私 立 東 海 大 學 資 訊 工 程 研 究 所

碩士論文

指導教授：林祝興 博士

Dr. Chu-Hsing Lin

共同指導教授：劉榮春 博士

Dr. Jung-Chun Liu

植基於伽瑪校正的廣泛半可見可視性浮水印技術

A Comprehensive Unseen Visible Watermarking Scheme Based on Gamma Correction

研究生：鍾蓉蓉

(Jung-Jung Chung)

中 華 民 國 九 十 九 年 六 月

Abstract

With the advent of the digital era, lots of files are stored in digital formats for quick and easy access. Documents stored as digital format have become the trend, and how to effectively prove the ownership of the digital document has developed into an important research issue. In this thesis, we propose a novel watermark scheme with unique features that consist of useful properties from the visible watermarking and invisible watermarking schemes. In this work, originally invisible patterns carrying metadata, or the watermark, can be revealed by the gamma correction method or by adjustment of saturation of the stego-image. One salient characteristic of the proposed watermark scheme is that we can obtain a stego-image similar to the cover image that is hard to tell them apart by the naked eye, however the unseen embedded watermarks can be revealed by adjusting the viewing angle. We embed unseen visible watermarks in the cover image by adjusting saturation values in the HSV model, a common cylindrical-coordinate representation of points in the RGB color model. The embedded watermark is revealed in the place where significant variances are found among neighboring pixels. Instead of mere binary image, the embedded watermark adapts its color according to the background color of the original cover image to have a better hidden effect. Also, based on ratios of R, G, and B values, we can adaptively adjust the strength of the watermark to retain the visual quality of the stego-image. As demonstrated by the experimental results, the PSNR values of the stego-image are more than 40 dB, sometimes even as high as 50 dB.

Keywords: Data hiding, Gamma Correction, *HSV* model, Saturation, Binary images.

中文摘要

隨著數位時代的來臨，越來越多的檔案是透過數位化方式儲存，這種方法更是方便與快速。數位化的儲存方式儼然已成為趨勢，但要如何證明此份文件的所有權已成為重要的研究議題。在本論文中，我們提出有別於一般的數位浮水印技術，它擁有可視性浮水印與不可視性浮水印的特性。我們所提出的方法，於一般的情況下，用來傳遞多媒體數位內容的詮釋資料 (Metadata) 或浮水印經由伽瑪校正 (Gamma Correction) 或飽和度的調整，便可將隱藏的浮水印顯示出來。提出的方法有個顯著的特點，嵌入浮水印後的圖 (Stego-images) 與原始圖片 (Cover image) 差異不大，人眼難以察覺，但調動可視角度後，即可顯示隱藏的浮水印。我們嵌入半可見可視性的浮水印於原始圖片是調整 *HSV* 模型中的飽和度 (Saturation)。*HSV* 模型是用來表示 *RGB* 色彩模型中的圓柱座標點。利用被嵌入範圍與週遭像素值的變化，可將浮水印顯示出來。被嵌入的浮水印可隨著圖片背景的顏色而去改變，不再只是單純的二元影像，所以擁有極高的隱藏效果。而且可以依照嵌入範圍內 *R, G* 和 *B* 的比例調整其浮水印的強度可保留原有的可視品質。由實驗結果得知，Stego-images 的 PSNR 值可超過 40 dB，甚至高達 50 dB。

關鍵字：資料隱藏、伽瑪校正、*HSV* 模型、飽和度、二元影像

致謝

在東海資工研究所的這兩年的日子裡，首先感謝我的家人 – 父親、母親、大哥與二哥，雖然我離家鄉是這麼的遙遠，但還是能感受到你們的溫暖與關心，誠心的感謝你們的支持與鼓勵。同時，也誠摯的感謝兩位指導教授 – 林祝興博士與劉榮春博士，在這些日子的指導與協助，讓我的碩士求學生涯可以順利進行與完成。在此也要感謝蓉蓉碩士班口試委員：張隆池教授與江憲坤教授，由於教授們的指導與叮嚀，讓這篇碩士畢業論文能更加完整。

感謝東海資訊安全實驗室的夥伴們，與慶儒、煒程、浩天、宗哲共同熬過這兩年的碩士生涯，能一同參加口試一起順利畢業。也謝謝美君學姊、建廷學長與志捷學長在我剛踏入研究所這陌生的環境時給了我許多的幫助。也特別感謝鎮宇學長對研究方向的指教與協助。

在這兩年的日子裡，也感謝 DMKFS 的各位摯友們，常常因為實驗室的忙碌而找不出時間與你們相聚，謝謝你們的包容與鼓勵，雖然大家現在各有自己的工作或學業分處於不同的角落，但依然能維持我們深厚的友誼。還有，謝謝郁屏與宇真平時的關心，讓我能平緩原本緊繃的神經。

再次感謝我的家人、師長及親友們，誠摯的感謝你們的支持、包容、鼓勵與協助，讓我能順利的完成碩士學位，在此蓉蓉獻上最高的心意與感謝。

最後，我要把這篇論文獻給我最摯愛的家人 – 父親、母親、大哥與二哥。

鍾蓉蓉 謹上 2010/7

Contents

Abstract 2

中文摘要 3

致謝 4

Contents 5

Figure List 7

Table List 8

Chapter 1 Introduction 9

Chapter 2 Background 11

2.1 Digital watermarking 11

2.1.1 Visible watermark 12

2.1.2 Invisible watermark 13

2.1.3 Unseen visible watermarking (UVW) 15

2.2 HSV color space 16

2.2.1 Hue 17

2.2.2 Saturation 18

2.2.3 Value 19

2.3 Peak signal-to-noise ratio (PSNR) 19

2.4 Unseen visible watermark scheme 20

Chapter 3 Proposed Scheme 24

3.1 Watermark embedding process 24

3.1.1 Gamma correction 26

3.1.2 The largest gradient 27

3.1.3 De-noising 28

3.1.4 Select embedding position and region 28

3.1.4.1 Embedding position 29

3.1.4.2 Embedding Region 29

3.1.5 Termination of the De-noising Operation 30

3.1.6 Finding the *MAX* of pixels in the embedding region 30
3.1.7 Pixels embedding technique 31
3.2 Watermark extracting process 32
3.2.1 Gamma correction method 32
3.2.2 Image processing software 33
3.2.3 Naked eyes identification 33
Chapter 4 The Experimental Results 34
4.1 Embedding watermark 34
4.1.1 Show the embedding region 35
4.2 Watermark Displaying Methods 35
4.2.1 Gamma correction method 36
4.2.2 Image processing tools method 36
4.2.3 Changing viewing angle of the LCD method 36
4.3 The extracted watermark 38
4.3.1 Various types of cover images to embed and extract watermarks 38
4.4 Robustness of the embedded watermark 40
4.4.2 Print-photocopy-scan attack 42
4.4.3 Contrast attack 43
4.4.4 Sharpen attack 44
4.4.5 Emboss attack 45
4.4.6 Spherize attack 46
4.4.7 Comparison of CUVW and UVW schemes under various attacks 47
Chapter 5 Conclusions 48
Bibliography 49

Figure List

Figure 1: Image with visible watermark 12
Figure 2: Image embedded with the invisible watermark.................. 14
Figure 3: HSV color space 17
Figure 4: Flowchart of CUVW scheme 25
Figure 5: The image after the gamma correction reveals with more detailed parts 26
Figure 6: The binary watermark... 34
Figure 7: The original image... 35
Figure 8: The extracted watermark 38

Table List

Table 1: The analysis and features of the visible watermark 13
Table 2: The analysis and features of the invisible watermark 14
Table 3: The analysis and features of the unseen visible watermark .. 16
Table 4: Description of the original image 25
Table 5: Description of the watermark 25
Table 6: The experimental results 37
Table 7: Embedding watermark in various types of images 39
Table 8: The experimental results of rotation attack 41
Table 9: The experimental results of print-photocopy-scan attack 42
Table 10: The experimental results of contrast attack 43
Table 11: The experimental results of sharpen attack 44
Table 12: The experimental results of emboss attack 45
Table 13: The experimental results of spherize attack 46
Table 14: Comparison robustness of CUVW with UVW under attacks 47

Chapter 1
Introduction

Network is essential to the modern life. People are accustomed to sending email or transferring multimedia information with each other. But some issues, such as tampering and illegal distribution, cannot be overlooked. To overcome these drawbacks, the watermark technique is applied to hide metadata into multimedia, where the so-called metadata contains useful information relating to the multimedia file.

In this thesis, we propose a Comprehensive Unseen Visible Watermarking (CUVW) scheme based on gamma correction to embed the watermark into the original image. The stego-image looks the same as the original image in normal viewing angles, but the embedded watermark can be revealed and become visible in particular viewing angles. Also, we can apply some image intensity enhancement methods to reveal or retrieve the embedded watermark.

Instead of black and white binary image, by adjusting saturation in the HSV color space, a color watermark is obtained and it can change its color following the background image. The color watermark intermingles naturally with the original image. It looks smooth and does not degrade image quality of the cover image as much as a binary watermark would do.

The organization of the rest of this thesis is as follows. Chapter 2 gives overviews of watermark techniques, related background information such as HSV and RGB color models, and the unseen visible watermarking method. Chapter 3 describes the methods to find the embedding area, to adjust pixel values of the watermark, and to embed the watermark into the cover image. Chapter 4 shows the experiment results of our scheme against some attacks. Finally, we conclude in Chapter 5.

Chapter 2
Background

In this chapter, we will overview the digital watermark technologies, introduce of the HSV color model and its applications, and an unseen visible watermark scheme proposed by Huang et al. for auxiliary information delivery via visual contents.

2.1 Digital watermarking

With the advent of the digital age, traditional media such as books, newspapers, audio and video tapes, are transformed and stored in digital formats. It is convenient and fast to duplicate and transmit digital multimedia. Since digital data have properties such as easy storage, duplication, modification, and transmission, numerous unauthorized digital files are offered freely in the Internet. To solve this problem, we can add additional information, or digital watermarks, on original personal works for proof of ownership.

Digital watermarking [1] means the technique to embed information in digital cover data. To apply the digital watermarking technology, different types of watermarks, with different advantages and disadvantages, are used in different occasions to prove the legitimacy of the copyright owner and protect intelligent property rights.

In recent years, as intellectual property right becomes important issues, many researchers have proposed various watermarking methods to defend violation to it. According to requirement of applications, one can select appropriate digital watermark technology for his task.

In terms of visual effect, the digital watermark marks can be divided as visible, invisible, and unseen visible. We will explain these technologies in detail in this section.

2.1.1 Visible watermark

Visible watermarking technology [2][3][4][5] indicates that the watermark can be seen by human eyes, as shown in Figure 1. It does not require any computation or image processing to recognize the owner and its information. It is mainly applied on the declaration of copyrights of the owners and to prevent illegal use of their digital property. However, it causes distortion of the original images, and it is easily removed or tampered by existing image processing tools. Table 1 illustrates the analysis and features of the visible watermark.

Figure 1: Image with visible watermark

Table 1: The analysis and features of the visible watermark

Visible Watermark	
Features	1. The watermarks directly cover areas of the cover image. 2. To enhance ownership. 3. Trademarks and logos are used mostly as watermarks.
Advantage	1. Easy identification. 2. Fast processing.
Disadvantage	1. It can be destroyed easily. 2. It reduces the visual quality of the cover image.

2.1.2 Invisible watermark

The main characteristic of invisible watermark technology is that the embedded watermark cannot be recognized directly by human eyes [6][7][8]. Therefore, it has more privacy, cannot be removed easily, and so it has higher value for applications. This technology can be also applied in data hiding to hide the ownership information into the digital documents for a legal owner. Compared with the visible watermark, the embedded watermark needs to be retrieved first to use as evidence when disputing the ownership, so this method belongs a passive protection category. Figure 2 shows a cover image embedded with the invisible watermark.

Figure 2: Image embedded with the invisible watermark

But invisible watermark technology needs more stringent requirements than visible watermarking technology, and it must be resistant to various destruction techniques. Since when disputation of ownership occurs, hidden information, or the watermark, inside the attacked stego-image needs be retrieved and reconstructed accurately to use as evidence. Table 2 lists the analysis and features of the invisible watermark.

Table 2: The analysis and features of the invisible watermark

Invisible watermark	
Features	1. The most used watermarking method. 2. There are commercial considerations and requirements. 3. Use of the characteristics of the human visual system.
Advantage	Do not reduce the visual quality of the cover data.
Disadvantage	After destroying by image processing the original content may be modified and so the embedded watermark can not be retracted correctly.

2.1.3 Unseen visible watermarking (UVW)

The unseen Visible Watermarking scheme (UVW) [9] was proposed by Huang et al. in 2007 for auxiliary information delivery via visual contents. The hidden watermark can be revealed by appropriate operations, for example, one can inspect the screen in different angles such that the unseen watermark can be directly recognized by the human visual system.

The UVW method solves the problem that to see the embedded watermark in the invisible watermark technology one needs to apply in advance the watermark extraction process. The UVW method can embed information secretly and it does not affect the visual quality in normal viewing angles, thus it has very practical value in real applications.

Since the UVW method is still a very novel technology, there are not yet many studies on it. We believe the UVW method has potential to be used in many applications because that it possesses both characteristics of the visible watermark and invisible watermark. Table 3 illustrates the analysis and features of the unseen visible watermark.

Table 3: The analysis and features of the unseen visible watermark

Unseen Visible Watermarking	
Features	1. The most novel watermark embedding technology. 2. Use of the characteristics of the human visual system. 3. Have high practical value.
Advantage	1. Do not reduce the visual quality of the cover data. 2. Without extra watermark extraction process, the hidden watermark can be revealed. 3. Have both the characteristics of the visible and invisible watermarks.
Disadvantage	Do not have strong resistant against many watermark attacks at present.

2.2 HSV color space

Color has three factors: red (R), green (G) and blue (B). We denote the maximum value of these three factors as MAX, and, the minimum value as MIN. The HSV model is a common cylindrical-coordinate representation of points in the RGB color model. HSV color space [10] has three basic color attributes: hue, saturation, and value. Figure 3 shows HSV color space. The following introduce the three attributes separately.

HSV Color space is more consistent with the human visual system than the RGB color model, so it is applied on many image processing tools (e.g. Photoshop).

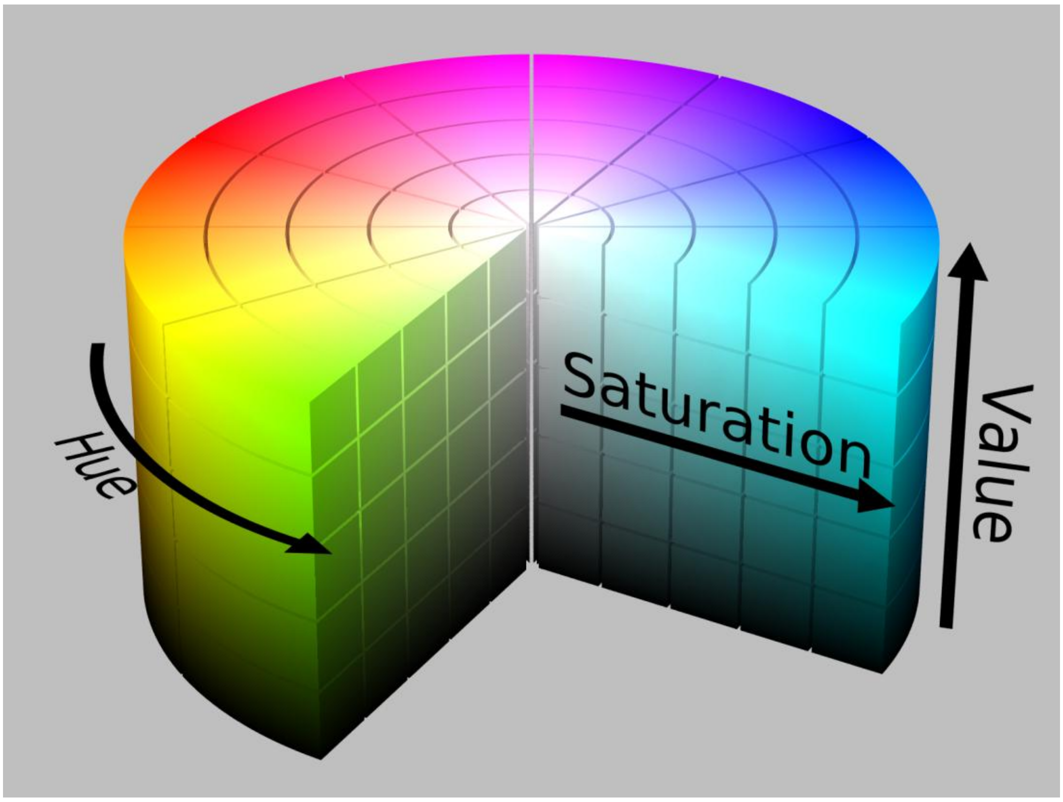


Figure 3: HSV color space

2.2.1 Hue

Hue [11] is the basic attribute of color, and commonly name of color refers to it. When objects illuminated by lights of different wavelength they are perceived by the human eyes as different colors (e.g. blue, green, and red). Hue can be composed of a color ring representing a range in degrees of $0° \sim 360°$.

Different angles express different colors. The following expressions are used for the hue:

$$H = \begin{cases} \left(6 + \dfrac{G - B}{MAX - MIN}\right) \times 60°, & if\ R = MAX \\ \left(2 + \dfrac{B - R}{MAX - MIN}\right) \times 60°, & if\ G = MAX \\ \left(4 + \dfrac{R - G}{MAX - MIN}\right) \times 60°, & if\ B = MAX \end{cases} \tag{1}$$

2.2.2 Saturation

Saturation [12] is the concentration of color, a higher value of it means closer to the primary colors, otherwise, closer to white. So, to achieve the effect of light color, low values of saturation are used. Saturation has relations with light strength and the intensity distribution of wavelength. The highest saturation can be achieved by single-wavelength light (e.g. laser light). With same wavelength distribution, the strong light has higher saturation value than the weak light. The following expression is used for saturation:

$$S = \frac{MAX - MIN}{MAX} \tag{2}$$

From above expression, we find that the saturation value is a percentage dependent of the *MAX* value. This aspect is used later in our proposed scheme.

2.2.3 Value

Value is the intensity of color. Different colors have distinct values. The value can be reduced to have the dark effect. If the value is adjusted to zero, any color will become black. The following expression is used for the value:

$$V = MAX \tag{3}$$

From the above formula, we observe that in HSV color space, value represents the maximum value of R, G and B.

2.3 Peak signal-to-noise ratio (PSNR)

Peak Signal-to-Noise Ratio (PSNR) [13] is computed between original image and stego-image to measure the quality of the stego-image. The higher PSNR value means that the stego-image is more similar to the original image. The PSNR is calculated as below:

$$PSNR = 10 \times \log_{10} \frac{255^2}{MSE} \quad (unit : dB) \tag{4}$$

Where the mean-squared error (MSE) between the stego-image ($m \times n$) and the original image ($m \times n$) is calculated by the following equation:

$$MSE = \left(\frac{1}{m \times n}\right) \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \left(\alpha_{ij} - \beta_{ij}\right)^2 \tag{5}$$

Where α_{ij} stands for pixel value of the original image, and the β_{ij} stands for pixel value of the stego-image.

2.4 Unseen visible watermark scheme

Unseen visible watermark scheme was proposed by Huang et al. in 2007. The UVW method adjusts intensity value of the original image to embed information by using the variance of the brightness and darkness to achieve the effect.

However, this method works only for dark images; besides, since the embedded blocks must belong to the same color family, when the watermark is embedded, it does not conceal well enough. In the following we describe the UVW method in detail.

The pixel values of the original image I are defined as:

$$I(x, y), 1 \le x \le w_I, 1 \le y \le h_I, 0 \le I(x, y) \le 255 \tag{6}$$

And the binary values of the watermark image W are defined as:

$$W(x, y), 1 \le x \le w_W, 1 \le y \le h_W, W(x, y) \in \{0, 1\} \tag{7}$$

Step 1: Gamma Correction

$$q = c \times p^{\gamma} \tag{8}$$

Where q is the output intensity, p is the input intensity, and c and γ are constants. Note that γ value is less than 1.

The intensity mapping function is expressed as:

$$F(i), 0 \le i \le 255, 0 \le F(i) \le 255 \tag{9}$$

Step 2：Best Level Selection

$$i^{*} = \arg\max \nabla F(i) \tag{10}$$

Where i^{*}, the best intensity, will be used to embed with the watermark.

Step 3：De-noising

$$I_{k}^{'} = Q(I, \delta_{k}), \delta_{k} \le \delta_{\max} \tag{11}$$

Where $I_{k}^{'}$ is the output after performing k times de-noising operations, and δ_{k}, limited by an upper bound $\delta_{\max}$, denotes the k times repeated de-noising operation.

Step 4：Selection of the Embedding Region

$$\left(x^*, y^*\right) = \arg\max_{x_0, y_0} \sum_{x=x_0}^{x_0+w_W-1} \sum_{y=y_0}^{y_0+h_W-1} | I_k^{'}\left(x, y\right) - i^* | \tag{12}$$

The position of the embedding area is selected to obtain a maximum sum of absolute differences between the de-noised intensity $I_k^{'}\left(x, y\right)$ and the best intensity i^*.

Step 5：The de-noising operation will not be terminated if the following condition is satisfied:

$$\sum_{x=x_0}^{x_0+w_W-1} \sum_{y=y_0}^{y_0+h_W-1} C\left(I_k^{'}\left(x, y\right) - i^*\right) \leq w_W \times h_W \times T \tag{13}$$

$$where\, C(t) = \begin{cases} 1, & if\ t = 0, \\ 0, & otherwise \end{cases}$$

The de-noising operation will be repeated until the sum of points with intensity value equal to the best intensity i^* is less than a threshold T multiplied by $w_W \times h_W$.

Step 6：Decision of the Watermark Strength

$$\Delta = \max(1, \sigma_S), \qquad (14)$$
$$where\ S = \{ I_k^{'}(x, y) \mid x_0 \le x < x_0 + w_W,\ y_0 \le y < y_0 + h_W \}$$

The degree of correction Δ is heuristically set to 3.

Step 7：Bit Embedding

$$\hat{I}(x, y) = \begin{cases} I_k^{'}(x, y) + \Delta, & W(x - x_0 + 1, y - y_0 + 1) = 1 \\ I_k^{'}(x, y), & otherwise \end{cases} \qquad (15)$$
$$x_0 \le x < x_0 + w_W,\ y_0 \le y < y_0 + h_W$$

The embedded image $\hat{I}$ is produced after performing the de-noising operation and adding watermark strength to the intensity.

Chapter 3
Proposed Scheme

In Chapter 3, we describe the proposed Comprehensive Unseen Visible Watermarking (CUVW) scheme, which is based on UVW [14]. The CUVW scheme retains merits of the UVW scheme that the embedded watermark can be revealed and sensed by the human visual system without the overhead to apply image processing to retrieve it. On normal viewing angles, the stego-image looks like the original one, but from certain angles, the embedded watermark is revealed clearly.

The CUVW scheme has a few extra features. After being processed by using the CUVW scheme, the embedded watermarks can follow the background color of the original images; moreover, by exploiting the difference of saturation, the depth of color of the embedded watermark can changed. In the following sections we will describe the CUVW scheme in detail.

3.1 Watermark embedding process

Our method uses the gamma correction for a better hidden effect. The flowchart of the CUVW scheme is shown in Figure 4. In the flowchart, the different parts of CUVW from UVW are highlighted by dashed boxes. We adopt UVW scheme in selecting the watermark embedding position and region. Table 4 gives descriptions of the original image *I*, and Table 5, the binary values of the watermark image *W*.

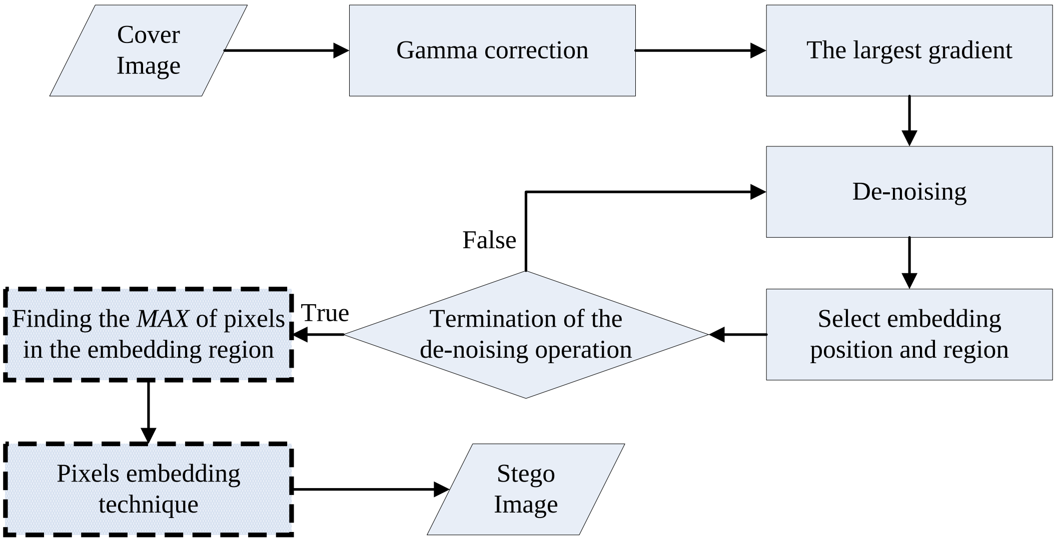


Figure 4: Flowchart of CUVW scheme

Table 4: Description of the original image

Original image			
Original image	I	**The scope of the original image**	$0 \le I(x, y) \le 255$
Length	I_l	**Length range**	$1 \le x \le I_l$
Width	I_w	**Width range**	$1 \le y \le I_w$

Table 5: Description of the watermark

Binary values of the watermark image			
Watermark image	W	**The scope of the watermark**	$0 \le W(x, y) \le 1$
Length	W_l	**Length range**	$1 \le x \le W_l$
Width	W_w	**Width range**	$1 \le y \le W_w$

3.1.1 Gamma correction

Many display devices possess power-law characteristics for the input and output intensity:

$$N_{output} = c \times N_{input}{}^{\gamma} \qquad (16)$$

Where c and γ are constants, N_{input} is input intensity, and N_{output} is output intensity. For common display devices, the γ value usually lies in between 1.8 and 2.5 to adjust the darker part to a proper intensity. Therefore, the so-called gamma correction method [15] is usually applied to correct this power-law phenomenon.

We can use gamma correction to increase the intensity values; the surface parts of the original image are revealed with more details after this action, as shown in Figure 5.

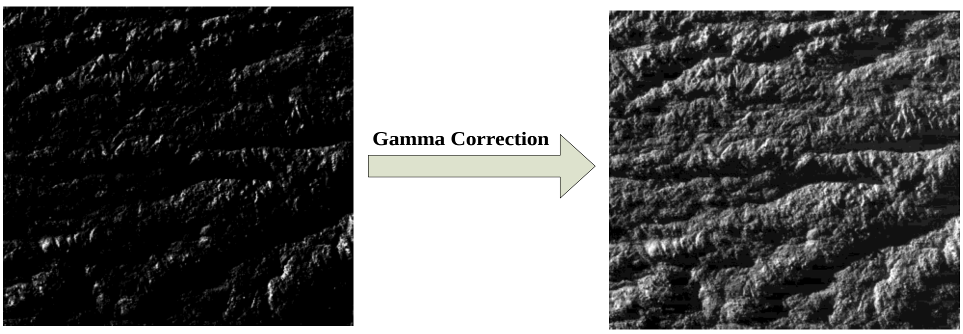


Figure 5: The image after the gamma correction reveals with more detailed parts
* Refer to http://www.nasa.gov/home/index.html

If the overall intensity of the image is increased, the color range of the image is expanded and makes it easier to select the watermark embedding region. When the γ value is less than 1, the output intensity value is higher than its corresponding input intensity value; therefore, we set the γ value to be less than 1.

The gamma correction function G with $\gamma < 1$, is constrained by:

$$G(i), 0 \le i \le 255, 0 \le G(i) \le 255 \quad (17)$$

3.1.2 The largest gradient

The best intensity i^* representing argument i with the greatest gradient as follows:

$$i^* = \arg\max_i \nabla G(i) \quad (18)$$

The best intensity i^* represents the parameter i that can be substituted in the $\nabla G(i)$ function to produce the largest gradient value. After performing gamma correction on the original cover image, the watermark will be embedded in the position with the largest gradient.

3.1.3 De-noising

Since gamma correction can amplify noises within the original images, before the watermark embedding process, we have to do the de-noising operation.

In order to ensure that the visual quality will not reduce seriously, de-noising is carefully controlled by a parameter δ_j according to the following formula:

$$I_j^{'} = D(I_G, \delta_j), \quad \delta_j \leq \delta_{\max} \tag{19}$$

Where δ_j value is used to perform the *j*th de-noising operation and is limited by an upper bound $\delta_{\max}$, which is manually selected. I_G is the cover image after gamma correction. $I_j^{'}$ is the cover image after de-noising operation, and it is used to embed the watermark.

3.1.4 Select embedding position and region

After performing de-noising operation on the original image, we get $I_j^{'}$, which is used to find the embedding position and region to embed the watermark.

3.1.4.1 Embedding position

We use a window block with the same size of the watermark. The most suitable embedding position P is selected to have a maximum sum of absolute differences between intensity $I_j^{'}$ and the best intensity i^* as expressed in the following:

$$P = \arg\max \sum_{x=x_0}^{x_0+l-1} \sum_{y=y_0}^{y_0+w_w-1} | I_j^{'}(x, y) - i^* | \tag{20}$$

3.1.4.2 Embedding Region

After the embedding position is selected, we define the embedding region R, which has the same size of the watermark, by the following conditions:

$$R = \left\{ I_j^{'}(x, y) \mid x_0 \le x \le x_0 + W_l - 1,\ y_0 \le y \le y_0 + W_w - 1 \right\} \tag{21}$$

3.1.5 Termination of the De-noising Operation

The de-noising operation is terminated follows the judgment function *S*,

$$S = \sum_{x=x_0}^{x_0+W_l-1} \sum_{y=y_0}^{y_0+W_w-1} D\left(I_j^{'}(x, y) - i^*\right) \le W_l \times W_w \times T$$

$$D(k) = \begin{cases} 1, if\ k = 0 \\ 0, otherwise \end{cases} \tag{22}$$

Where *T* is a predefined threshold. The judgment function *S* is established if the percentage of pixels with intensity equal to the best intensity i^* is less than *T*. When the above statement is established, we terminate the de-noising operation and find the best watermark embedding position.

3.1.6 Finding the *MAX* of pixels in the embedding region

We use *MAX* to denote the maximum value of the three factors of color: red (R), green (G), and blue (B) in the RGB color model, and *MIN* to denote the minimum value of them. Since the saturation value is a ratio of *MAX*, when the embedding region is found, the *MAX* value of each pixels within this region are used as an index. When a point has same *R*, *G*, *B* values then the *MAX* is assigned to *R*, *G*, or *B* if it has the highest count of being indexed as *MAX* in the four neighboring top, bottom, left, and right points. In this way, an index is used to record maximum of R, G or B values as expressed in the following equation :

$$MAX = \max(R, G, B) \tag{23}$$

Within the watermark embedding region, based on the index information, we are able to adjust intensity of each pixel to embed the watermark.

3.1.7 Pixels embedding technique

The embedded watermark is revealed due to the abrupt variance or difference of intensity because we adjust intensity of each pixel according to its index in the watermark embedding region.

For a binary image used as the watermark, if the pixel value is 1, the intensity of the watermark is set to be α; otherwise, set to be β. In order to create difference to reveal the embedded watermark, we have $\alpha > \beta$.

If the sum of the intensity of $I_j^{'}$ and the watermark strength is greater than 255, we will replace the addition operation with subtraction operation, as expressed in the following equation:

$$\tilde{I}(x,y)=\begin{cases} I_j^{'}(x,y)-\omega, & if\ \left(I_j^{'}(x,y)+\omega\right)>255 \\ I_j^{'}(x,y)+\omega, & otherwise \end{cases}$$

$$\begin{cases} \omega=\alpha, & if\ W(x-x_0+1,\ y-y_0+1)=1, \\ \omega=\beta, & otherwise \end{cases} \tag{24}$$

Also, we can adaptively adjust watermark intensity α and β. When the number of R, G, or B indexes exceed a certain proportion of the total indexes, we can adjust the watermark intensity α and β according to the ratios. That is, we assign highest α and β to the one with highest ratio, and so on.

3.2 Watermark extracting process

The embedded watermark can be retrieved or sensed by the following three methods: gamma correction, image processing tools, and the human visual system.

3.2.1 Gamma correction method

Gamma correction can be used to increase intensity of the embedded image and reveal the embedded watermark. After gamma correction, we can directly retrieve the hidden information to claim ownership.

3.2.2 Image processing software

We can load the embedded image by using some image processing software such as Photoshop and use the saturation adjustment function to reveal the embedded watermark.

3.2.3 Naked eyes identification

We can exploit characteristic of the LCD screen to reveal the embedded watermark. We output the embedded image into the LCD screen. Then we can adjust the screen angle such that the embedded watermark can be sensed by the human visual system directly. Apparently, the best benefit of using this method is that no extra processing or overhead is needed to extract the embedded watermark.

Chapter 4
The Experimental Results

In the experiment, the original images are colorful images with 400 × 400 pixels. The binary watermark is a binary image with 160×60 pixels as shown in Figure 6.

Figure 6: The binary watermark

4.1 Embedding watermark

Figure 7 shows an original image. After embedded it with the watermark by the CUVW scheme, we can use gamma correction, image processing tools, or change the viewing angles of the LCD to reveal the watermark. As shown in Table 6, the watermark is no longer a binary image, but instead, become a color image that intermingles well with the background color of the embedded image. We also find that the PSNR of the stego-image in Table 6 (a) is more than 40 dB, sometimes even as high as 50 dB.

Figure 7: The original image
* Refer to http://www.taipei-101.com.tw/index_en.htm

In the following, we will explain in detail for image collections in Table 6.

4.1.1 Show the embedding region

As shown in Table 6 (b) the watermark embedded region, a block of the cloud in the sky, is marked red.

4.2 Watermark Displaying Methods

We use gamma correction, image processing tools and change viewing angles of the LCD to reveal the embedded watermark.

4.2.1 Gamma correction method

After applying gamma correction on the stego-image, the embedded watermark information can be seen clearly, as shown in Table 6 (c).

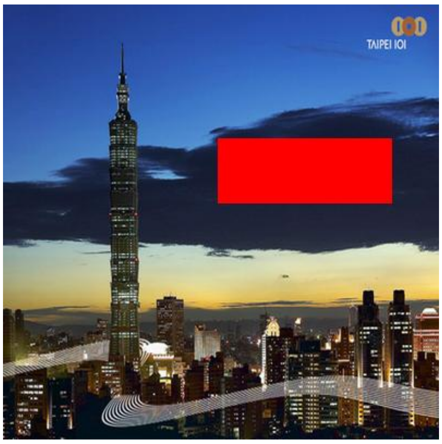
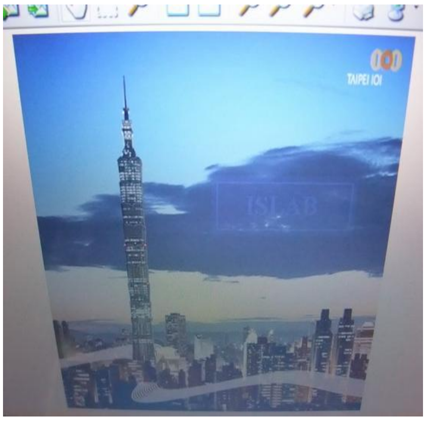
4.2.2 Image processing tools method

We load the stego-image in Photoshop, an image processing tool, and use the saturation adjustment function to reveal the embedded watermark, as shown in Table 6 (d).

4.2.3 Changing viewing angle of the LCD method

Without further image processing, the embedded watermark can be revealed by changing viewing angles of the LCD. In Table 6 (e), under the normal viewing angle of the LCD, the embedded watermark is hidden well and can not be perceived by the eyes. But after adjusting the viewing angle, the embedded watermark is revealed, as shown in Table 6 (f).

Table 6: The experimental results

(a). Stego-image (PSNR=50.250667)	(b). The embedding region
	
(c). After gamma correction	**(d). After image processing tools**
	
(e). In normal viewing angles	**(f). After angle adjustment of LCD**
	

4.3 The extracted watermark

The original watermark is a binary image, but the extracted watermark is changed to be a color image, as shown in Figure 8. It appears that the embedded watermark changes its color according to the background color to have better hidden effect.

Figure 8: The extracted watermark

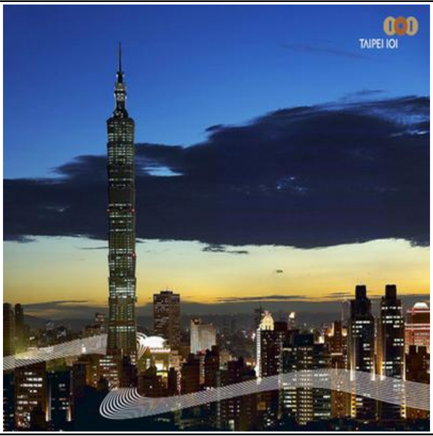
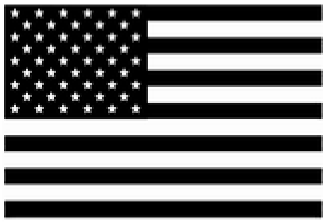
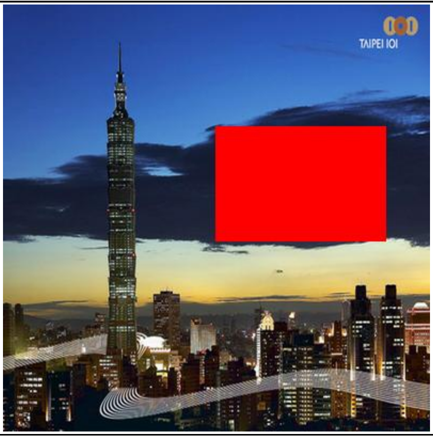
4.3.1 Various types of cover images to embed and extract watermarks

In the following experiments, we use images of various types as cover images. The stego-images, the embedding regions, and the extracted watermarks are tabulated in Table 7 (a)(b)(c). Besides, other watermarks with more complicated patterns are used in experiments, as shown in Table 7 (d).

Table 7: Embedding watermark in various types of images

* Refer to http://eng.taiwan.net.tw/

(a). Stego-image (PSNR = 48.973508)	**Extracted watermark**
	
	Showing the embedding region
	
(b). Stego-image (PSNR = 44.513726)	**Extracted watermark**
	
	Showing the embedding region
	
(c). Stego-image (PSNR = 46.295828)	**Extracted watermark**
	
	Showing the embedding region
	

(d). Stego-image (PSNR = 44.543843)	Embedded watermark
	 * Refer to http://www.whitehouse.gov/ (The binary watermark with 160 × 108 pixels)
Showing the embedding region	**Extracted watermark**
	

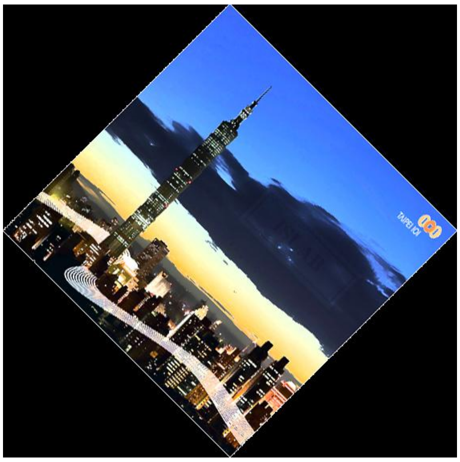
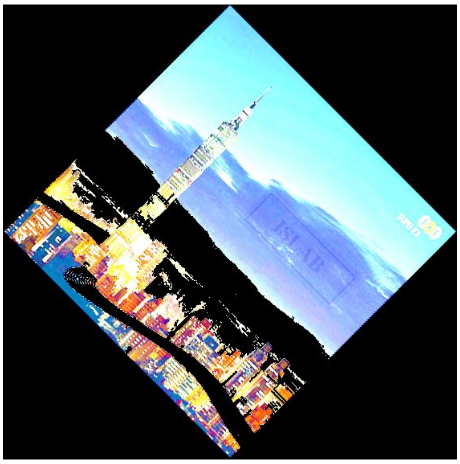
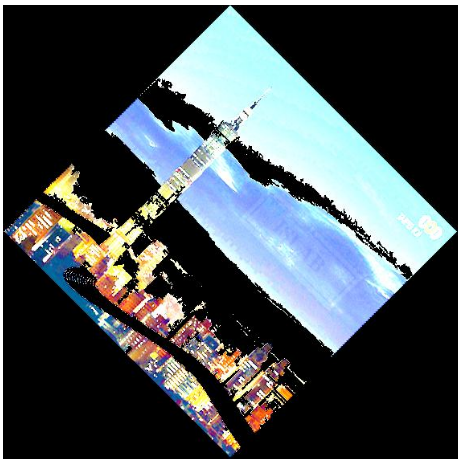
4.4 Robustness of the embedded watermark

To verify the robustness of the CUVW scheme, we launch a series of attack on the stego-images. These image attacks are rotation, print-photocopy-scan, contrast, sharpen, emboss, and spherize. To demonstrate robustness of the CUVW scheme, we compare it with the UVW scheme against same kinds of attack. By performing gamma correction on the attacked stego-image, the invisible watermark can still be revealed if the corresponding watermark embedding scheme is robust against specific attack.

4.4.1 Rotation attack

The stego-images are rotated 45° clockwise after the rotation attack [17], as shown in Table 8. We observe that after gamma correction, the watermark information, embedded by using CUVW scheme, is clearly perceived in the rotated image.

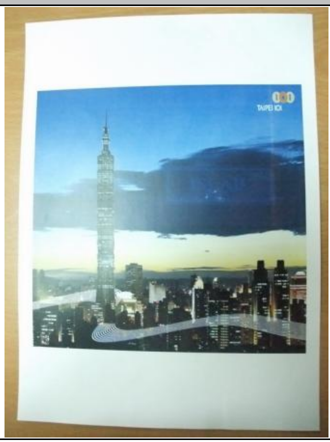
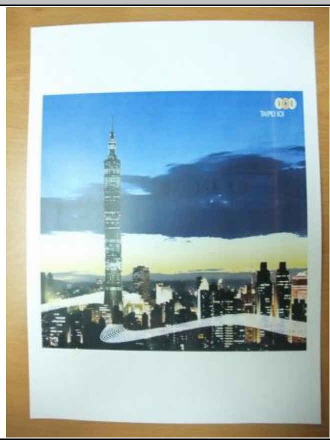
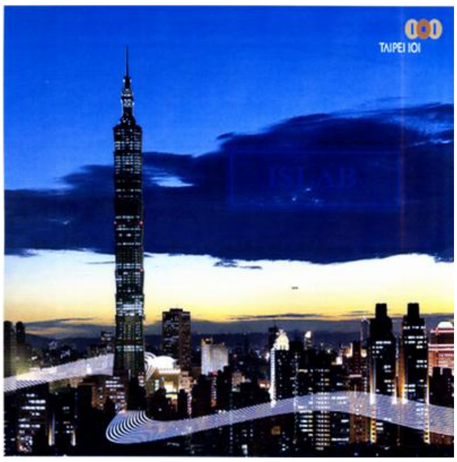
Table 8: The experimental results of rotation attack

	CUVW	UVW
Attacked-image		
Gamma Correction		

4.4.2 Print-photocopy-scan attack

For print-photocopy-scan attack, we first print the stego-image and then scan the printed photocopy. The stego-images after the print-photocopy-scan attack are shown in Table 9. Even after print-photocopy-scan attacks, the extracted watermarks can be identified. The extracted watermark of our scheme is shown clearer than that of the UVW method.

Table 9: The experimental results of print-photocopy-scan attack

	CUVW	**UVW**
Printed Document		
Scanned Document		

4.4.3 Contrast attack

For contrast attack, the contrast parameter is set to +75. The experimental results after contrast attacks are shown in Table 10. We observe that the CUVW scheme is more robust against contrast attacks than the UVW scheme.

Table 10: The experimental results of contrast attack

	CUVW	UVW
Attacked-image		
Gamma Correction		

4.4.4 Sharpen attack

For sharpen attack, the amount is set to 200%, the radius is set to 80 pixels, and the threshold is set to 0 levels.

The experimental results are shown in Table 11. The watermark of our scheme is revealed clearly after gamma correction, but the watermark disappears for the UVW method. We observe that our CUVW scheme can resist sharpen attack but the UVW method cannot.

Table 11: The experimental results of sharpen attack

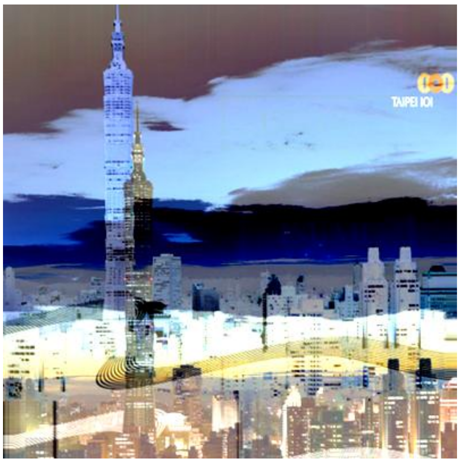
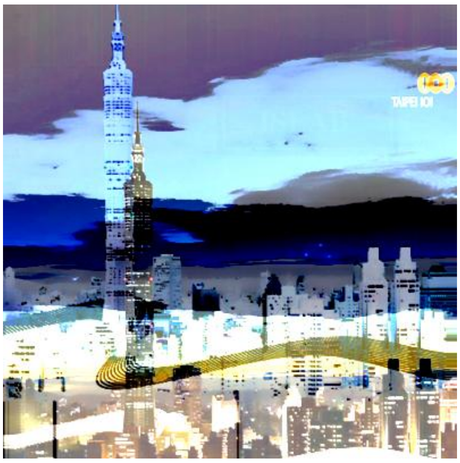
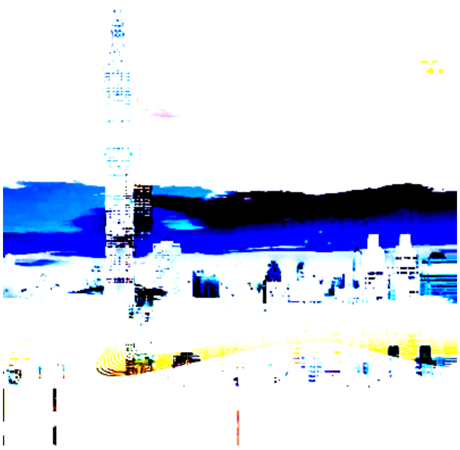
	CUVW	UVW
Attacked-image		
Gamma Correction		

4.4.5 Emboss attack

For emboss attack, the angle is set to $100°$, the height is set to 100 pixels and the amount is set to 100%.

Table 12 shows the experimental results. We observe that the watermark of our scheme is revealed clearer than that of the UVW method.

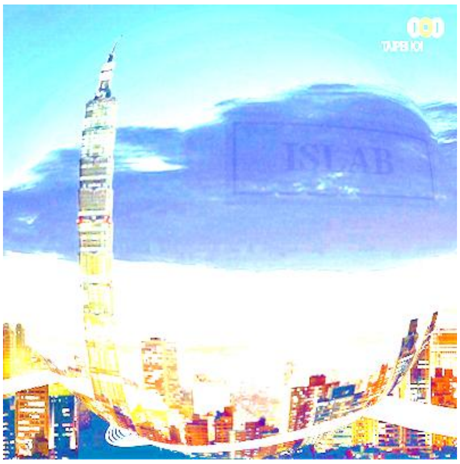
Table 12: The experimental results of emboss attack

	CUVW	**UVW**
Attacked-image		
Gamma Correction		

4.4.6 Spherize attack

For spherize attack, the amount is set to 80%. The experimental results are showed in Table 13. We observe that the watermark of our scheme is revealed clearer than that of the UVW method.

Table 13: The experimental results of spherize attack

	CUVW	UVW
Attacked-image		
Gamma Correction		

4.4.7 Comparison of CUVW and UVW schemes under various attacks

In Table 14, we collect attack results to show our scheme is more robust than the UVW scheme. If the method can resist the indicated attack, the solid dot ● is used; otherwise, the empty dot ○ is used.

We observe that our CVW scheme is more robust than the UVW scheme in many types of attacks:

- Both CUVW and UVW extracted watermarks are robust against the rotation, print-photocopy-scan, and spherize attacks.
- CUVW can resist the contrast, sharpen, and emboss attacks, but UVW cannot.

Table 14: Comparison robustness of CUVW with UVW under attacks

Attacks	**CUVW**	**UVW**
Rotation Attack	●	●
Print-Photocopy-Scan Attack	●	●
Contrast Attack	●	○
Sharpen Attack	●	○
Emboss Attack	●	○
Spherize Attack	●	●

* ●: the method can resist the attack. ○: the method cannot resist the attack.

Chapter 5
Conclusions

In this thesis, we propose a novel Comprehensive Unseen Visible Watermarking (CUVW) scheme. The merit of the proposed CUVW scheme is that without further watermark extraction processes, the embedded metadata can be recognized directly by the naked eye in some easy ways.

We show in the experiments that after embedding watermark by the CUVW scheme, the watermark is invisible under normal viewing conditions. However, we can change the viewing angles of LCD screen, or do image processing operations such as gamma correction, or use saturation enhancement function to reveal the embedded watermark information.

The original watermark is a binary image, but after applying in the CUVW scheme the embedded watermark is changed to a color image that can intermingle well with the background color. The CUVW scheme is very useful in practical situations: the stego-image has a very high PSNR value, above 40 dB or sometimes, as high as 50 dB, since the embedded watermark conceals well. Moreover, we experimental prove that the CVUW scheme is robust against most common attacks.

Bibliography

[1] Yanqun Zhang, "Digital Watermarking Technology: A Review," *Proceedings of International Conference on Future Computer and Communication* (FCC '09), Wuhan, China, Jun. 6-7, 2009, pp. 250-252.

[2] Ying Yang, Xingming Sun, Hengfu Yang, Chang Tsun Li and Rong Xiao, "A Contrast-Sensitive Reversible Visible Image Watermarking Technique," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 19, no. 5, May 2009, pp. 656-667.

[3] Yongjian Hu and Byeungwoo Jeon, "Reversible Visible Watermarking and Lossless Recovery of Original Images," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 16, no. 11, Nov. 2006, pp. 1423-1429.

[4] Han Min Tsai and Long Wen Chang, "A High Secure Reversible Visible Watermarking Scheme," *Proceedings of IEEE International Conference on Multimedia and Expo*, Beijing, China, Jul. 2-5, 2007, pp. 2106-2109.

[5] Hsiang Cheh Huang, Tai Wan Chen, Jeng Shyang Pan and Jiun-Huei Ho, "Copyright Protection and Annotation with Reversible Data Hiding and Adaptive Visible Watermarking," *Proceedings of Second International Conference on Innovative Computing, Information and Control* (ICICIC '07), Kumamoto, Japan, Sep. 5-7, 2007, pp. 292-292.

[6] Khattak F.U., Bais A. and Khawaja Y.M., "An Invisible Dual Watermarking Scheme for Authentication and Copyrights Protection," *Proceedings of*

International Conference on Emerging Technologies (ICET 2009), Islamabad, Pakistan, Oct. 19-20, 2009, pp. 247-251.

[7] Saraju P. Mohanty, Parthasarathy Guturu, Elias Kougianos and Nishikanta Pati, "A Novel Invisible Color Image Watermarking Scheme Using Image Adaptive Watermark Creation and Robust Insertion-Extraction," *Proceedings of Eighth IEEE International Symposium on Multimedia* (ISM'06), San Diego, America, Dec. 2006, pp.153-160.

[8] Das S., Bandyopadhyay P., Paul S., Ray A.S. and Banerjee M., "A New Introduction Towards Invisible Image Watermarking on Color Image," *Proceedings of IEEE International Advance Computing Conference* (IACC 2009), Patiala, India, Mar. 6-7, 2009, pp. 1224-1229.

[9] Shang Chih Chuang, Chun Hsiang Huang and Ja Ling Wu, "Unseen Visible Watermarking," *Proceedings of IEEE International Conference on Image Processing* (ICIP 2007), vol.3, San Antonio, America, Sep. 16- Oct. 19, 2007, pp. III-261-III-264.

[10] Ji Quan Ma, "Content-Based Image Retrieval with HSV Color Space and Texture Features," *Proceedings of International Conference on Web Information Systems and Mining*, (WISM 2009), Shanghai , China, Nov. 7-8, 2009, pp. 61-63.

[11] Jong Won Kim, Jang Gun Jo, Jae Yong Seo, Hyun Chan Cho and Sang Gil Yoo, "Intelligent Hue Control System for Display Panel," *Proceedings of IEEE International Conference on Information Acquisition, 2006,* Shandong, China, Aug. 20-23, 2006, pp. 1197-1201.

[12] Jang J.H. and Ra J.B., "Pseudo-Color Image Fusion Based on Intensity-Hue-Saturation Color Space," *Proceedings of IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems* (MFI 2008), Seoul, Korea, Aug. 20-22, 2008, pp. 366-371.

[13] Zhaohui Cui, Jingliang Fu, Jiwei Liu and Ang Li, "What Statistics is PSNR Related Using JPEG2000," *Proceedings of IEEE Conference on Cybernetics and Intelligent Systems, 2008*, Chengdu, China, Sep. 21-24, 2008, pp. 984-989.

[14] Chun Hsiang Huang, Shang Chih Chuang, Yen Lin Huang and Ja Ling Wu, "Unseen Visible Watermarking: A Novel Methodology for Auxiliary Information Delivery via Visual Contents," *IEEE Transactions on Information Forensics and Security*, vol. 4, no. 2, Jun., 2009, pp. 193-206.

[15] Xu Guan, Su Jian, Pan Hongda, Zhang Zhiguo and Gong Haibin, "An Image Enhancement Method Based on Gamma Correction," *Proceedings of Second International Symposium on Computational Intelligence and Design* (ISCID '09), vol. 1, Changsha, China, Dec. 12-14, 2009, pp. 60-63.

[16] Jun Xiao and Ying Wang, "Semi-Fragile Watermarking Based on Image Gradient," *Proceedings of International Conference on Computational Intelligence and Security* (CIS '08), vol. 1, Suzhou, China, Dec. 13-17, 2008, pp. 285-289.

[17] Guo Juan Xu and Rang Ding Wang, "A Blind Video Watermarking Algorithm Resisting to Rotation Attack," *Proceedings of International Conference on Computer and Communications Security* (ICCCS '09), Hong Kong, China, Dec. 5-6, 2009, pp. 111-114.