).
   d. Comparisons are made between R1 and R2. If R1 ≥ R2 then the bit value ‘1’ can be extracted, while R1 < R2 the bit value ‘0’ can be extracted. So it is obtained an extracted watermark image.
4. The extracted watermark image quality is measured using NC.
5. Test the aspect of robustness by extracting a watermark. Add some attacks such as JPEG compression, JPEG2000, Gaussian noise, and salt & paper for and testing robustness.

5. Implementation and Results

The image used for this study is the RGB color image as the original host image. The original image has a size of 512 × 512 pixels with the format *.bmp. Whereas as a watermark image using a binary image with *.bmp format. The watermark image has a size of 128 × 128 pixels. Host images are obtained from online repositories, namely sipi.usc.edu/database and hlevkin.com/06testimages.htm. The original host image used in this research is shown in Fig. 3. As for the watermark image presented in Fig. 4.

![Baboon](image1.png) ![Cablecar](image2.png) ![Girl](image3.png)
![Lena](image4.png) ![Yacht](image5.png) ![Zelda](image6.png)

Figure 3. Original host image used.

![Watermark](image7.png)

**Figure 4.** Watermark image

The watermarked image is measured by the quality of imperceptibility using PSNR and SSIM. PSNR functions to find out how much noise is generated by SSIM’s embedding process to determine the structural changes that occur in watermarked images. The higher the PSNR value and the SSIM value, the higher the similarity level of the watermarked image and original image. To calculate PSNR and SSIM, the psnr () and ssim () functions in Matlab R2015a are used. The results of the calculation of PSNR and SSIM values are presented in Table 1.
Table 1. PSNR and SSIM measurement results

| Image  | PSNR  | SSIM  |
|--------|-------|-------|
| Baboon | 48.0612 | 0.9978 |
| Cablecar | 47.8761 | 0.9930 |
| Girl | 47.9743 | 0.9937 |
| Lena | 48.1123 | 0.9933 |
| Yacht | 47.7869 | 0.9939 |
| Zelda | 48.0404 | 0.9939 |
| Average | 47.9752 | 0.9943 |

From the results shown in Table 1, it appears that the PSNR value generated from the entire image is 40dB so that the image quality can be said to be very good and very similar to the original image [12]. Nevertheless, the results of the measurement of imperceptibility from this research also need to be compared with other methods as presented in Table 2.

Table 2. Comparison of average PSNR results with other methods

| Research            | Method              | Cover Image Type | Watermark dimension | PSNR (dB) |
|---------------------|---------------------|------------------|---------------------|-----------|
| Hajiramezan et al. [16] | IWT + PRNG          | Grayscale        | 64 × 64             | 44.6157   |
| Sari et al[12]      | DWT + SVD           | Colour           | 32 × 32             | 41.8218   |
| Proposed Method     | IHWT + CRT          | Colour           | 128 × 128           | 47.9752   |

Table 2 shows that the method proposed in this study has a better quality of imperceptibility compared to the previous method. Even if it is truly compared, the proposed method should be even better. This is caused by the difference in the size of the embedded watermark, where the size of the watermark used is greater than the comparable method. A larger size watermark directly affects the increase in payload, where a larger payload can automatically reduce the quality of imperceptibility. The next step is the robustness test, where watermarked images are manipulated such as the addition of Gaussian noise, salt and pepper, JPEG compression and JPEG 2000 compression. After manipulation of watermarked images, the watermarked image is extracted and the extraction results are measured by measuring NC by watermark images. original. NC measurements are measured by the corr2 () method in Matlab R2015a, where the measurement results are presented in Fig. 5.

Figure 5. NC Measurement results
6. Conclusions
This research succeeded in combining the combination of the IHWT and CRT methods to improve the quality of the watermarked color image. Initially, the RGB image was converted to YCbCr with the aim of embedding a watermark on the Y channel. The purpose of embedding the Y channel is to increase the durability of the watermark. From the test results of the method, the results of the measurement of imperceptibility quality show an average figure of 47.9752dB for PSNR and 0.9943 for SSIM. This indicates that the quality produced is very good and the senses of human vision will not be detected. Besides robustness testing also shows a very satisfactory NC value where the average value of NC without attack is 0.999 and the average NC of various attacks above 0.8.

7. References
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