Robustness of Watermarking Spectral Images with 3D Wavelet Transform Subject to Various Illumination Conditions

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Abstract

Digital imaging continues expansion to various applications. Spectral images are becoming more popular as one field of digital imaging. In this study we utilize a watermarking method for spectral images, based on the three-dimensional wavelet transform. We study the illumination influence to the watermarked images. The experiments were performed on a large dataset of 58 spectral images. The experiments indicate that using the proposed watermarking method the embedded watermark is robust to the compression attack. Guidelines for the parameter selection for robust watermarking are given.

Introduction

Image watermarking is an emerging method for supporting intellectual properties in digital media [1]. If the human visual system is used for measuring the embedding quality then it is rather easy to define embedding procedures that provide robust watermarking without visual changes in the image. This is the case for most of the color images.

Spectral color imaging is an imaging method, where color of an object is represented more accurately than in the traditional RGB images. Spectral imaging is becoming a practical tool in many applications, e.g. in digital commerce, industrial quality control, and digital museum [2]. For spectral images the requirements set by the various applications may be diverse. Again, for visual assessment watermarking is easy. For classification applications it might be too risky to modify the original, measured spectra through watermark embedding. The same applies to the lossy compression of spectral images. Now, the utilization of spectral images is spreading to various areas and the requirements for storing and transmitting the data must be solved. Lossless compression provides lower compression ratios comparing to lossy compression. This means that lossy methods with high compression ratios are required in practice. Even though the watermarking is modifying the original content of the image, the intellectual rights should be somehow managed. This study confesses the requirements of the reality and as such, provides a practical approach to watermark embedding. We embed a gray-scale watermark in spectral images in the three-dimensional wavelet transform domain like in [3] and extensively analyze the method and draw some general conclusions. The size of image database is 58 spectral images [5]. This is a rather large database in this domain, since spectral images are still not too easy to acquire. The properties of the watermarking on a large set of spectral images are studied. Especially we study the robustness of the embedded watermark against compression.

The paper is organized as follows. First we describe the three-dimensional wavelet transform. Then, the procedure for embedding and extracting the watermark is given. In next section we describe the compression procedure and the illumination attack. After that we report the experiments on the illumination attacks and draw the conclusions.

Three-dimensional wavelet transform

Spectral images are three-dimensional signals with two spatial dimensions and a spectral dimension. The spatial dimensions contain the visual information, and the spectral dimension presents the reflectance spectrum connected to each pixel. Three-dimensional transform is derived from 2D DWT by taking into account one extra dimension. As with 2D transform, each dimension of the image is dilated separately. Thus, the original spectral image of size X•Y•Z is filtered into octants of size X/2, Y/2, Z/2, (see Fig.1). Here X•Y is the number of pixels in the spatial dimension and Z is the number of bands in the spectral dimension. More detailed information on three-dimensional wavelet decomposition could find in [3].

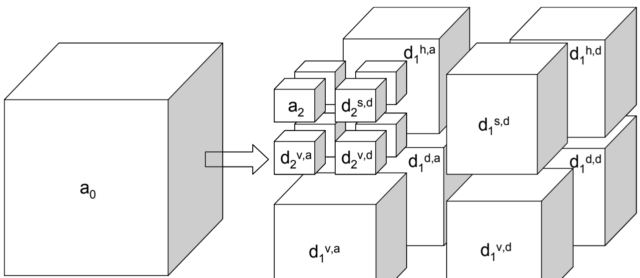

***Figure 1**. Three-dimensional wavelet transform schema. The coefficients a come from the low pass filtering and the coefficients d from the high pass filtering. The transform is applied twice. The first level we indexed as a_1,d_1, and the second level as a_2,d_2 with respective superscripts.*

Watermark embedding and extracting

The embedding procedure follows the method described in [3]. The watermark is embedded in the 3D wavelet transform domain. First, a three-dimensional wavelet transform I_{wt} of the spectral image I is computed. Then, a two dimensional wavelet transform W_{wt} of the watermark W is computed. The spatial size of the watermark is equal to the spatial size of the transformed block of the image. The transformed values of the watermark are added to the values of the transformed block B_{wt} of the spectral image, resulting to the watermarked block:

$$B_{wt,wm} = B_{wt} + \alpha W_{wt} \tag{1}$$

where α is a weighting coefficient that controls the strength of the watermark. The larger the multiplier α is, the better the watermark survives from attacks, but at the same time the signal to noise ratio for the watermarked image is decreasing.

The spectral image reconstructed by the inverse 3D DWT now containing the watermark.

Watermark extraction is an inverse operation to the embedding procedure. The three-dimensional wavelet transform is calculated both for the original image and watermarked image. Then, the difference of the original I and watermarked image I_{wt} in the transformed domain contains the watermark:

$$W_r = I_{wm} - I \tag{2}$$

Knowing the bands where the watermark pixels were embedded, the watermark W_{wt} in the transform domain can be reconstructed by collecting the corresponding values. Then the 2D inverse wavelet transform will finally output the watermark W_r.

Lossy compression attack

Spectral images are used in many tasks where exact spectral information is required and those applications may have different requirements to spectral images. Due to high amount of data, spectral images are most likely to be compressed. We study the robustness of the embedded watermark in the PCA-wavelet compression attack. The original spectral images were watermarked, and then watermarked spectral images were compressed in a lossy manner with the following procedure. To reduce the spectral dimension, principal component analysis (PCA) was applied to spectral images. The compression was achieved by selecting only a limited number of principal components to reconstruct the image. The resulting principal images were compressed with the wavelet-based SPIHT method [4]. Spectral image were reconstructed by multiplying the restored principal images by the corresponding principal vectors.

The following measures were used to evaluate the quality of reconstruction. The quality of reconstructed watermarked image is measured using the signal to noise ratio. The correlation coefficient was used as a quality measure between the original watermark and the extracted watermark.

Illumination attack

The viewing conditions change the perceptual color of the spectrum. External illumination can be compensated through combining the spectra of the image with the spectrum of the illumination. A set of light sources was used to illuminate the spectral images. Relative spectral radiance factors of the light sources are shown in Fig.2. We evaluated two ways of illumination attack - illumination before watermarking and illumination after watermarking:

In illumination before watermarking, the original spectral image is multiplied by the illumination vector, and then the result image is watermarked and compressed. The watermark is extracted from the reconstructed image and compared to the original watermark.

In illumination after watermarking, the original spectral image is watermarked, and then multiplied by the illumination vector, and then the resulting image is compressed. The watermark is extracted from the reconstructed image and compared to the original watermark.

Experiments

The proposed embedding procedure was applied to watermarking. In the experiments, 58 spectral images were watermarked and then compressed with different bit rates. The embedded watermark was extracted from the reconstructed watermarked images. The signal to noise ratio was calculated between the original image and the reconstructed watermarked image. For the extracted watermark, the correlation coefficient between the original and extracted watermark was calculated

The original spectral images had different number of the bands and different spatial sizes. We normalized all the images before watermarking, in order to have a constant spatial size and a constant number of bands. The spatial size of the normalized spectral images was 256x256 pixels. The number of bands was 32. As a watermark we used a gray-scale image with a spatial size of 128x128 pixels, see Fig.3.

The compression procedure described above was applied to the watermarked images. We used 8 principal components of the spectral image and wavelet compression with bit rate [4 1 0.5 0.25 0.015625] bits per pixel, which result to compression ratios [16, 64, 128, 256, 4096].

In these experiments we used both illumination before watermarking and illumination after watermarking as an illumination attack.

In the experiment we wanted to find a reasonable range for the watermark's strength controller α. A large value would mean strong embedding and thus, it would yield to a visible error in the watermarked image. A small value would result to weak embedding and thus to fragile watermarking. As such, robust watermarking means relatively strong embedding without visible or otherwise annoying errors in the watermarked image. In this experiment we used a large set of spectral images, but the results were averaged to define only one common value of α for all images.

Illumination before watermarking

Signal to noise ratios were calculated for the watermarked images. The results are shown on left in Fig.4 as a function of α .Correlation coefficients were calculated for the extracted watermarks. The results are shown on right in Fig.4 as a function of α.

According to the experiment the reasonable range for α would be from 0.02 to 0.08. With smaller values the embedding is too weak against compression and the quality of the extracted watermark is too low for registration. The values larger than 0.08 would output an image with a visible watermark. See Fig.4 for these results.

Illumination after watermarking

For the watermarked images, the signal to noise ratios were calculated. Signal to noise ratio between the original and reconstructed image as a function of α is shown in Fig.5, left. Correlation coefficient between the original and the extracted watermark as a function of α is shown in Fig 5, right.

As can be seen in Fig.5, the illumination has strongest effect to the watermarked image then the compression and parameter α . In illumination process the spectrum of the spectral image is significantly changed according to light source spectrum. Due to changing of the pixel values of the image the SNR measure is very low, but the RGB versions of the illuminated spectral images have acceptable visual quality. The compression does not significantly effect to correlation coefficient of the extracted watermarks, most disturbance occurs due to illumination. In order to compensate the changes in dynamic range, the illuminated images were normalized.

In Fig.6 an example of "D65" illuminated image and extracted watermark is shown. In column 1 is presented the extracted watermark from illuminated watermarked image. In column 2 is presented the extracted watermarks from illuminated watermarked image after normalization and compression. In column 2 the reconstructed image is presented.

For low values of the parameter α , the watermarked image has good quality, but the extracted watermark contains only noise. Increasing the parameter α vanish the illuminated image.

Discussion and conclusions

We considered a technique for embedding a watermark into a spectral image. We embedded the gray-scale watermark in a spectral image in the three-dimensional wavelet transform domain. The properties of the watermarking on a large set of spectral images were studied. Especially we studied the robustness of the embedded watermark for different illumination conditions. We considered two ways of illumination of the watermarked image.

In illumination before watermarking, we found the values for the watermark strength α which gives good quality of the watermarked image and reliable watermark extraction. According to the extensive experiments with 58 spectral images, we found the reasonable range for α would be from 0.02 to 0.08. With smaller values the embedding is too weak against compression and the quality of the extracted watermark is too low for registration. For the values larger than 0.08 the watermark is getting visible in the spectral image. The choice of the watermark strength α is illumination dependent. We found that for the illuminators "A" and "D65" the watermark strength $\alpha = 0.02$ and for the illuminator "F11" the watermark strength $\alpha = 0.04$ should be used.

In illumination after watermarking, we found the value for parameter α which gives good visual quality of the extracted watermark. The quality of the watermarked image is poor. The proper normalization of the illuminated image could improve the results. The quality of the watermarked image and the quality of the extracted watermark depends more on illumination then on α parameter and compression. For the illuminator "A" and "D65", the visual quality of the extracted watermark is good for α in [0.5, 1]. For the illuminator "F11", the extracted watermark is not visible for $\alpha < 0.5$. For higher values of α , the visual quality of the image is poor.

Difference in SNR between these two illumination cases (Figs 4 and 5) is due to difference in reference image in SNR calculation. In the first experiment, the reference image is the image after illumination. The changes of the spectrum due to watermarking are small, thus the SNR measure is good. In the second experiment, the reference image is the original image. The illumination changes the spectrum remarkably especially for F11. This leads to low values of SNR in Fig.5.

Using SNR as a quality measure for spectrum images under different illumination conditions is not reliable due to significant changes in image spectrum. Methods for evaluating the quality of the image with respect to the changes of the color might be considered as a better alternative.

References

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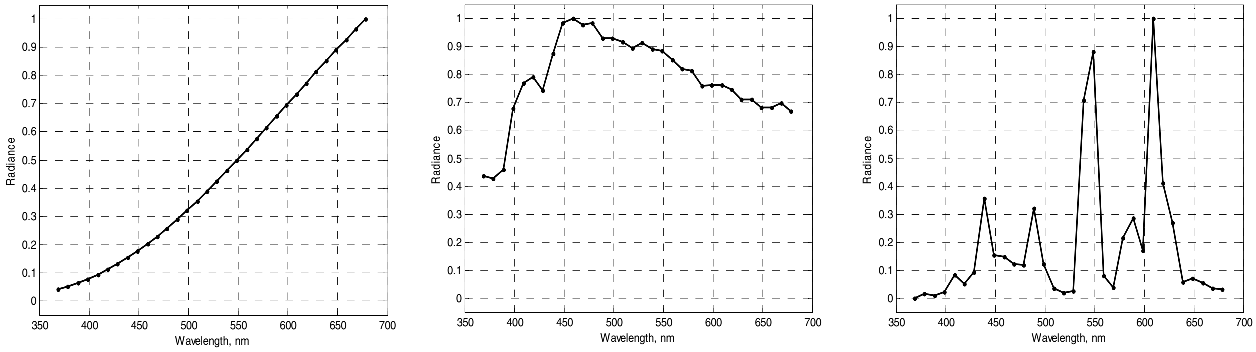
Author Biography

Konstantin Krasavin received his M.Sc. degree in mathematics from the University of St. Petersburg (2001) and his M.Sc. degree in computer science from the University of Joensuu (2003). He is continuing his Ph.D. research on watermarking of spectral images at the Department of Computer Science, University of Joensuu, Finland. His research areas are Image Processing, Digital Watermarking and Pattern Recognition.

Figures



A D65 F11

Figure 2*. Relative spectral radiance factors of the light sources.*

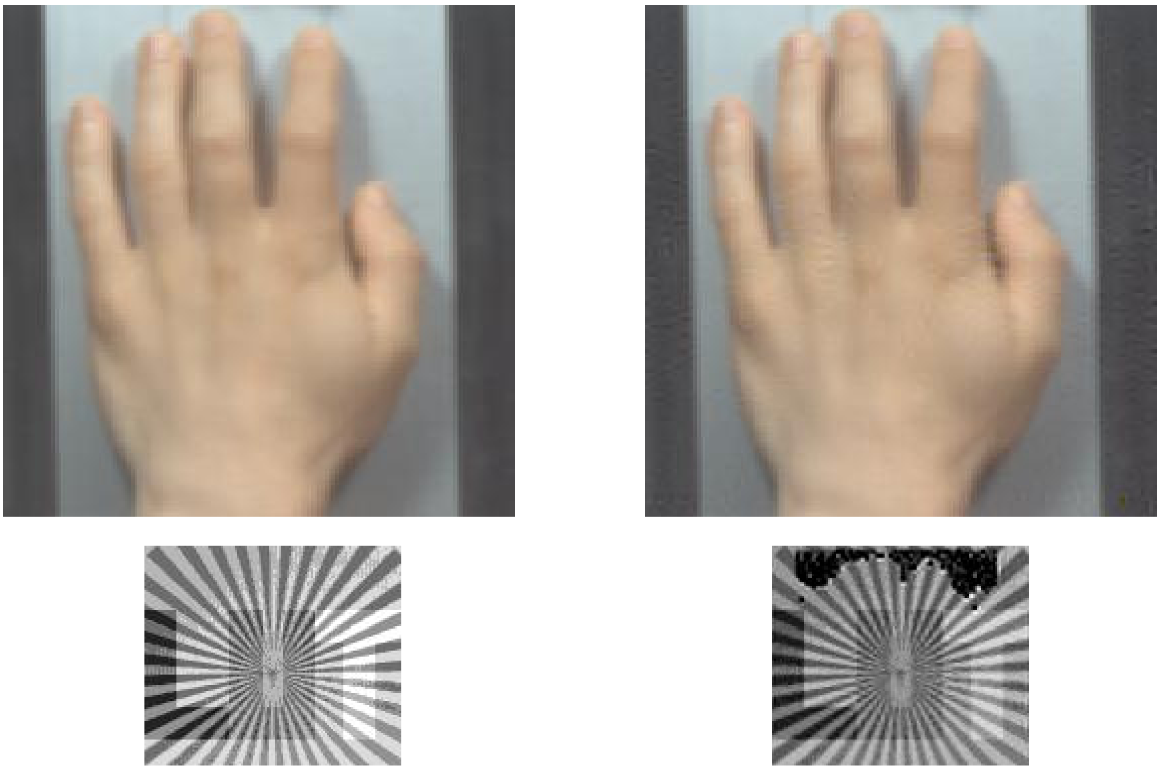
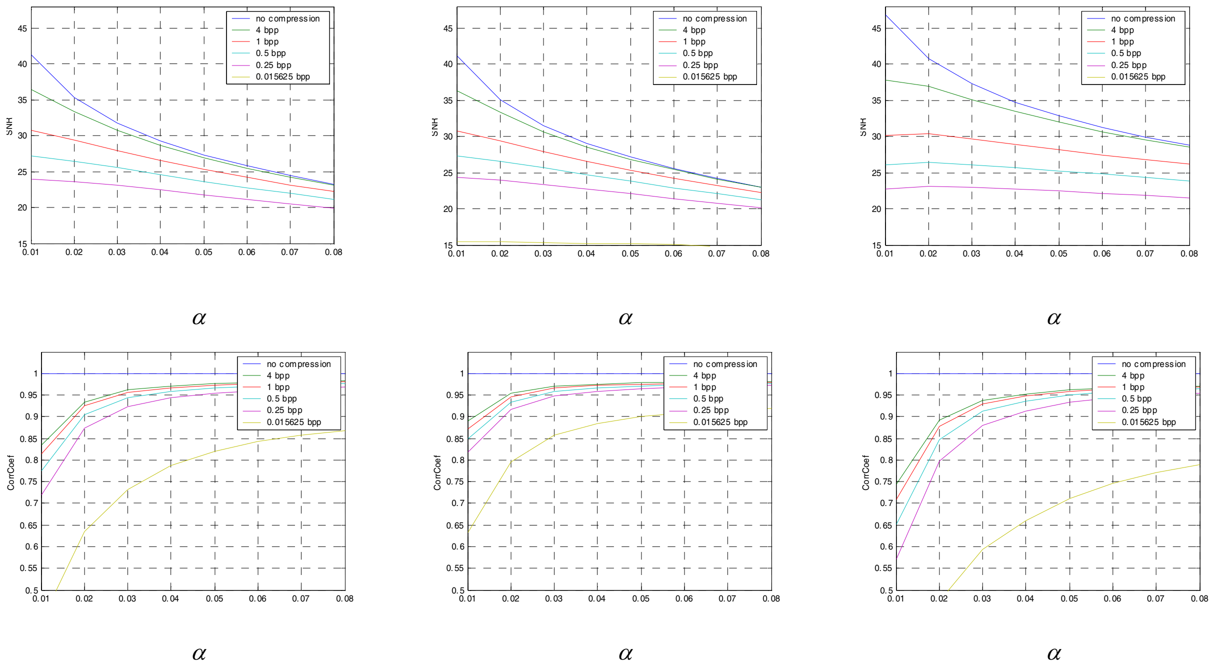
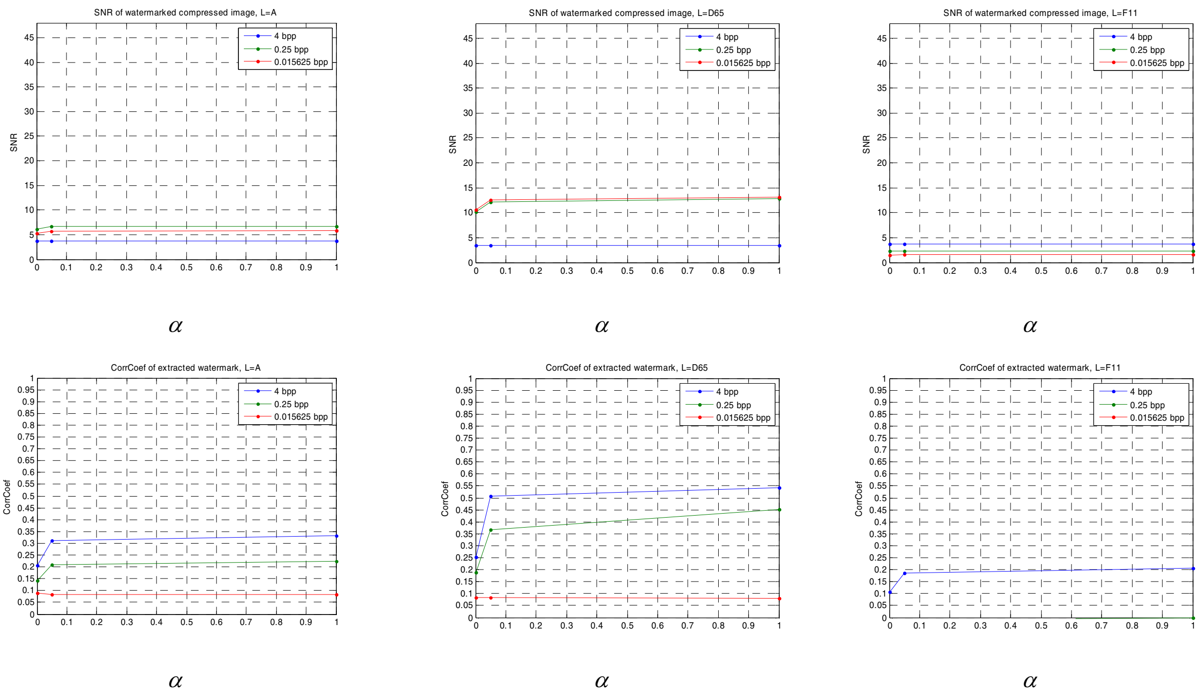


Figure 3*. An example of results for watermarking without illumination and compression attack. Original spectal image (top. left), watermarked spectral image (top, right), original watermark (bottom, left), extracted watermark (bottom, right).The parameter* $\alpha = 0.05$.



Light source A Light source D65 Light source F11

Figure 4. *Illumination before watermarking. Quality dependence on* α *, SNR of the watermarked image (top row), Correlation coefficient for extracted watermark (bottom row). The results are averaged over 58 spectral images. Note: SNR is calculated between the illuminated image and the reconstructed watermarked image.*

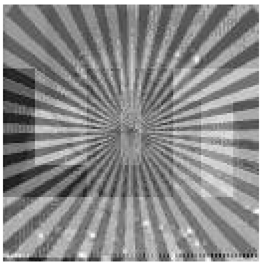


Light source A Light source D65 Light source F11

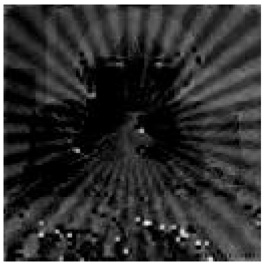
Figure 5.*Illumination after watermarking. Quality dependence on* α *, SNR of the watermarked image (top row), Correlation coefficient for extracted watermark (bottom row). The results are averaged over 58 spectral images .Note: SNR is calculated between the original image and the illuminated watermarked image. The illumination has strongest effect to SNR and CC measures then parameter* α *.*

Original image after D65 illumination

Reconstructed image



Extracted watermark: after illumination with "D65"



Extracted watermark:after illumination with "D65"and compression with 0.25bpp

Figure 6. *Examples of extracted watermark and reconstructed image for light source "D65".The parameter* $\alpha = 0.05$.