Dual-subband Watermarking Scheme Based on Integer Wavelet Transform

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Abstract

A dual-subband watermarking method based on integer wavelet transform (IWT) is proposed. A host media is first transformed to the wavelet domain, a variety of secret bits is then embedded into the low-low subband of IWT by module substitution. To alleviate further the error, a fine-labeling procedure is employed. Moreover, an extra watermark is concealed in the low-high subband of IWT by feature-embedding procedure so as to further increase the robustness of the proposed method. Simulations show that PSNR and embedding rate are not bad while the perceptual quality is good. The third parties are not easily aware of the existence of the message. Besides, the proposed method has certain robustness against intentional (or unintentional) manipulations such as JPEG2000, JPEG, uniform noise addition, horizontal cropping, edge sharpening, and brightness.
Keywords: Digital watermarking, integer wavelet transform, module substitution, fine-labeling, feature-embedding.

1. Introduction

With the fast growth of computer networks and hardware technologies, people are easily and economically using the broadband network equipments, such as asymmetric digital subscriber line (ADSL), cable modem, or worldwide interoperability for microwave access (WiMAX) to access their interested data from the Internet. However, data could be grabbed or eavesdropped upon by the third parties during transmission. Some researchers presented digital watermarking techniques (or the robust data hiding methods) in the literature (Cox et al., 1998; Katzenbeisser & Petitcolas, 2002; Wang et al., 2002; Pan et al., 2004) to against the hackers from tampering or extracting data. Several hiding schemes (Noda et al., 2002; Chang et al., 2003; Chan & Chen, 2004; Wang & Chen, 2006; Zhu et al., 2007) also known as fragile (or semi-fragile) data hiding methods are suggested to promote the hiding space while maintaining a certain degree of resulting perceptual quality. On the other hand, the approaches (Xuan et al., 2002; Zou et al., 2006) which referred to as lossless data hiding methods are emphasized on the capability of recovering the original host media after the secret bits have been successfully extracted.

In this paper, we focus on the area of fragile watermarking and try to propose a watermarking method with a larger capacity, high PSNR, and robust to intentionally (or unintentionally) manipulations. That is, we use module substitution (Yang & Lin, 2006) and feature-embedding techniques to hide message in an image based on integer wavelet transform (IWT). More specifically, the secret bits to be embedded into a block by module substitution are determined by the base-value (BV) of the block. The BV b_k of a block taken from low-low (LL) subband of IWT coefficients is computed by $b_k = \max_{0 \le j \le n \times n-1} q_{kj} - \min_{0 \le j \le n \times n-1} q_{kj} + 1$, where $\{q_{kj}\}_{j=0}^{(n \times n)-1}$ denotes the kth $n \times n$ block of the LL subband and q_{kj} represents for the jth pixel value in the kth block. Besides, to increase the robustness of the proposed method, the low-high (LH) subband of IWT coefficients is used to hide another watermark by using the feature-embedding procedure.

The rest of the paper is organized as follows. The module substitution and the fine-labeling procedure are briefly described in Section 2. The feature-embedding procedure as well as the algorithms for the encoding part and decoding part of the proposed method are also included. Section 3 demonstrates the simulations. Section 4 gives a brief conclusion.

2. Proposd method

The idea of the proposed method is that the level one IWT coefficients is first obtained by performing a two-dimensional Haar wavelet transform (Calderbank et al., 1998) to a host media. Then, the module substitution and feature-embedding techniques are used to embed a message into the LL and LH subbands of IWT coefficients, respectively.

2.1 Module substitution

The aim of module substitution is used to embed data bits into a block of which BV is greater than or equal to τ. The τ used here is a controlled parameter. More specufically, the blocks in LL subband of IWT coefficients are used for hiding data by module substitution. Assume that Mod ϕ substitution is to be applied to hide data. Take $L = \lfloor (n \times n)\log_2 \phi \rfloor$ bits from the (secret) binary data. Convert this binary numebr to a (base ϕ) value of n^2 digits, and each digit is in the range {0, 1, 2, …, ϕ-1}. To hide a data digit $d \in$ {0, 1, 2, …, ϕ-1} in a pixel with gray value x, we first evaluate $g_0 = (x - x_{\bmod \phi}) + d$. Then let $g_0^+ = g_0 + \phi$ and $g_0^- = g_0 - \phi$. Choose from $\{ g_0^-, g_0, g_0^+ \}$ the one whose distortion to x is the smallest, and call it g. Then, replace the gray value x of the host pixel by the new value g.

After data embedment, to help the decoder identify the block type, we have to label the mixed block if the new BV c'_k of the block is not satisfying $c'_k \geq \tau$. To do labeling, we add or subtract full multiples of ϕ to or from the gray values of certain pixels. However, to reduce further the distortion, a fine-labeling procedure is employed to the proposed method and the details are specified in the following subsection.

2.2 Fine-labeling procedure

Without loss of generality, let H_{kb} be the kth host block of a host image, namely, $H_{kb} = \{g_i \mid i = 1,2,...,|H_{kb}|\}$ with $|H_{kb}| = n^2$ gray values and S_{kb} be the corresponding (temporary) stego-block $S_{kb} = \{s_i \mid i = 1,2,...,|S_{kb}|\}$ with $|S_{kb}| = n^2$ stego-pixels generated by Mod ϕ substitution. Also let the (sparse) kth minus-block M_{kb} be the $M_{kb} = \{m_i \mid 1 \leq i \leq n^2\}$ with $m_i = s_i - \phi$ if $|s_i - \phi - g_i| = \min\{|s_i + \phi - g_i|, |s_i - g_i|, |s_i - \phi - g_i|\}$, otherwise, m_i is a null; and the (sparse) kth plus-block P_{kb} be the $P_{kb} = \{p_i \mid 1 \leq i \leq n^2\}$ with $p_i = s_i + \phi$ if $|s_i + \phi - g_i| = \min\{|s_i + \phi - g_i|, |s_i - g_i|, |s_i - \phi - g_i|\}$, otherwise, p_i is a null.

Algorithm. The design of the fine-labeling procedure for Mod ϕ substitution.

Input: A stego-block S_{kb}, a minus-block M_{kb}, a plus-block P_{kb}, a control parameter τ, and an integer ϕ.

Output: A stego-block of which BV c'_k is satisfying $c'_k \geq \tau$.

Step 1. Choose the maximum value $m_{\max}$ from M_{kb}, presumably, $m_{\max}$ was located at the rth pixel of M_{kb} with $1 \leq r \leq n^2$, add ϕ to $m_{\max}$ to obtain $\tilde{m}_{\max} = m_{\max} + \phi$, and compute the BV c'_i of S_{kb} with $\tilde{m}_{\max}$ but excluding s_r .

Step 2. Choose the minimum value $m_{\min}$ from P_{kb}, presumably, $m_{\min}$ was located at the qth pixel of P_{kb} with $1 \leq q \leq n^2$, subtract ϕ from $m_{\min}$ to obtain $\tilde{m}_{\min} = m_{\min} - \phi$, and compute the BV c'_j of S_{kb} with $\tilde{m}_{\min}$ but excluding s_q .

Step 3. If both c'_i and c'_j are satisfying $c'_i \geq \tau$ and $c'_j \geq \tau$, respectively, then we employ the one from Steps 1 and 2 with the minimum distortion, and replace s_r (or s_q) by $\tilde{m}_{\max}$ (or $\tilde{m}_{\min}$), and go to Step 9. However, if either $c'_i \geq \tau$ or $c'_j \geq \tau$ is true, we replace either s_r by $\tilde{m}_{\max}$ or s_q by $\tilde{m}_{\min}$, and go to Step 9.

Step 4. Evaluate the BV c'_k by $c'_k = \tilde{m}_{\max} - \tilde{m}_{\min} + 1$. If $c'_k \geq \tau$, then substitute $\tilde{m}_{\max}$ and $\tilde{m}_{\min}$ for s_r and s_q , respectively, and go to Step 9.

Step 5. Choose the maximum value $s_{\max}$ of S_{kb}, add ϕ to $s_{\max}$ to get $\tilde{s}_{\max} = s_{\max} + \phi$, and compute the BV c'_l of S_{kb} with $\tilde{s}_{\max}$ instead of $s_{\max}$.

Step 6. Choose the minimum value $s_{\min}$ of S_{kb}, subtract ϕ from $s_{\min}$ to get $\tilde{s}_{\min} = s_{\min} - \phi$, and compute the BV c'_m of S_{kb} with $\tilde{s}_{\min}$ instead of $s_{\min}$.

Step 7. If both c'_l and c'_m are satisfying $c'_l \geq \tau$ and $c'_m \geq \tau$, respectively, then we take the one from Steps 5 and 6 with the minimum distortion, and replace $s_{\min}$ (or $s_{\max}$) of S_{kb} by $\tilde{s}_{\min}$ (or $\tilde{s}_{\max}$), and go to Step 9. However, if either $c'_l \geq \tau$ or $c'_m \geq \tau$ is true, then either $s_{\min}$ of S_{kb} was replaced by $\tilde{s}_{\min}$, or $s_{\max}$ of S_{kb} was replaced by $\tilde{s}_{\max}$, and go to Step 9.

Step 8. Substitute $\tilde{s}_{\min}$ and $\tilde{s}_{\max}$ for $s_{\min}$ and $s_{\max}$ of S_{kb}, respectively, and compute the new BV c'_k of S_{kb}. If $c'_k \geq \tau$, then go to Step 9, otherwise, repeat Step 5.

Step 9. Stop.

2.3 Feature-embedding procedure

Since most of the coefficients in the LH subband of IWT coefficients can be located in the range of -β and β, where β is a predefined integer, we therefore utilize this characteristic for data embedment. More specifically, instead of embedding data bits directly into the block, a feature-embedding procedure is used to mark a block so that it can be used to carry a bit 0, bit 1, or null bit. The feature-embedding procedure consists of two approaches, namely, X-sampling approach and directional-sampling approach. The details are specified in the following subsection.

2.3.1 X-sampling approach

Firstly, the diagonal and anti-diagonal coefficients of a block which taken from the LH subband of IWT coefficients are examined. Then, the block is marked as a bit 1 if all the examined coefficients are larger than or equal to 0 and less than β. Conversely, a bit 0 can be represented by a block which is satisfying with all the examined coefficients be less than 0 and greater than -β. For the clear specification of the procedure later, a block of the LH subband in the wavelet domain is referred to as a candidate block if this block can be used to represent either bit 1 or bit 0. Without loss of generality, let the 4 × 4 coefficients of the LH subband be a candidate block as shown in Fig. 1. During the embedding if an input bit is 1 and the values of all the 8-cefficient, namely, g_0, g_3, g_5, g_6, g_9, g_{10}, g_{12}, and g_{15} are larger than or equal to 0 and less than β, then do nothing, which means this block being used to carry a data bit 1; otherwise, any coefficient in the block which is less than 0 has to be forcedly changed to +1. In the case of input bit is 0 and the values of all the 8-cefficient are less than 0 and greater than -β, then do nothing, which means a data bit 0 being carried by this block; otherwise, any coefficient in the block which is larger than or equal to 0 has to be forcedly changed to -1.

At the receiver, the data bits are acquired by means of examining the candidate blocks. Let α_h be number of coefficients in a candidate block which is larger than or equal to 0, and α_l be number of coefficients in a candidate block which is less than 0. If α_h is greater than or equal to a predefined majority-voting parameter γ, then a data bit 1 is obtained. Similarly, if $\alpha_l \geq \gamma$, then a data bit 0 is obtained.

2.3.2 Directional-sampling approach

To further enlarge the hidden space, the directional-sampling approach is employed in the feature-embedding procedure. The process of bit-marked and bit-extracted for the directional-sampling approach is similar to those for the X-sampling approach. The primary difference is that the other eight coefficients, namely, g_1, g_2, g_4, g_8, g_7, g_{11}, g_{13}, and g_{14} of a candidate block shown in Fig. 1 are examined.

From the above specification, it seems that there are two data bits can be carried by a candidate block at most. However, a candidate block can be extended to carry four bits by the feature-embedding procedure but at the cost of diminishing the robustness of the proposed method.

2.4 Data embedment and extraction

The encoding part of the proposed method is summarized in the following algorithm.

Algorithm. The design of hiding method by using module substitution and feature-embedding techniques based on IWT.

Input: A test secret image treated as a (very long but finite) binary sequence, a control parameter τ and an integer ϕ for module substitution; a threshold β and a majority-voting γ for feature embedding.

Output: Both LL and LH subands of IWT coefficients contain the secret messages.

Methods:

Step 0: A host image is transformed to the wavelet domain by Haar transform.

Step 1: Input a $n \times n$ block from the LL subband of IWT not process yet, and compute the BV b_k of the block. However, if all the blocks are processed then go to Step 4.

Step 2: If $b_k \geq \tau$, then the number of $\lfloor n^2 \log_2 \phi \rfloor$ bits of data are embedded to the block by Mod ϕ substitution and the new BV c'_k of the mixed block is evaluated.

Step 3: If $c'_k < \tau$, then the fine-labeling policy was performed to the mixed block and go to Step 1; otherwise, go directly to Step 1.

Step 4: Input a $m \times m$ block from the LH subband of IWT not process yet, and examine each coefficient in the block.

Step 5: If this block is a candidate block qualified by X-sampling procedure then the block is ready for carrying a data bit.

Step 6: If this block is a candidate block also qualified by directional-sampling procedure then the block is used to carry the second bit and repeat Step 4, otherwise, go to Step 4.

Step 7: Stop.

Notice that both the LL and LH subbands of IWT were used to hide data. The main reason is that the LL subband of IWT coefficients can be viewed as a quarter-sized image of a host image. It is suitable for the proposed method to hide a message via module substitution. On the other hand, the data bits embedded into the LH subband of IWT coefficients has a merit of increasing the robustness of the proposed method. The other two subbands, namely, HL and HH remain unchanged due to the BV of those blocks are too large to be used for hiding data. In addition, the variation of the coefficients in both two subbands are too spread to be used for hiding message. After the embedding, the mixed image was obtained by performing inverse IWT.

The decoding part of the proposed method is a reverse process of the encoding one. First, a mixed image is decomposed to the wavelet domain, read into the next $n \times n$ block of LL subband IWT that is not processed yet, and compute the BV c_k of the block. If $c_k \geq \tau$, then the n^2-digit are extracted from the block by Mod ϕ and converted to $\lfloor n^2 \log_2 \phi \rfloor$

bits, otherwise, the block is ignored. The above procedure is repeated until the embedded bits are completely extracted. Subsequently, the second watermark is acquired by the following procedure. Read into a $m \times m$ block of LH subband IWT that is not processed yet. If this block is a candidate block identified by X-sampling then one data bit is extracted. If this block is also identified by directional-sampling then the second bit is obtained. Otherwise, the block is skipped because it contains no message. The process is repeated until all data bits are completely obtained.

3. Experimental Results

Several commonly used grayscale images of size 512 × 512 were used as host images. An image *Lena* sized 256 × 256 was used as the test data. The mixed images generated via the proposed method, by hiding the test image into four host images, were illustrated in Fig. 2. The block size is 3 × 3. A control parameter τ used here is 2 and an integer ϕ used for module substitution is 8. From Fig. 2 we can see that the perceptual quality of the mixed images is good. Their average peak signal-to-noise ratio (PSNR) is 39.32 dB with an embedding rate of 0.63. The embedding rate is a percentage defined as a ratio between the number bits being hidden and the size of a host image. Generally speaking, the larger the value of ϕ, the higher the embedding rate, and low the PSNR. However, if we increase the value of τ, then a lower embedding rate is obtained accompanied with a higher PSNR.

Two semi-fragile data hiding schemes vigorously suggested by authors in Refs. [11, 9] (Zou et al., 2006; Zhu et al., 2007) were compared with the proposed method. The performance of these methods is listed in Table 1. As can be seen from Table 1, the proposed method has the best PSNR among them even at a higher embedding rate. In addition, a prominent data-hiding scheme based on integer wavelet transform presented by authors in Ref. [10] (Xuan et al., 2002) was also used to compare the proposed method. The PSNR and embedding rate generated by their method and ours are given in Table 2. It is obvious that the proposed method provides a much better PSNR performance than Xuan et al.'s technique does under the same (or larger) hidden capacity. Notice as well the proposed method uses ony the LL subband of IWT (with a quarter-sized of host image) for the embedding while their scheme utilizes a full-sized host image.

Besides, the mixed images generated by the proposed method have the merits of resisting some image processing operations imposed by the third parties. To demonstrate the survived capability of the proposed method, a logo-image referred to as the 'Icon-pattern' of size 150 × 150 with two-color shown in Fig. 3(a) was used as the test watermark. Examples of the survived images extracted from intentionally distorted images are listed in Table 3. Here, the value of τ and ϕ are set to be 4 and 8, respectively. From Table 3 we can see that most of the survived images are easily recognized. Note that the extracted image at the last row of Table 3 is visually an inversion of the original logo-image, it is clearly recognizable. In fact, the normalized correlation (NC) of the survived image at the second-last row of Table 3 is 0. The NC is defined by

$$NC = \frac{\sum_i \sum_j [w(i,j) \times w'(i,j)]}{\sum_i \sum_j [w(i,j) \times w(i,j)]},$$

where $w(i,j)$ and $w'(i,j)$ represents the values of the original watermark and the extracted watermark, respectively.

Finally, to further promote the robustness of the proposed method, another logo-image referred to as the 'Text-pattern' of size 30 × 30 with two-color as shown in Fig. 3(b) was embedded into the LH subband of IWT coefficients. Some image processing operations, such as JPEG, noise addition, or low-pass filtering which originally caused the first logo-image 'Icon-pattern' failed to be extracted from the distorted images. Due to the embedding of the second watermark 'Text-pattern,' the survived images is now successfully obtained. Experiments introduced by the proposed method are given in Table 4. The block size is 4 × 4. The threshold β and majority-voting parameter used for feature embedding procedure are set to be 10 and 5, respectively. It can be seen from Table 4 that the extracted images are apparently recognizable. From Tables 3 and 4 we can conclude that the mixed images generated by the proposed method are free from several kinds of image processing operations.

4. Conclusions

In this paper, a dual-suband watermarking based on integer wavelet transform (IWT) is obtained. A host media is first transformed to the wavelet domain, various data bits are embedded into the LL subband of IWT coefficients by module substitution. To alleviate further the error, a fine-labeling procedure is employed to achieve the goal. In addition, to further increase the robustness of the proposed method, the LH subband of IWT coefficients is used for hiding an extra watermark by feature-embedding procedure. Experiments show that PSNR and embedding rate for the proposed method are not bad while the perceptual quality is good. The third parties are not easily aware of the existence of the embedded message. Moreover, the mixed images generated by the proposed method does survive from several kinds of image processing operations, such as JPEG2000, JPEG, uniform noise addition, low-pass filtering, horizontal cropping, edge sharpening, and brightness. The application of the proposed method can be found in image authentication and image tagging.

References

[1] I.J. Cox, I.J., & Linnartz, J.P. (1998). Some general methods for tampering with watermarks. IEEE J. Selected Area Comm., 16 (4), 587-593.

[2] Katzenbeisser, S. & Petitcolas, F.A.P. (Eds.) (2000). Information Hiding Techniques for Steganography and Digital Watermarking. MA: Artech House.

[3] Wang, Y., Doherty, J.F., & Van Dyck, R.E. (2002). A wavelet-based watermarking algorithm for ownership. IEEE T. Image Process., 11 (2), 77-88.

[4] Pan, J.S., Huang, H.C., & Jain, L.C. (Eds.) (2004). Intelligent Watermarking Techniques. Singapore: World Scientific.

[5] Noda, H., Spaulding, J., Shirazi, M.N., & Kawaguchi, E. (2002). Application of bit-plane decomposition steganography to JPEG2000 encoded images. IEEE T. Signal Process. Lett., 9 (12), 410-413.

[6] Chang, C.C., Hsiao, J.Y., & Chen, C.S. (2003). Finding optimal least-significant-bit substitution in image hiding by dynamic programming strategy. Pattern Recog., 36, 1583-1595.

[7] Chan, C.K., & Chen, L.M. (2004). Hiding data in images by simple LSB substitution. Pattern Recog., 37, 469-474.

[8] Wang, R.Z., & Chen, Y.S. (2006). High-payload image steganography using two-way block matching. IEEE T. Signal Process. Lett, 13 (3), 161-164.

[9] Zhu, X., Ho, A.T.S., & Marziliano, P. (2007). A new semi-fragile image watermarking with robust tampering restoration using irregular sampling. Signal Process.:Image Comm., 22, 515-528.

[10] Xuan, G., Zhu, J., Chen, J., Shi, Y.Q., Ni, Z., & Su, W. (2002). Distortionless data hiding based on integer wavelet transform. Electronics. Lett., 38 (25), 1646-1648.

[11] Zou, D., Shi, Y.Q., Ni, Z., & W. Su. (2006) A semi-fragile lossless digital watermarking scheme based on integer wavelet transform. IEEE T. Circuit and System for Video Tech., 16 (10), 1294-1300.

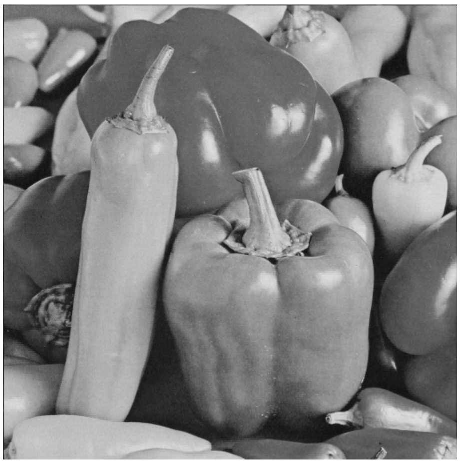
[12] Calderbank, A. R., Daubechies, I., Sweldens, W., & Yeo, B. (1998). Wavelet transforms that map integers to integers. Appl. Comp. Harmonic Anal., 5 (3), 332-369.

[13] Yang, C.Y., & Lin, J.C. (2006). Image hiding by base-oriented algorithm. Optical Eng., 45 (11), 117001-1~117001-10.

g_0	g_1	g_2	g_3
g_4	g_5	g_6	g_7
g_8	g_9	g_{10}	g_{11}
g_{12}	g_{13}	g_{14}	g_{15}

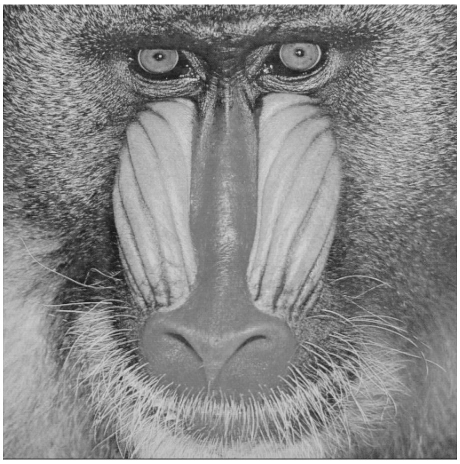
Fig. 1. A 4 × 4 block consists of 16 coefficients in the LH subband of wavelet domain.

(a) Lena



(a) Peppers

Fig. 2. The mixed images generated via the proposed method by hiding the test image into four 512 × 512 host images. (a) Lena, (b) Peppers, (c) Baboon, and (d) Jet.



(c) Baboon

(d) Jet

Fig. 2. (cont.)

(a) Icon-pattern

(b) Text-pattern

Fig. 3. Two test logo-images. (a) Icon-pattern and (b) Text-pattern.

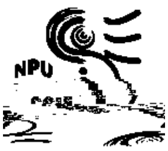
Table 1. Hiding performance generated by the proposed method and other schems on image Lena.

Methods	PSNR/ Embedding rate
Zou et al. technique (2006)	40.09/ 0.007
Zhu et al. technique (2007)	36.73/ 0.094
Proposed method	41.75/ 0.124

Table 2. Performance comparision between Xuan et al.'s technique (2002) and the proposed method on several images.

Host images	PSNR/ Embedding rate	
	Xuan et al. technique	Proposed method
Lena	36.64/ 0.33	41.01/ 0.33
Peppers	29.11/ 0.26	41.30/ 0.26
Baboon	32.76/ 0.06	41.68/ 0.22
Jet	36.30/ 0.36	41.42/ 0.36

Table 3. The survived images 'Icon-pattern' and the corresponding NC value.

Attacks	Survived images	NC
JPEG2000 (CR[+]=1.8)		0.9245
Horizontal cropping from the top by a factor of 33%		0.5881
Horizontal cropping from the bottom by a factor of 33%		0.6907
Edge sharpening		0.9471
Brightness with a factor of 5%		0

[+]CR stands for compression ratio.

Table 4. The survived images 'Text-pattern' and the corresponding NC value.

Attacks	Survived images	NC
JPEG2000 (CR=1.8)		1
JPEG2000 (CR=3.4)		0.9982
JPEG (QF=95)		0.9951
Uniform noise addition by a factor of 2%		0.9980
Median filtering		0.9963
Mean filtering		0.9950