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Robust Multispectral Data Hiding in RGB Image Using Digital Watermarking

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Abstract

In this paper, we propose a method of embedding the spectral information into an RGB image by robust watermarking. The difference between an original image and a multispectral image estimated from the RGB image by Wiener estimation is referred to as the residual. The estimated spectral residual data are compressed by JPEG2000 and embedded into the wavelet coefficients of chrominance channel. When a multispectral image is reconstructed from an RGB image, our proposed method can improve the quality of the reconstructed multispectral image in comparison with a multispectral image estimated by Wiener estimation because the residual data can be extracted from the watermarked RGB image. Additionally, if the watermarked RGB image is compressed with a lossy compression method, the proposed method can obtain the high-quality reconstructed multispectral image because this method uses robust watermarking. The experimental results show that there is almost no significant difference in the RGB image.

1. Introduction

Multispectral images (MSIs) enable more accurate color reproduction than RGB images. MSIs have been used in remote sensing and digital archive of artworks. Because MSIs have a large amount of data, MSI compression methods which based on Karhunen-Loève transform (KLT) [1] and discrete wavelet transform (DWT) [2], [3] are proposed. The MSI compression is a useful method for efficient transmission and storage, but this method is not compatible with the conventional RGB imaging system widely used for image reproduction. Therefore, an MSI is difficult to transmit, display and store in the conventional color imaging system. If we can use MSIs in the RGB imaging system, the transmission, display, and storage of MSIs become more efficient. An MSI can be used as an RGB image by converting the MSI into the RGB image, but the spectral information is mostly lost by this conversion. Although high-dimensional signals such as MSIs can be estimated from the RGB images by solving linear inverse problems [4], [5], the estimated MSI is greatly inferior to the original MSI because it is estimated from limited spectral information. The conventional spectral reconstruction methods from the RGB images with additional data [6] can improve the quality of the reconstructed multispectral image, but this method is not compatible with a conventional RGB imaging system. A method of embedding binary data into JPEG2000 bit streams based on the layer structure [7] can extract the embedded binary data perfectly. Therefore, the MSI can be reconstructed by the same way as Shinoda et al.'s method [6]. However, this method does not have complete compatibility with the conventional color imaging. On the other hand, in the spectral reconstruction methods without additional data, embedding the compressed residual data of the estimated spectral information into lower bit planes of the RGB image [8] has been proposed. This method improves restoration accuracy of multispectral image

Table 1. The data format of spectral information and RGB images, the quality of RGB images and restored MSIs, and the compression tolerance of RGB images in each method.

Method	Data format	Quality of RGB image	Quality of restored MSI	Compressio n tolerance of RGB image
Wiener estimatio n	RGB	Ideal	Low	Yes
Shinoda et al. [6]	RGB and JPEG200 0	Adjust-able	Adjustabl e	Yes
Ando et al.[7]	JPEG200 0	Adjust-able	-	-
Shinoda et al. [8]	RGB	High	High	No
Proposed	RGB	High	High	Yes

because the reconstructed MSI can be obtained by adding the residual data to the MSI residual data to the MSI estimated from the watermarked RGB image. However, if the watermarked image is compressed, this method cannot reconstruct the MSI because lower significant bits may be changed by this compression. The conventional embedding methods by robust watermarking have been proposed [9]-[11], but a method which can embed a large amount of data such as the residual data into RGB images and extract embedded data perfectly has not been proposed.

Table 1 shows the data format of spectral information and RGB images, the quality of RGB images and restored MSIs, and the compression tolerance of RGB images in each method. From the comparison of the conventional methods, a practical method, which can convert an MSI into a true RGB format, have a compression tolerance of the RGB image, and reconstruct a high-quality MSI from the RGB image, has not been proposed.

We propose a method of embedding the estimation error of MSI into an RGB image to have a tolerance against JPEG2000 compression. An RGB image calculated from an original MSI by using the CIE XYZ color matching function under the standard illuminant of D65, color conversion matrix and a gamma function. The RGB image is converted to YCbCr color space. The difference between the original MSI and the MSI estimated from the RGB image by Wiener estimation is defined as the residual data. The estimated residual data are compressed and embedded into wavelet coefficients of one of chrominance channel. This watermarked RGB image can be used as a simple RGB image. If the MSI is required, the residual data are extracted from the RGB image and the reconstructed MSI is obtained by adding the residual data to the MSI estimated from the RGB image. If the watermarked RGB image is compressed, the MSI can be reconstructed because our proposed method uses robust watermarking. Additionally, conventional methods [8], [12] are difficult to reconstruct images of non-visible wavelength, but our proposed method can improve the image quality of non-visible wavelength because these data are embedded into the wavelet domain of watermarked RGB image.

This paper is organized as follows. Our proposed method is presented in Section 2. The results are given in Section 3. We conclude this paper in Section4.

2. Watermark embedding and MSI reconstruction

The flow diagram of embedding and reconstructing process of our method is shown in Figure 1. In the embedding side, the original B-band MSI is defined as $\boldsymbol{f} = [f_1, f_2, \cdots f_i, \cdots f_B]^T$. The original MSI is obtained from spectrum reflectance $\boldsymbol{r} = [r_1, r_2, \cdots r_i, \cdots r_L]^T$ as

$$\boldsymbol{f} = \boldsymbol{H}\boldsymbol{r}, \tag{1}$$

where $\boldsymbol{H}$ is $B \times L$ matrix including illuminant and camera function. Thus, $\boldsymbol{r}$ can be estimated by Wiener estimation as

$$\boldsymbol{r} = \boldsymbol{D}\boldsymbol{f}, \tag{2}$$

$$\boldsymbol{D} = \boldsymbol{R}_{rr}\boldsymbol{H}^T(\boldsymbol{H}\boldsymbol{R}_{rr}\boldsymbol{H}^T)^{-1}, \tag{3}$$

where $\boldsymbol{D}$ is a $L \times B$ matrix and represent the Wiener estimation matrix to convert from an MSI to a spectral reflectance and $\boldsymbol{R}_{rr}$ is an $L \times L$ autocorrelation matrix of $\boldsymbol{r}$. An original MSI is converted to a linear RGB image by using a spectral reflectance and the CIE XYZ color matching functions under the standard illuminance D65 as

$$\boldsymbol{G} = \boldsymbol{CTEDf} \tag{4}$$

$$= \boldsymbol{Af}, \tag{5}$$

where $\boldsymbol{G}$ is a linear RGB image calculated by an MSI, $\boldsymbol{C}$ is a 3×3 matrix and represent the XYZ to linear RGB color transform, $\boldsymbol{T}$ is the CIE XYZ color matching functions of $3 \times L$ matrix, $\boldsymbol{E}$ is a $L \times L$ diagonal matrix and represent the spectrum of illuminant, and $\boldsymbol{A}$ is a $3 \times B$ matrix to convert from a spectral reflectance to a linear RGB image. $\boldsymbol{G}$ is converted to nonlinear sRGB color space by gamma correction, the nonlinear RGB image is defined as $\boldsymbol{g}$. $\boldsymbol{g}$ is applied on inverse gamma correction. The MSI defined as $\boldsymbol{f}'$ is estimated from $\boldsymbol{g}$ by Wiener estimation as

$$\boldsymbol{f}' = \boldsymbol{U}\boldsymbol{g}, \tag{6}$$

$$\boldsymbol{U} = \boldsymbol{R}_{ff}\boldsymbol{A}^T(\boldsymbol{A}\boldsymbol{R}_{ff}\boldsymbol{A}^T)^{-1}, \tag{7}$$

where $\boldsymbol{U}$ is a $B \times 3$ matrix and represent the Wiener estimation matrix to convert from an linear RGB image to an MSI, $\boldsymbol{R}_{ff}$ is a $B \times B$ autocorrelation matrix of $\boldsymbol{f}$.

Then the residual data is obtained from the difference between $\boldsymbol{f}$ and $\boldsymbol{f}'$. However, non-visible components of $\boldsymbol{f}'$ are zero

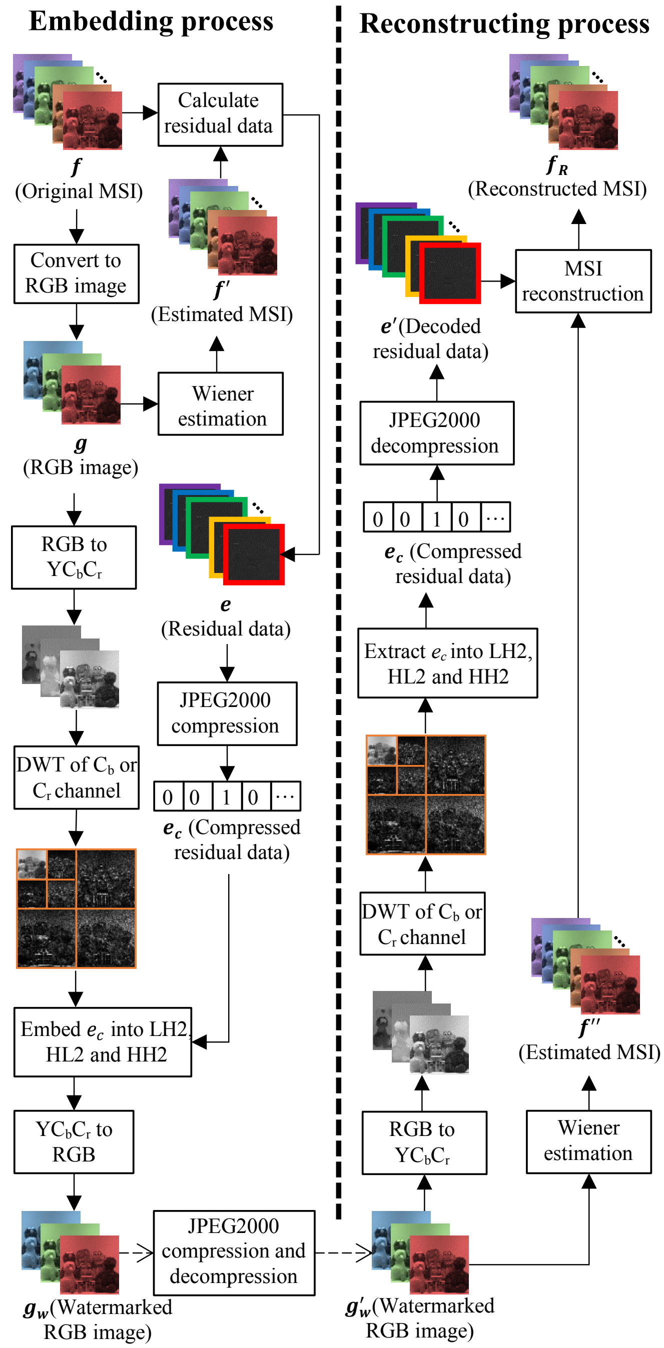


Figure 1. Proposed embedding and reconstruction scheme.

since non-visible components cannot be estimated from the RGB image. In this case, the residual data distributions are different between visible and non-visible components and it is hard to embed (and reconstruct) non-visible components. Thus, we update $\boldsymbol{f}'$ for reducing such effects before calculating the residual data. We use the shortest and longest wavelengths of visible components for interpolating such zero components as

$$f' := \begin{cases} f_s' & \text{if } i < s \\ f_i' & \text{if } s \le i \le l \\ f_l' & \text{if } l < i \end{cases}, \quad (8)$$

where, s and l are the band indices corresponding to the shortest and longest visible wavelengths, respectively. We set the shortest and longest wavelengths to 380 and 780 nm according to the domain of the color matching function $\boldsymbol{T}$. After updating f', the residual data defined as $\boldsymbol{e}$ can be obtained as

$$\boldsymbol{e} = \boldsymbol{f} - \boldsymbol{f}'. \quad (9)$$

$\boldsymbol{g}$ is converted to YCbCr color space defined by the ITU-R BT.601, and two-dimensional DWT is applied on one of chrominance channel. In this paper, a 9/7 real wavelet filter is used. When high frequency sub-bands such as LH1, HL1 and HH1 is used for watermarking, it is difficult to have a compression tolerance because the edge information of an image is likely lost by the compression. When low frequency sub-bands such as LL2 is used for watermarking, the watermarked RGB image is greatly deteriorated. Therefore, we choose the intermediate frequency sub-bands such as LH2, HL2 and HH2 for robust watermarking. The obtained residual data are encoded by JPEG2000 with multi-component transform lossy mode with KLT. If *M* and *N* is the height and width of an RGB image respectively, the compressed residual data defined as $\boldsymbol{e_c}$ are truncated into $M/4 \times N/4 \times 3$ bits equal to the total number of wavelet coefficients in sub-bands LH2, HL2 and HH2. $\boldsymbol{e_c}$ is divided into 3 parts and made two-dimensional data as $W_k(x,y)$ $(1 \le k \le 3, 1 \le x \le M/4,\ 1 \le y \le N/4)$ to embed $\boldsymbol{e_c}$ into LH2, HL2 and HH2 defined as S_1, S_2, and S_3 respectiveley. $\boldsymbol{e_c}$ is embedded into LH2, HL2 and HH2 of one of chrominance channel as

$$S_k(x,y) = \begin{cases} +\alpha_k & \text{if } W_k(x,y) = 1 \\ -\alpha_k & \text{if } W_k(x,y) = 0 \end{cases}, \quad (10)$$

where α_k is the parameter of watermark strength. If we increase the value of α_k, a tolerance against compression can be strong, but the quality of the watermarked RGB image is deteriorated. Therefore, the minimum value of α_k in a range that the embedded data can be extracted perfectly is embedded into S_k. Our previous work [12] used the same α for those three sub-bands, but the proposed method uses three different α for each sub-band. After watermarked channel is composed, YC_bC_r is reconverted to the watermarked RGB image, and the watermarked RGB image is defined as g_w. Because we suppose that the watermarked RGB images are compressed in RGB imaging system, the watermarked RGB image compressed and decompressed by JPEG2000 is defined as g_w'.

The reconstructed process is an inverse process of the embedding side. The watermarked RGB image defined as g_w' is converted to YC_bC_r color space. The watermarked channel is conducted by 9/7 real wavelet transform. If sub-bands LH2, HL2 and HH2 of the watermarked channel is defined as $S_k{}'$, the compressed residual data are extracted from $S_k{}'$ as

$$W_k{}'(x,y) = \begin{cases} 1 & \text{if } S_k{}'(x,y) \ge 0 \\ 0 & \text{if } S_k{}'(x,y) < 0 \end{cases}, \quad (11)$$

where, $W_k{}'$ are the extracted residual data. These residual data are merged into a vector data and decoded by JPEG2000. An MSI estimated from $g_w{}'$ by Wiener estimation is defined as f''. The reconstructed MSI defined as f_R is obtained as

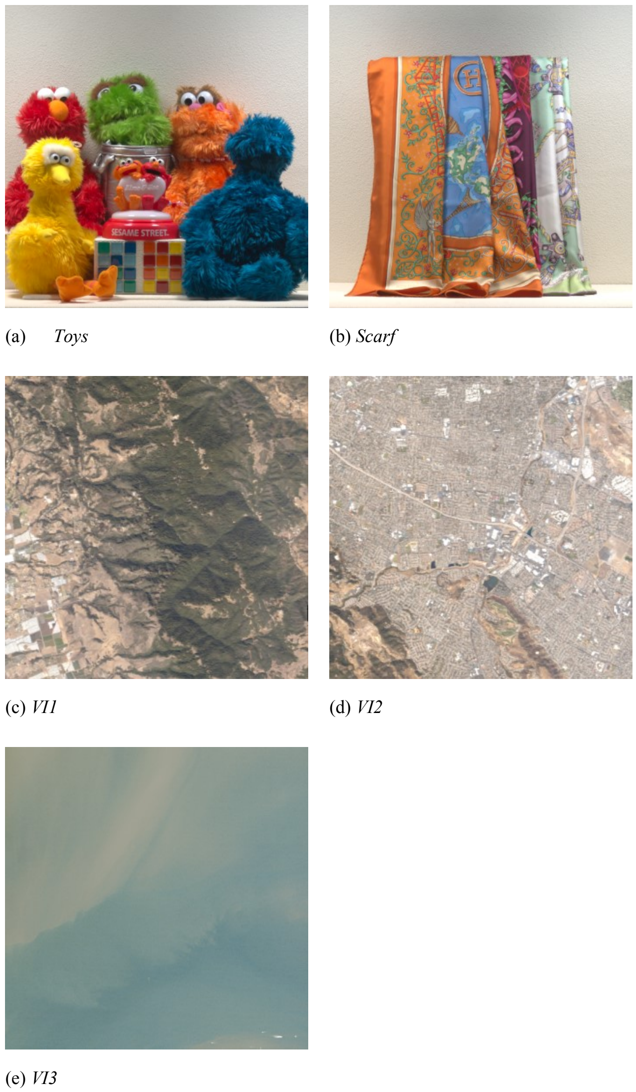
$$\boldsymbol{f_R} = \boldsymbol{f}'' + \boldsymbol{e}'. \quad (12)$$

3. Experimental Results

In this section, we show the peak signal-to-noise ratio (PSNR) of both watermarked RGB images and reconstructed MSIs in the conventional method and our proposed method. Figure 2 shows test images. Figure 2 (a) and (b) consist of 512×512 pixels, 8 bits / pixel with 16 bands. These images were captured with a camera with 16 band filters [13] having the spectral sensitivity shown in Figure 3. These filters cover only visible wavelengths. Figure 2 (c) and (d) are airborne visible/infrared imaging spectrometer data [14] consist of 782×15892 pixels, 16 bits / pixel with 224 bands from 366nm to 2496nm. In figure 2 (c), (d), and (e), We trim the imaging spectrometer data [14] to 512×512 pixels and choose 9 bands which the center of wavelength are 443nm, 492nm, 541nm, 589nm, 638nm, 665nm, 714nm, 763nm, and 802nm. The watermarked RGB images are compressed by JPEG2000 with lossy mode because it is presumed that the watermarked RGB images are compressed in RGB imaging system. In this paper, Kakadu [15] is used as a compression tool. Table 2 shows the value of α_k in each image. In the Table 2, α_k are obtained by the following procedures. Firstly, α_k are set to 1. Secondly, we increment α_k in each band so that the embedded binary data can be extracted perfectly when the watermarked RGB image are compressed by JPEG 2000 with bit rate from 24.0 bpp to 2.4 bpp. Table 3 shows the PSNR of watermarked RGB images and reconstructed MSIs in the conventional method and the proposed method. The watermarked RGB images are compressed by JPEG2000 with bit rate of 4.8 bpp and 2.4 bpp. In the case of bit rate = 24.0 bpp, the RGB image is not compressed by JPEG 2000.The MSIs reconstructed by only Wiener estimation are estimated from RGB images compressed by JPEG2000 with each bit rate. The watermarked RGB images in Shinoda et al.'s method are embedded the residual data into the lowest bit plane of the RGB images. If the watermarked images in Shinoda et al.'s method are compressed, it is difficult that the MSIs are reconstructed from the decoded RGB image because the embedded data cannot be extracted perfectly. Therefore, the PSNR which MSI reconstruction is difficult is replaced by "-" in Table 3.

The quality of MSIs reconstructed by our proposed method outperforms that of MSIs reconstructed by only Wiener estimation. Even if the watermarked RGB images are compressed, our proposed method can reconstruct the high-quality MSIs from the decoded RGB images.

Figure 4 and Figure 5 show the original RGB images, the watermarked RGB images, and the watermarked RGB images compressed with 2.4 bpp in the proposed method. It is almost no significant difference relative to the original RGB image. Figure 6 shows the reconstructed image of *Toys* in each method. From Figure 6, the proposed method can reconstruct higher quality MSI than Wiener estimation. Figure 7 shows the reconstructed image of *VI1* in each method. In Figure 7, it is difficult to reconstruct the near-infrared image in Wiener estimation method, but proposed method can reconstruct the non-visible image.



(a) *Toys* (b) *Scarf*

(c) *VI1* (d) *VI2*

(e) *VI3*

Figure 2. Test images.

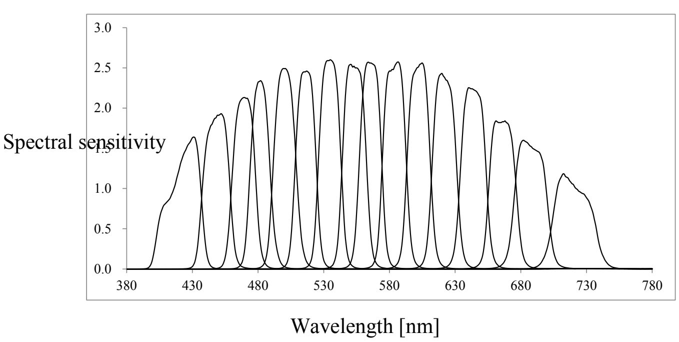


Figure 3. The spectral sensitivity used for Figure 2 (a) and (b).

Table 2. The value of α in each sub-band.

Image	LH2	HL2	HH2
Toys	5	5	7
Scarf	6	8	9
VI1	5	5	7
VI2	6	6	10
VI3	2	3	3

Table 3. The PSNR of watermarked RGB images and reconstructed MSIs.

Image	Bit rate of RGB image [bpp]	Wiener estimation [dB]	Shinoda et al's method [dB]		Proposed [dB]	
		MSI	MSI	RGB	MSI	RGB
Toys	24.0	27.73	47.50	51.14	38.24	37.20
	4.8	27.65	-	42.71	37.57	35.77
	2.4	27.49	-	37.60	36.21	33.90
Scarf	24.0	28.74	46.29	51.14	35.49	33.49
	4.8	28.72	-	39.71	34.80	32.62
	2.4	28.60	-	34.63	33.43	30.93
VI1	24.0	25.51	36.88	51.13	32.43	37.30
	4.8	24.86	-	39.88	32.24	34.43
	2.4	23.64	-	36.07	31.19	31.65
VI2	24.0	29.26	44.80	51.09	38.18	38.86
	4.8	29.25	-	36.89	38.17	36.51
	2.4	29.23	-	33.01	38.02	34.06
VI3	24.0	41.37	49.69	51.13	47.79	46.40
	4.8	41.07	-	49.69	46.61	44.15
	2.4	40.73	-	42.77	45.69	41.78

(a) Original RGB image (b) non-compression (c) compression with 2.4 bpp

(d) Original RGB image (e) non-compression (f) compression with 2.4 bpp

Figure 4. The watermarked RGB image of Toys in proposed method.

(a) Original RGB image (b) non-compression (c) compression with 2.4 bpp

(d) Original RGB image (e) non-compression (f) compression with 2.4 bpp

Figure 5. The watermarked RGB image of VI1 in proposed method.

(a) Original MSI (b) Wiener estimation (c) Proposed

Figure 6. The reconstructed image of Toys in 730nm.

(a) Original MSI (b)Wiener estimation (c) Proposed

Figure 7. The reconstructed image of VI1 in 802nm.

4. Conclusion

We proposed a new method of embedding the estimated residual data into intermediate frequency sub-bands of chrominance channel to have a compression tolerance. The proposed method can display the high-quality watermarked RGB image with the conventional RGB systems. Additionally, the high-quality MSI can be reconstructed by the proposed method. In the future work, we would like to give the tolerance to resolution conversion and JPEG compression to the watermarked RGB image. Additionally, the future work is the improvement of the embedding method in order to adjust the quality of the reconstructed MSI and the watermarked image depending on the amount of the embedding residual data.

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