การทำภาพพิมพ์ลายน้ำดิจิตอลโดยการปรับแต่งค่าความสว่างในระบบกล้ำความลึกของสัญญาณ

ธำรงรัตน์ อมรรักษา [1] และ รพี พืชพันธ์ [2]
มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี บางมด ทุ่งครุ กรุงเทพฯ 10140

บทคัดย่อ

บทความฉบับนี้ได้นำเสนอวิธีการที่ใช้ฝังสัญญาณลายน้ำดิจิตอลโดยอาศัยการปรับแต่งค่าความสว่างของรูปภาพ นอกจากสัญญาณสีพื้นฐานที่เป็นส่วนประกอบที่อยู่ในรูปภาพ นั่นคือ สีแดง เขียว และน้ำเงิน ซึ่งโดยทั่วไปจะถูกใช้ในการซ่อนสัญญาณลายน้ำดิจิตอลแล้ว สัญญาณความสว่างนับเป็นอีกส่วนประกอบหนึ่งที่ถูกนำมาพิจารณาเพื่อใช้ในการซ่อนสัญญาณลายน้ำดังกล่าว ยิ่งไปกว่านั้นในกระบวนการฝังสัญญาณลายน้ำดิจิตอล เทคนิคการกระจายค่าถ่วงน้ำหนักแบบเกาส์เซียนถูกนำมาประยุกต์ใช้เพื่อเพิ่มคุณภาพของรูปภายหลังจากการถูกฝังสัญญาณลายน้ำ นอกจากนี้ในกระบวนการกู้คืนสัญญาณลายน้ำ เทคนิคการกรองสัญญาณรูปภาพ เช่น การกรองสัญญาณค่าความถี่ต่ำได้ถูกนำมาใช้ในการกู้คืนสัญญาณลายน้ำโดยไม่จำเป็นต้องใช้รูปภาพต้นฉบับ ผลการทดลองได้แสดงให้เห็นถึงประสิทธิภาพที่เพิ่มขึ้น เมื่อมีการประยุกต์ใช้วิธีการที่ได้นำเสนอมา ทั้งในกระบวนการฝังและกู้คืนสัญญาณลายน้ำดิจิตอล

[1] *อาจารย์ ภาควิชาวิศวกรรมคอมพิวเตอร์*

[2] *นักศึกษาระดับบัณฑิตศึกษา ภาควิชาวิศวกรรมคอมพิวเตอร์*

Digital Watermarking Method Based on Luminance Modification in Amplitude Modulation

Thumrongrat Amornraksa [1] and Rapee Puertpan [2]

King Mongkut's University of Technology Thonburi, Bangmod, Toongkru, Bangkok 10140

Abstract

A watermark embedding method based on luminance modification is proposed in this paper. Beside of three color components contained within an image: red, green and blue, which are normally used to carry a watermark signal, the luminance is another component that was considered to convey the watermark signal. Moreover, in the embedding process, a technique based on Gaussian pixel-weighting marks was used to improve the quality of the watermarked image. In the retrieval method, the image filtering techniques such as lowpass filtering were utilized to extract the watermark signal, with no need of original image. The experimental results showed that a higher performance could be obtained when applying our proposed method in both embedding and retrieval processes.

[1] *Lecturer, Department of Computer Engineering.*

[2] *Graduate Student, Department of Computer Engineering.*

1. Introduction

Copyright protection for multimedia data is an important issue since rapid evolution of Internet makes digital media easy to be accessed or distributed throughout the network. As a result, replications of digital media are simple and identical to the original one. A technique called digital watermarks has been then considered as a means for intellectual property right protection of multimedia data. By embedding a digital signature or a unique watermark signal into the media, which indicates the ownership or intellectual property right of multimedia data, the watermark can later be extracted from an illegally distributed copy and then used to identify the creator or the traitor.

The main requirements for digital watermarking are both invisibility to the human eye and robustness to alterations. One of outstanding methods applied the technique of modifying the amplitude of the image's pixel. The method embeds the watermark bits into the blue channel of the image, and then uses average value of cross-shaped neighboring pixels to retrieve those embedded watermark bits. The results showed the acceptable outcome concerning the invisibility and robustness. However, the percentage of watermark bit retrieval was not impressive.

In this paper, a method for watermarking a color image is proposed to yield a higher level of robustness, and simultaneously suppress the perceptibility of the embedded watermark. The embedding process is based on luminance modification, while in the retrieval process, the lowpass filter retrieval is used. The luminance modification is a technique, which manipulating the amplitude of luminance channel according to the watermark's amplitude. To retrieve the embedded watermark bit, the amplitude of the watermarked pixel is differentiated with the value resulted from the lowpass filter of the neighboring pixels to determine whether the watermark bit is one or zero.

We organized the experiments into two parts, the embedding and the retrieval processes. In the experiments, we compared 3 different extracting methods, namely the cross-shaped neighboring pixels, lowpass and median filter retrieval techniques, while in the embedding process, we utilized a technique based on Gaussian pixel-weighting marks on a luminance channel of an image. The performance of the proposed method is evaluated by the improved percentage value of correct retrieved watermark bits.

2. Background

A watermarking procedure based on spread spectrum techniques was proposed by Cox *et al* [1]. The watermark consists of a sequence of independent and identically distributed Gaussian random variables that are added to the perceptually most significant DCT coefficients. Placing the watermark in the perceptually relevant components of the original image provides a high level of robustness against many signal processing techniques aimed at eliminating noise from the image. However, the main limitation of this technique is the need for the original image in the ownership verification process.

Among the earliest work, Bender *et al.* [2] proposed two different approaches to watermark the digital media. The first was a statistical method called "*Patchwork*" and the second called "*texture block coding*". Patchwork randomly chooses *n* pair of image point (a_i, b_i), then increases the brightness of a_i by one unit and decreases the brightness of b_i by one. Text block coding was a visual approach. It hides data within the continuous random texture patterns of a picture. This technique is implemented by copying a region from a random texture pattern found in a picture to an area that has similar texture. This results in a pair of identically textured regions in the image. However, they were sensitive to image cropping and affine transforms, since the spatial reference is fundamental for the correct operation of the decoding algorithm. They were also weak against random additive noise attacks.

In [3], another watermarking method was presented. It is based on the addition in the frequency (DCT) domain of spread spectrum signal shaped by a perceptual mask that guarantees that the hidden signal is invisible. The watermarking process is performed clockwise, but the original image was still required in the verification test. A data hiding scheme based on a similar approach was described in [4]. In this scheme, an alternative spatial domain watermarking technique was suggested. The original image was segmented into blocks, which will be modified by a single bit of the hidden message. For this reason, this data hiding scheme was not robust against cropping attack. However, the original image was not required for information decoding. Similar techniques were applied for authentication and distortion measurement of images [5] and for watermarking the audio signals [6].

Recently, Tsai *et al.* [7] proposed a new watermarking scheme, which incorporates wavelet and spatial transformations. This algorithm utilizes the wavelet multi-resolutional structure to construct the image in frequency components, and the spatial transform to select the location of watermark bits in the embedding process. This method required very few parameters as the side information to extract the watermark. Xia *et al.* [8] described a new multi-resolution watermarking method for digital image. This method is based on the Discrete Wavelet Transform (DWT) in which the watermark signal is first transformed into independent identical distribution (i.i.d.) as Gaussian distribution, and then embedded into the significant component at high and mid-frequency bands of the DWT of the image.

Similar principle to our work is a watermarking method proposed by Kutter *et al.* [9] for digitally signing the image using amplitude modulation. In this method, the signature bits were multiply embedded by modifying pixel values in the blue channel. The experimental results showed that this method was immune to a variety of attacks. The main improvement brought by such method is that the watermark can be retrieved regardless of the original, unmarked image.

3. Fundamental Concept

A color model is a method for explaining the properties or behavior of color within some particular context. In this section, a fundamental concept of $RGB - YIQ$ color model and a technique based on Gaussian pixel-weighting marks are described.

3.1 RGB-YIQ Color Model

Based on the tristimulus theory of vision [10], our eyes perceive color through the stimulation of three visual pigments in the cone of the retina. These visual pigments have a peak sensitivity at wavelength of about 630 nm (red), 530 nm (green), and 450 nm (blue). By comparing intensities in a light source, we perceive the color of the light. This theory of vision is the basis for displaying color output on a video monitor using the three color primaries, red, green and blue, referred to as the RGB color model.

We can represent this model with the unit cube defined on R, G and B axes. Vertices of the cube on the axes represent the primary colors, and the remaining vertices represent the complementary color for each of the primary colors. Thus the pixels in spatial domain can be represented by the *RGB* color model.

Lumination for each color pixel was found by using the relationship between *YIQ* and *RGB* models. In *YIQ* color model, luminance information is contained in *Y* parameter while chromaticity information is incorporated in *I* and *Q* parameters. Generally, the luminance carries the information on lightness and brightness. It measures the amount of energy an observer perceive from a light source and proportional to the amount of light perceived by the eye, which the luminance component of an image can be processed without affecting its color content. The term chromaticity is used to refer collectively to the two properties describing color characteristics: hue and purity. The hue is also called the dominant frequency, or simply the color, of the light. The term purity describes how washed out or how '*pure*' the color of the light appears. Generally, the relationship between *YIQ* and *RGB* can be described as follows :

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

and the relationship between *RGB* and *YIQ* is as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.0 & 0.956 & 0.620 \\ 1.0 & -0.272 & 0.647 \\ 1.0 & -1.108 & 1.705 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad (2)$$

3.2 Gaussian Pixel-weighting Marks

Gaussian pixel-weighting marks, also known as super-sampling algorithm, is often implemented by giving more weight to neighboring pixels near the center of pixel area, since we would expect these neighboring pixels to be more important in determining the overall luminance of a pixel. The distribution of the weight in the masks can also be implemented with the joint of Gaussian distribution [11] having characteristics as follows:

$$G_{gaussian}\ (x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}} \quad (3)$$

By applying 3x3 pixels mark with the mean value of 0, and the variance σ^2 of 0.5 at coordinate *x* and *y* to the joint of Gaussian distribution above, the result we expected will be 3x3 Gaussian distribution matrix as follows:

$$\begin{bmatrix} 0.0431 & 0.1171 & 0.0431 \\ 0.1171 & 0.3183 & 0.1171 \\ 0.0431 & 0.1171 & 0.0431 \end{bmatrix} \quad (4)$$

Let the amplitude of the image pixels under the mask at any location be $z_1, z_2, \ldots, z_9$, the response of a linear mark can be found as follows:

$$R = 0.0431 \times z_1 + 0.1171 \times z_2 + \ldots + 0.0431 \times z_9 \quad (5)$$

If the center of the mark is at location (x,y) in the image, the amplitude of that pixel will be replaced by *R*. The mask is then moved to the next pixel location in the image and the process is repeated. This continues until all pixel locations are covered.

4. Experimental Design

All experiments were performed by simulation program, which was written on Borland Delphi 4. The original image in bitmap standard type used in our experiments was '*peppers*' with the size of 256x256 pixels. Also, a binary image '*MCL*' was formed with the size of 256x256 pixels as a watermark signal. The details of the methods used in the watermark embedding and retrieval processes are described below.

4.1 Watermark Embedding Method

Our goal is to embed a watermark bit (w), which is a pre-defined pattern e.g. *MCL* logo in our experiments, into an original image pixel (*OPixel* [x,y]) to obtain a watermarked image (*WPixel* [x,y]). We specify two scaling parameters as coarse scale (c), sometimes referred to as a signature strength, and fine scale (L [x,y]), which both of them alter the amplitude of the watermark signal. The embedding methods can normally be separated into two categories: additive and multiplicative watermark embedding, as shown below:

$$WPixel\,[x,y] = OPixel\,[x,y] + wcL\,[x,y] \quad (6)$$

$$WPixel\,[x,y] = OPixel\,[x,y] \times wcL\,[x,y] \quad (7)$$

The additive method is appropriate when the amplitude's range of the original image pixel varies in narrow band, since the imperceptibility can be achieved when altering the watermark portion. On the other hand, the advantage of the multiplicative method is that it is more robust against large differences in scale between the watermark signal and the original image. For example, when the *OPixel* [x,y] equals to 10^6, then adding 100 using the first method may be insufficient for establishing the mark. However, in our experiment, each channel of *RGB* color components varies in the range from 0 to 255, which is considered to be in narrow band, thus for this reason, the additive embedding method is suited to be used with the proposed embedding method.

Another important issue we have not mentioned yet is the locations or pixels within the image used to embed the watermark signal. Basically, it will be understood that, in the process of watermark embedding, the locations for embedding the watermark signal will be protected from the attacker's discovery simply by an approach based on a pseudo-random number generating. For instance, a position or pixel within the image will be pseudo-randomly selected to embed the watermark signal, which depends on on a secret key that is used as a seed to the pseudo-random number generator.

4.2 Watermark Retrieval Method

In the retrieval process, we can retrieve the watermark bits without using the original image because the original image can be constructed by using the image averaging technique [12], often known as 'lowpass filter'. Consider a watermarked image as a noisy image $g\ (x,\ y)$ formed by the addition of watermark or noise $n\ (x,\ y)$ to an original image $f\ (x,\ y)$; that is

$$g(x,y) = f(x,y) + n(x,y) \qquad (8)$$

Where the assumption is that at every pair of coordinates $(x,\ y)$ the watermark is uncorrelated. The objective of the following procedure is to reduce the watermark effects by applying any low pass filter such as lowpass and median filters, and thus the original image can be obtained. By using the lowpass filter, in the retrieval process, the watermark bit *Wbit* $(x,\ y)$ is formed by applying unity gain of a general mark 3x3 pixels to the watermarked image, and then subtracted with the center of watermarked pixel.

$$WBit(x,y) = \frac{1}{9}\left[\sum_{u=x-1}^{x+1}\sum_{v=y-1}^{y+1}\mathrm{WPixel}(u,v)\right] - \mathrm{WPixel}(x,y) \qquad (9)$$

Similar to the lowpass filter, the image filtering technique using cross-shaped neighboring pixels is formed by utilizing four directions of neighboring pixels, and then subtracted with the center of the watermarked pixel.

$$WBit(x,y) = \frac{1}{4}\left[\sum_{u=x-1}^{x+1}\mathrm{WPixel}(x,v) + \sum_{v=y-1}^{y+1}\mathrm{WPixel}(u,y)\right] - \frac{5}{4}\mathrm{WPixel}(x,y) \qquad (10)$$

An alternative approach in the image filtering techniques is the median filter where a pixel value is replaced by the median of its neighbors. The median of a set of numbers is the value such that 50% are above and 50% below. Conceptually simple, if the set of numbers is so large, the median filter is then somewhat awkward to implement because the pixel value sorting process is required. However, according to the image filtering techniques we applied, only 3x3 pixels of window size was used, the median filter was therefore selected to be used in the experiments to observe its performance, compared to other two techniques i.e. lowpass filter and cross-shaped neighboring pixels based filter.

5. Experimental Results and Discussion

The two images merely mentioned and their corresponding versions as the watermarked image and the retrieved watermark are showed as an example in the figure next page.

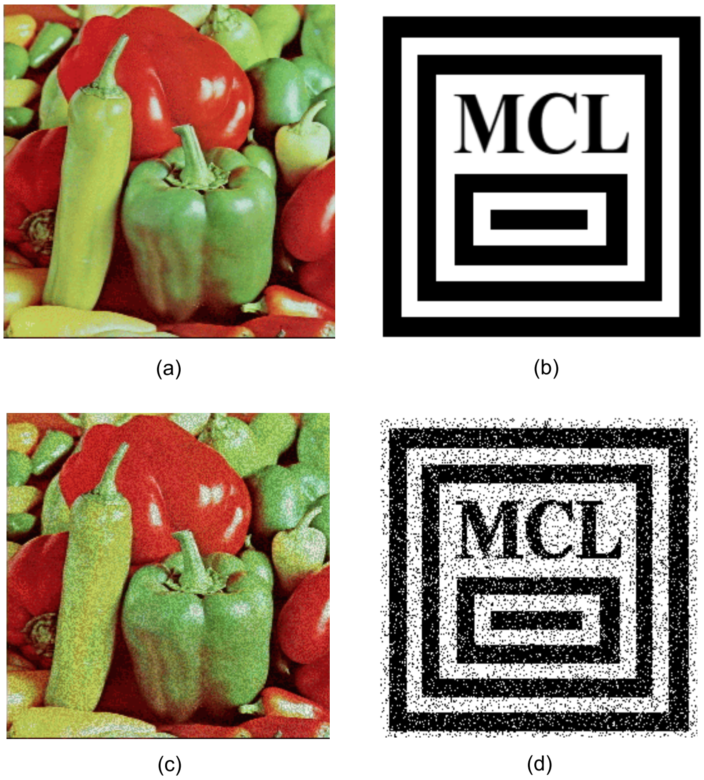


Fig. 1 (a) the original image '*peppers*' (b) the watermark image '*MCL*'
(c) the watermarked image (d) the retrieved watermark

The degradation in the watermarked image can be noticed when the signature strength was increased to the threshold value in which the quality of the image will be unacceptably degraded, if the value of the signature strength is higher than this threshold's. The same signature strength value as the threshold value's was also used to protect the re-watermarking attack. The watermarked image and the retrieved watermark at the signature strength of 0.1 and 0.5 are shown in the Fig. 2 and 3, respectively.

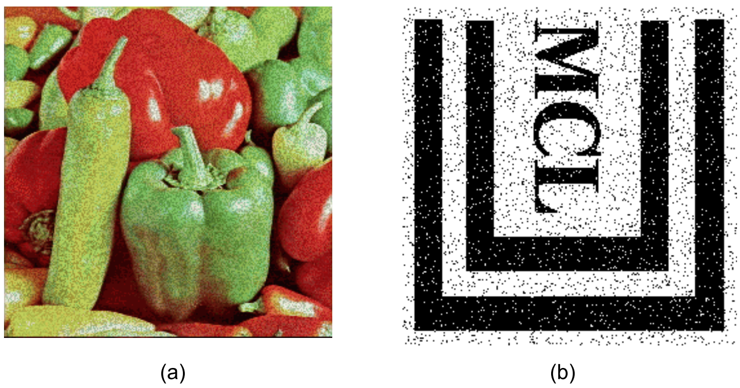
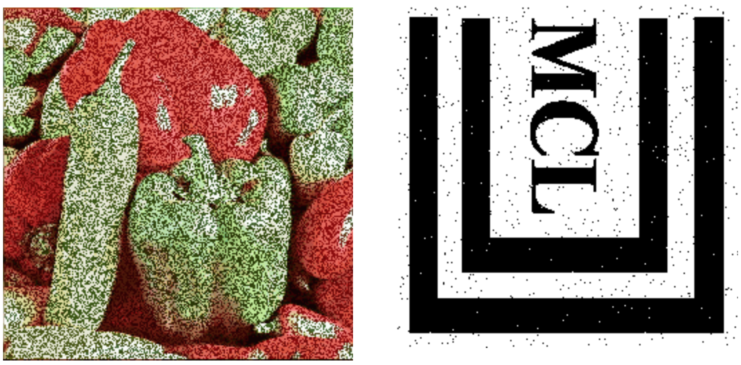


Fig. 2 (a) the watermarked image
(b) the extracted watermark in luminance channel with the signature strength = 0.1



(a) (b)

Fig. 3 (a) the watermarked image
(b) the extracted watermark in luminance channel with the signature strength = 0.5

As can be clearly seen that the larger the value of signature strength, the poorer the quality of the watermarked image. In contrary, the larger the value of signature strength, the better the quality of the retrieved watermark. In practice, the optimal value is needed to find out, depending on the original and watermark images, which is a trade off between the quality of watermarked image and retrieved watermark.

To improve the quality of the watermarked image, a technique based on Gaussian pixel-weighting marks was applied in the embedding process, and the Fig. 4 illustrates the PSNR at various levels of the signature strength for watermark embedding in each embedding type.

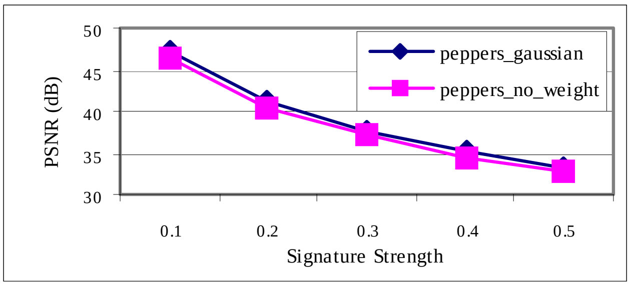


Fig. 4 The comparison of PSNR at various values of signature strength with Gaussian and No pixels-weighting marks techniques

From the figure, we can see that the plot of Gaussian pixel-weighting marks was above the existing technique. The quality of the watermarked image was improved by approximately 0.5 dB. However, it should be noticed that the values of PSNR we obtained resulted directly from the watermark embedding method applying the 3x3 Gaussian distribution matrix as stated in equation (4), where the variance of 0.5 was used. Other values of the variance will hence result in different values of PSNR shown in the Fig. 4 To determine the most effective watermark retrieval method based on the image filtering technique, various types of filter were used and their performance was compared. The result is shown in Fig. 5.

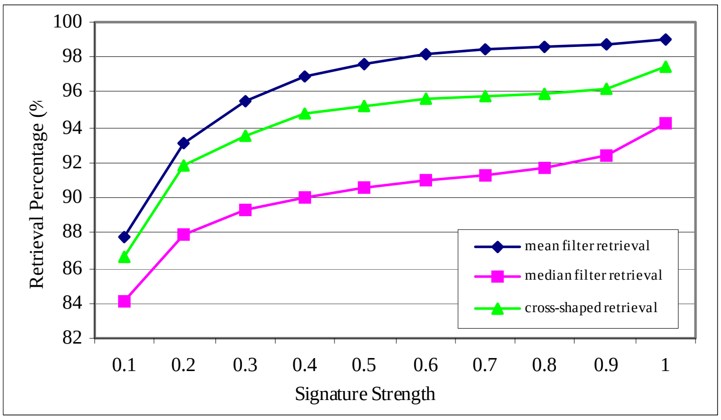


Fig. 5 The comparison between three retrieval methods in the luminance channel

When performing the retrieval process using 3 different techniques, it is obvious from the result that at the same level of signature strength, the retrieval technique based on lowpass filter gave the best retrieval percentage (%) of the watermark signal, compared to the median filter and cross-shaped neighboring pixels techniques.

6. Conclusions

In this research, we have introduced a watermark embedding method, based on Gaussian pixel-weighting marks technique, on a luminance channel of the image. The experimental results showed the improvement of around 0.5 dB, when applying our proposed method. In the retrieval process, the image filtering technique based on the lowpass filter was suggested for the use in practice, according to the experimental results, compared to other two techniques.

Acknowledgment

This work was supported by project NT-B-06-4C-20-319 funded by the National Electronics and Computer Technology Center (NECTEC), Thailand.

References

1. Cox, J., Killian, J., Leighton, T. and Shamoon, T., 1997, "Secure Spread Spectrum Watermarking for Multimedia", *IEEE Transactions on Image Processing*, December, pp. 1673-1687.

2. Bender, W., Gruhl, D., Morimoto, N., and Lu, A., 1996, "Techniques for Data Hiding", *IBM System Journal*, Vol. 35, pp. 313-336.

3. Swanson, M.D., Zhu, B., and Tewfik, A.H., 1996, "Transparent Robust Image Watermarking", *Proceedings of IEEE International Conference on Image Processing*, Vol. 3, September, pp. 211-214.

4. Swanson, M.D., Zhu, B., and Tewfik, A. H., 1996, "Robust Data Hiding for Images", *Proceedings of IEEE Digital Signal Processing Workshop*, September, pp. 37-40.

5. Zhu, B., Swanson, M.D., and Tewfik, A.H., 1996, "A Transparent Robust Authentication and Distortion Measurement Technique for Images", *Proceedings of IEEE Digital Signal Processing Workshop*, September, pp. 45-48.

6. Boney, L., Tewfik, A.H., and Hamdy, K.N., 1996, "Digital Watermarks for Audio Signals", *Proceedings of the EUSIPCO-96, VIII European Signal Processing Conference*, September, pp. 1697-1700.

7. Tsai, M.J., Yu, K.Y., and Chen, Y.Z., 2000, "Joint Wavelet and Spatial Transformation for Digital Watermarking", *IEEE Transaction on Consumer Electronics*, February, pp. 241-245.

8. Xia, X.G., Boncelet, C.G., and Arce, G.R., 1997, "A Multiresolution Watermark for Digital Images", *Proceedings of International Conference on Image processing*, pp. 548-551.

9. Kutter, M., Jordan, F., and Bossen, F., 1998, "Digital Signature of Color Images using Amplitude Modulation", *Journal of Electronic Imaging*, Vol. 7, pp. 326-332.

10. Hearn, D. and Baker, M.P., 1997, *Computer Graphics C Version*, Prentice Hall Inc.

11. Alberto, L.G., 1994, *Probability and Random Process for Electrical Engineering*, Addison-Wesley Publishing Company, Inc.

12. Gonzalez, R.C. and Woods, R.E., 1992, *Digital Image Processing*, Addison-Wesley Publishing Company, Reading, MA