An Analysis of Imperceptibility and Robustness Performance in CRT Image Watermarking based on Color Space Theory

L B Handoko¹, Utariyanto¹, D R I M Setiadi¹, E H Rachmawanto¹, C A Sari¹, and R R Ali²

¹ Department of Informatics Engineering, Dian Nuswantoro University, 207 Imam Bonjol Street, Semarang 50131, Indonesia.
² Faculty of Computer Science and Information Technology, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia

Abstract. Color images have more information and more storage space than gray images. The process of computing color images is also more complex compared to gray images. Nevertheless, human vision is more sensitive to color images compared to gray images, so color image processing is so important. Image watermarking is a method of copyright protection by embedding copyrights in the image. The embedding process can cause changes in the pixel value of the image, so it needs to be analyzed and measured the quality of watermarked images both visually or imperceptibility and watermark durability. In general, color images use the RGB color space model and color space conversion is not done when embedding watermarking. But several studies have suggested converting RGB color space to YCbcCr color space for a specific purpose. This research proposes to analyze the robustness and imperceptibility performance in the R, G, B and Y color spaces in the CRT method. CRT is one of the methods of image watermarking in the spatial domain, where this method was previously also used as a cryptographic algorithm. So that the CRT method excels in durability and security watermarks. Based on the results of testing with the CRT method, the color space R has an advantage in the aspect of imperceptibility compared to other color spaces, the difference is very thin with the G and B color spaces, but when compared with the Y color space the difference reaches 3dB based on the PSNR calculation. But for testing the robustness of the color space Y is far superior compared to other color spaces even though extraction without attack, not all watermarks can be extracted perfectly.

1. Introduction

Digital file authentication is very important now. This is caused by the negative impact of increasingly sophisticated technology. Human habits that used to physically save files now turn to digital storage. Digital storage is indeed more practical, because it is easy to find, duplicate, modify and share via the network. This will be dangerous if the digital file is stolen, duplicated and manipulated with malicious intent. Then the security of digital files becomes very important[1–3]. Currently, research on watermarking, especially on image objects continues to be developed [4–6]. Image watermarking is one of the best ways to authenticate digital image files [6]. Image watermarking can be done with two domains, namely spatial domain, and frequency domain. In the spatial domain, it is better in terms of imperceptibility, capacity, and low complexity [5], while the frequency domain can withstand manipulations [2]. However in the latest research conducted by Abraham and Paul [5] about image watermarking in the spatial domain, the resulting imperceptibility is very good, robustness performance is not inferior to the method at the frequency domain.
Imperceptibility and robustness performance can also be influenced by color space selection\[7,8\]. wherewith the same method can produce very different robustness and imperceptibility performance. Chinese remainder theorem (CRT) method [9–13] is one of the spatial domain methods that is quite widely used in image watermarking. This method has advantages in imperceptibility and security performance because CRT is also a method that can be applied to cryptography. Where the seeding technique in the CRT method is based on residual values. In watermarking image research there are still many grayscale images used in the testing phase, this means that there is no analysis of the effect of color space on this algorithm. While research on the comparison and analysis of color spaces in the frequency domain has been carried out and concluded that the use of color space is very influential on the performance of watermarking images\[7,8\]. This research aims to analyze the performance of CRT image watermarking as one of the methods in the domain in the RGB and YCbCr color spaces, especially on the Y channel.

2. Color Space Theory in Data Hiding

Color images have at least three times the size of memory compared to gray images, this is caused because color images usually have three spaces, where each color space has an 8-bit size while gray images only have one color space. This means that color image processing will be longer and heavier than gray images, however, this is very important because the human visual system is more sensitive to color images and edge areas compared to grayscale images\[14\]. There are various color images storage models such as RGB, XYZ, CMY or CMYK, HSI, YUV, NTSC or YIQ and YCbCr. Red, green, and blue (RGB) are the most common color space models used in composing color images on computers. The combination of these three colors is arranged linearly. The RGB color model is also very widely used in data research specifically image watermarking\[5,15,16\]. But in a number of watermarking researches, there are also many proposed YCbCr color models especially with the aim of increasing robustness, although in some research imperceptibility also increases\[1,17,18\]. In other studies that have compared the influence of color space in watermarking images using the same method\[7,8\], that in general it is concluded that the RGB color model has a better imperceptibility, whereas in the YCbCr color model, in particular, the Y space has the best robustness, which in this research is carried out in the frequency domain.

The YCbCr color space is often used in digital video. The YCbCr model focuses more on the image energy on the Y component while on the RGB color model the intensity is evenly distributed. Cb and Cr are the difference between the blue component for Cb and the red component for Cr with a reference value. Because the image energy in the Cb and Cr components is relatively small, manipulation in this section will not have a major effect on the image\[14\]. With this theory, it can be concluded that in hiding data, the Cb and Cr color space will provide a level of imperceptibility while the Y component will provide stronger robustness. RGB color space can be converted to YCbCr or vice versa with the formula (1) and formula (2), where formula (1) to convert RGB to YCbCr and formula (2) to convert YCbCr to RGB.

\[
\begin{align*}
[\begin{bmatrix}
Y \\
Cb \\
Cr
\end{bmatrix}] &= \begin{bmatrix}
16 \\
128 \\
128
\end{bmatrix} + \begin{bmatrix}
65.481 & 128.553 & 24.966 \\
-37.797 & -74.203 & 112.000 \\
112.000 & -93.786 & -18.214
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} \\
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} &= \begin{bmatrix}
0.0046 & 0.0000 & 0.0063 \\
0.0046 & -0.0015 & -0.0032 \\
0.0046 & 0.0079 & 0.0000
\end{bmatrix} \begin{bmatrix}
Y \\
Cb \\
Cr
\end{bmatrix}
\end{align*}
\]  

3. Image Watermarking using Chinese Remainder Theorem (CRT)

CRT was originally an encryption method, but in its development CRT was implemented in image watermarking. One of the earliest CRT studies for watermarking images that was quite popular was conducted by Patra et al \[13\]. In his research, CRT is said to have better performance than SVD against the addition of noise attacks if measured using a tampering assessment function (TAF). Because CRT is included in the spatial domain, CRT has faster computing, even in the research of
Where $\mathcal{R}$ is meant is the residual value. Whereas the solution to get the integer value $Z$ is calculated by the formula (4)

$$ Z \equiv \left( \sum_{j=1}^{\ell} \mathcal{R}_j \frac{N}{N_j} L_j \right) \pmod{N_i} $$

Where $N = N_1 N_2 ... N_{\ell}$, and $L_j$ can calculate by formula (5).

$$ L_j \frac{N}{N_j} \equiv 1 \pmod{N_i} $$

Whereas to inverse CRT is to represent the integer value $Z$, where the $Z$ value in the range $\{0 < Z \leq N - 1\}$ which is a set of integers $Z = \{\mathcal{R}_1, \mathcal{R}_2 ... \mathcal{R}_{\ell}\}$. Then $\mathcal{R}_j$ can be calculated congruency in formula (3).

### 4. Analysis Imperceptibility and Robustness

In this research, the testing of imperceptibility quality uses two measurement methods, namely PSNR and SSIM. Imperceptibility means that watermarks embedded in the host image cannot be detected by the human sense of sight. This can also mean the visual quality of the output image in the watermarking process, which is the watermarked image. SSIM and PSNR are two standard measurement tools that are widely used in image watermarking research and other image processing.

PSNR refers to the highest noise measurement that allows reducing the quality of the image. This can be calculated from the square of the error that occurs in the watermarked image. Whereas SSIM measures image quality based on differences in structure, intensity, and contrast[19]. The PSNR formula can be calculated with the formula (6), while the SSIM can be calculated with the formula (7).

$$ PSNR = 20 \log_{10} \left( \frac{2^8 - 1}{\frac{1}{WH} \sum_x \sum_y [I(x,y) - I'(x,y)]^2} \right) $$

$$ SSIM \left( I, I' \right) = \frac{(2 \mu_I \mu_{I'} + C_1)(2 \sigma_{I I'} + C_2)}{\left( \mu_I^2 + \mu_{I'}^2 + C_1 \right) \left( \sigma_I^2 + \sigma_{I'}^2 + C_2 \right) } $$

Where $W$ is the width of image (in pixels); $H$ is height of image (in pixels); $I$ is original host image; $I'$ is a watermarked image; $x$ and $y$ are pixel value based on coordinate $x$ and coordinate $y$; $\mu$ is intensity; $\sigma$ is a standard deviation.

Whereas the robustness test is carried out by using NC measurement tools, namely by comparing the original watermark image with the extraction watermark image. This measurement tool has also been widely used as a standard measure of robustness tests in various watermarking researches, to calculate the value of NC can be used formula (8).

$$ NC = \frac{\sum_W \sum_H \left( l_{xy} - \bar{l} \right) \left( l'_{xy} - \bar{l'} \right)}{\sqrt{\left( \sum_W \sum_H \left( l_{xy} - \bar{l} \right)^2 \right) \left( \sum_W \sum_H \left( l'_{xy} - \bar{l'} \right)^2 \right) } } $$
5. Results and Analysis
In this section the CRT method in Patra et al's research[13] was replicated to be tested in this research, only the data set used was different, both from the cover image, watermark image, and image resolution used. This research uses true color imagery with a depth of 2^{24}. While watermark images are binary images, these images can be seen in Fig.1 and Fig.2.

![Airplane](image1)
![Lena](image2)
![Lichtenstein](image3)

**Figure 1.** Original host image

![Peppers](image4)
![Sailboat](image5)
![Splash](image6)

**Figure 2.** Watermark image

All host images have the same resolution of 512 × 512, the host image also does not undergo preprocessing before it is used in the next step. While the watermark image is a binary image with a resolution of 128 * 128. The size of the binary image used is relatively larger than the research conducted by Patra et al[13], so the difference in embedding a watermark is in the process of dividing the image in the form of small blocks, where the block size used is 4 × 4. In the initial stage the host image is read, then separate the color space where each color space will be inserted watermark alternately so as to get three kinds of watermarked images, namely watermarked image-R where the watermark is embedded in red space, watermarked image-G where the watermark is embedded in the space green, and watermarked image-B where the watermark is embedded in the blue space, This is a watermark embedding technique in the RGB color space. Whereas for embedding in the Y color space on the YCbCr model, the RGB image is converted to a YCbCr image, then the Y color space is selected to insert a watermark by the CRT method, so that the Y color space is watermarked, this color
space is then combined with the Cb and Cr color spaces to get the Y-watermarked image. After obtaining four kinds of watermarked images, the first test of watermarked image quality was measured using PSNR and SSIM measurement tools. The measurement results are presented in Table 1.

| Image      | R   | G   | B   | Y   | PSNR (dB) | SSIM |
|------------|-----|-----|-----|-----|-----------|------|
| Airplane   | 58.3919 | 58.5550 | 58.5522 | 55.4575 | 0.9991 | 0.9990 |
| Lena       | 59.0512 | 59.0880 | 58.7910 | 56.0214 | 0.9993 | 0.9990 |
| Lichtenstein | 59.1561 | 59.2370 | 59.1492 | 56.0012 | 0.9993 | 0.9992 |
| Peppers    | 59.8230 | 58.0200 | 57.9367 | 55.9567 | 0.9996 | 0.9992 |
| Sailboat   | 59.0213 | 59.4310 | 58.9905 | 56.1230 | 0.9996 | 1.0000 |
| Splash     | 58.9934 | 58.5150 | 58.1472 | 54.7890 | 0.9990 | 0.9989 |
| Average    | 59.0728 | 58.8577 | 58.5945 | 55.7248 | 0.9993 | 0.9992 |

In table 1 it appears that the results indicated by the color space R have the best level of imperceptibility based on both the PSNR and SSIM measurement tools. The color space Y has the worst results, however, all of these values are included in very good criteria [20].

At the robustness test stage, NC is used to make measurements. At this stage the watermark extraction process is carried out on the watermarked image, the extracted watermark image is then measured by comparing the original watermark image with the extracted watermark image. The extraction process is carried out on watermarked images without attacks and manipulated watermarked images. The manipulation performed on watermarked images is the addition of SS (salt and peppers) noise, Gaussian noise, JPEG compression JPEG 2000 compression. The NC measurement results are presented in Tables 2 through Table 6, respectively.

| Image      | R   | G   | B   | Y   | NC   |
|------------|-----|-----|-----|-----|------|
| Airplane   | 1   | 1   | 1   | 0.9995 |
| Lena       | 1   | 1   | 1   | 1    |
| Lichtenstein | 1   | 1   | 1   | 1    |
| Peppers    | 1   | 1   | 1   | 0.9988 |
| Sailboat   | 1   | 1   | 1   | 0.9993 |
| Splash     | 1   | 1   | 1   | 0.9979 |
| Average    | 1   | 1   | 1   | 0.9993 |

| Image      | R   | G   | B   | Y   | NC   |
|------------|-----|-----|-----|-----|------|
| Airplane   | 0.9890 | 0.9915 | 0.9898 | 0.9870 |
| Lena       | 0.9921 | 0.9900 | 0.9897 | 0.9895 |
| Lichtenstein | 0.9908 | 0.9906 | 0.9914 | 0.9901 |
| Peppers    | 0.9915 | 0.9911 | 0.9904 | 0.9900 |
| Sailboat   | 0.9907 | 0.9904 | 0.9895 | 0.9900 |
| Splash     | 0.9888 | 0.9902 | 0.9899 | 0.9897 |
| Average    | 0.9905 | 0.9906 | 0.9901 | 0.9894 |
Table 4. NC results of extracted watermark image (Gaussian noise addition).

| Image     | R    | G    | B    | Y    |
|-----------|------|------|------|------|
| Airplane  | 0.5661 | 0.5878 | 0.5495 | 0.7499 |
| Lena      | 0.5945 | 0.6079 | 0.6110 | 0.7625 |
| Lichtenstein | 0.6049 | 0.6048 | 0.6365 | 0.7723 |
| Peppers   | 0.6303 | 0.6349 | 0.6119 | 0.7811 |
| Sailboat  | 0.6005 | 0.6176 | 0.6012 | 0.7599 |
| Splash    | 0.5809 | 0.6483 | 0.6419 | 0.7501 |
| Average   | 0.5962 | 0.6169 | 0.6087 | 0.7626 |

Table 5. NC results of extracted watermark image (JPEG Compression attack).

| Image     | R    | G    | B    | Y    |
|-----------|------|------|------|------|
| Airplane  | 0.3788 | 0.4529 | 0.3574 | 0.7564 |
| Lena      | 0.3983 | 0.4704 | 0.4002 | 0.7830 |
| Lichtenstein | 0.4244 | 0.4847 | 0.4409 | 0.8100 |
| Peppers   | 0.4522 | 0.4857 | 0.4078 | 0.8086 |
| Sailboat  | 0.3866 | 0.4528 | 0.3943 | 0.7712 |
| Splash    | 0.3895 | 0.5123 | 0.4708 | 0.8175 |
| Average   | 0.4050 | 0.4765 | 0.4119 | 0.7911 |

Table 6. NC results of extracted watermark image (JPEG 2000 Compression attack).

| Image     | R    | G    | B    | Y    |
|-----------|------|------|------|------|
| Airplane  | 0.7305 | 0.8295 | 0.7007 | 0.8786 |
| Lena      | 0.652 | 0.748 | 0.7187 | 0.8312 |
| Lichtenstein | 0.6342 | 0.7063 | 0.6505 | 0.7887 |
| Peppers   | 0.6376 | 0.7068 | 0.569 | 0.7628 |
| Sailboat  | 0.5744 | 0.6759 | 0.5465 | 0.7239 |
| Splash    | 0.7684 | 0.8447 | 0.7288 | 0.9056 |
| Average   | 0.6662 | 0.7519 | 0.6524 | 0.8151 |

Based on the robustness test results presented in Table 2 to Table 5, it appears that the NC value in extraction without attack presented in Table 2, the color space Y cannot produce a perfect value, this is due to the process of converting color space from RGB to YCbCr which causes slight changes to the watermarked image. In contrast to the color space Y, the color space R, G and B can be extracted perfectly, namely with the NC value 1. In Table 3 the NC value of the watermark image is extracted after being given an SS noise attack which returns the NC value in the Y color space has the lowest value, this is because the SS noise attack makes dominant changes to certain pixels, coupled with the color space conversion process. In Table 4 the watermark extraction values are presented after a Gaussian attack, this time the color space Y has the strongest resistance, the NC value difference is quite a lot, which is around 0.15. In Table 5 and Table 6 the Y color space also has the most dominant resistance where the NC gap is even greater, which is around 0.3 for JPEG compression attacks and around 0.05 to 0.15 in JPEG 2000 compression attacks. Based on this it can be concluded as a whole, the color space Y has the best resistance compared to other color spaces. This is also in accordance with the color theory described in the research [14], that is, the core of image information is stored in the Y color space, so the compression process is maximized in the Cb and Cr color spaces. As for the RGB color space, each color space is compressed with the same relative portion. The results of this
test are also quite similar to the research conducted in [7,8], where the Y color space is also superior in general robustness aspects in the image watermarking frequency domain.

6. Conclusions
This research aims to analyze and test the performance of the CRT image watermarking method, testing based on the importance of measuring the quality of watermarked images on color images, as well as their effect on various color spaces. Based on the test results it is proven that the color space model greatly affects the performance and quality of watermarked images. This is very different when compared to grayscale images that only have one color space with a depth of 8bit, where all image information is embedded in one color space. While the color space model in color images varies greatly, especially in the RGB and YCbCr color space models. The RGB model stores information with the same relative distribution in each color space, while YCbCr stores the core information of the image in the Y color space, so modification of the Y color space must be done wisely to get optimal watermarked image quality. Based on the test results, it is proven that the imperceptibility aspect is better in the RGB color space, whereas to get better robustness you can choose the Y color space by first converting to the YCbCr model.

7. References
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