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A Robust Procedure for Image Watermarking based on the Hermite Projection Method

Original scientific paper

A procedure for combined image watermarking and compression, based on the Hermite projection method is proposed. The Hermite coefficients obtained by using the Hermite expansion are used for watermark embedding. The image can be efficiently reconstructed by using a set of Hermite coefficients that is quite smaller than the number of original ones. Hence, the watermark embedding is actually done in the compressed domain, while maintaining still high image quality (measured by high PSNR). The efficiency of the proposed procedure is proven experimentally, showing high robustness even for very strong standard attacks. Moreover, the method is robust not only to the standard attacks, but to the geometrical attacks, as well. The proposed approach can be suitable for different copyright and ownership protection purposes, especially in real-applications that require image compression, such as multimedia and Internet applications, remote sensing and satellite imaging.

Key words: Image watermarking, Image compression, Hermite projection method, Hermite functions, Watermark robustness

Robusna procedura za umetanje vodenog žiga u sliku zasnovana na Hermitovoj projekcijskoj metodi. U radu je predložena procedura za umetanje vodenog žiga u sliku i kompresiju slike zasnovana na Hermitovoj projekcijskoj metodi. Odgovarajući koeficijenti, dobiveni kao rezultat primjene razvoja slike u red Hermitovih funkcija, korišteni su za umetanje vodenog žiga (watermark). S obzirom na to da se slika može efikasno rekonstruirati korištenjem znatno manjeg broja Hermitovih koeficijenata u odnosu na broj originalnih koeficijenata slike, umetanje vodenog žiga zapravo je provedeno u domeni kompresije, uz očuvanje visoke kvalitete slike (velika vrijednost PSNR). Učinkovitost predložene procedure ispitana je eksperimentalno i pokazuje značajnu otpornost na uobičajene napade. Osim uobičajenih, procedura pokazuje robusnost i na geometrijske napade. Predloženi pristup može biti korišten u različitim aplikacijama za zaštitu autorskih prava, naročito u aplikacijama koje ujedno zahtijevaju i kompresiju slike, kao što su multimedijske i internetske aplikacije, daljinsko očitavanje podataka i satelitska snimanja.

Ključne riječi: Hermitove funkcije, Hermitova projekcijska metoda, kompresija slike, otpornost vodenog žiga, umetanje vodenog žiga u sliku

1   INTRODUCTION

Digital watermarking has become an active research area focused on digital data protection [1],[2]. During the last decade, a number of watermarking procedure has been proposed for different purposes: ownership protection, protection and proof of copyrights, data authenticity protection, tracking of digital copies, copy and access control, etc, [3],[4]. In general, a watermarking procedure consists of watermark embedding and watermark detection. A secret signal called watermark is embedded into digital content that should be protected. In order to fulfill its purpose, the watermark should be detectable within the host data. Non-blind detection assumes the presence of the original image. However, the original image is not always available, and thus blind watermark detection is desirable.

Depending on the application, the watermark should satisfy a number of requirements. Perceptual transparency is one of the most important requirements. Namely, the watermark should be adapted to the host content, in order to avoid perceptible artifacts and signal quality degradations. Also, the watermark has to be robust in the presence of malicious or non-malicious processing called attacks. Generally, the watermark imperceptibility and robustness are mutually opposite requirements and the main challenge is to find the best compromise [2]. Namely, in order to be imperceptible, the watermark strength should be low, which directly affects its robustness. Thus, an efficient watermarking procedure has to provide the trade-off between

the imperceptibility and robustness.

Various approaches have been developed for image watermarking [4]-[8]. The watermarking can be done in the spatial or in the transform domain [5]-[9] (e.g., Discrete Fourier transform (DFT), Discrete Wavelet Transform (DWT) or Discrete Cosine Transform (DCT) domain). Generally, transform domain watermarking provides higher robustness to attacks. For instance, in order to improve robustness to quantization attacks, especially in the case of JPEG compression, the block-based DCT has been commonly employed [6],[7].

Most of the existing image watermarking procedures are performed in raw signal domain, while the efforts are made to provide the robustness to compression that may occur afterwards. Instead, several compressed-domain algorithms have been reported in the literature [10]-[12]. It means that the watermarking and compression are performed simultaneously. In this way, we may achieve that any further compression produces significant image degradation. In such a case, the watermark will be destroyed and probably undetectable, but at the cost of highly degraded image. Additionally, when the data are processed directly in the compressed domain, important savings can be made in terms of computational and memory requirements, processing speed, etc.

In this paper we propose an image watermarking procedure by using the Hermite expansion coefficients. By applying the Hermite projection method, the image is expanded into a certain number of Hermite coefficients, which are used for watermark embedding. It has been shown that the Hermite projection method is efficient in image filtering, compression, image deblocking and texture analysis [13]-[15]. The image can be efficiently reconstructed even when the number of Hermite functions is significantly lower than the number of original coefficients. Here, the Hermite projection method and corresponding coefficients are used to provide a simple and efficient watermarking method robust to various attacks. Especially, it is important to emphasize that the procedure performance is almost invariant to image darkening and lightening, while the high robustness is achieved also in the case of strong Gaussian and impulse noise. Additionally, the proposed method provides robustness in the presence of JPEG compression and geometrical attacks, such as rotation and scaling.

The paper is organized as follows. The Hermite projection method is presented in Section 2. The image watermarking procedure based on the Hermite expansion coefficients is proposed in Section 3. The experimental results are presented in Section 4, while the concluding remarks are given in Section 5.
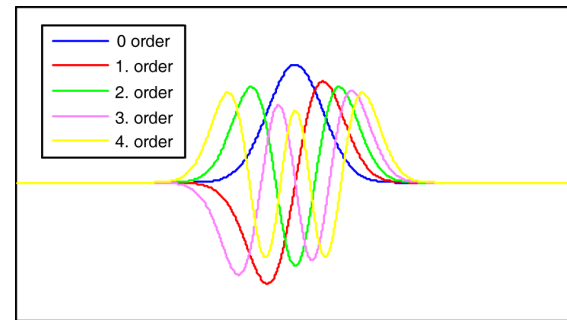

Fig. 1. Illustration of Hermite function for p=0,1,2,3,4

2 HERMITE PROJECTION METHOD

The Hermite projection method has been introduced in various image and speech processing applications [13]-[15]. The Hermite functions are used as the basis functions due to their favorable properties. They represent an independent set of orthogonal functions, with good localization in both signal and transform domain. Therefore, they can provide a unique representation of signals, while the coefficients of expansion are easily computed. Furthermore, by using the Hermite expansion, the signal energy is approximated by the numerical integral of the Gauss-Hermite type and converges more rapidly than the rectangle rule in the case of the DCT [16]. Therefore, the Hermite functions allow for a higher concentration of signal energy at lower frequencies and lead to better compression.

The Hermite functions can be easily obtained using recursive realization as follows [13], [14]:

$$\Psi_0(x) = \frac{1}{\sqrt[4]{\pi}}e^{-x^2/2}, \qquad \Psi_1(x) = \frac{\sqrt{2}x}{\sqrt[4]{\pi}}e^{-x^2/2},$$
$$\Psi_p(x) = x\sqrt{\frac{2}{p}}\Psi_{p-1}(x) - \sqrt{\frac{p-1}{p}}\Psi_{p-2}(x), \;\; \forall p \geq 2. \tag{1}$$

The illustration of the first few Hermite functions is given in Fig. 1. The first step in the Hermite projection method is to remove the baseline, since $\psi_p(x) \to 0$, $|x| \to \infty$. Assuming that the two-dimensional signal is given by the function $F(x, y)$, the baseline for a fixed coordinate y can be defined as [13]:

$$b_y(x) = F(0, y) + \frac{F(M, y) - F(0, y)}{M} \cdot x, \tag{2}$$

where $x = 0, \dots, M$ and $y = 1, \dots, M$, while the baseline is $b(x, y) = b_y(x)$ for a fixed y.

In order to perform the projection method into the entire 2D signal (image), the baseline should be calculated for each y. Note that the baseline could be also calculated along the y axis for a fixed x.

Furthermore, the baseline is subtracted from the original signal values:

$$f(x,y) = F(x,y) - b(x,y). \tag{3}$$

The Hermite projection method for the two-dimensional signal is defined as:

$$f(x,y) = \sum_{p=0}^{\infty} \sum_{q=0}^{\infty} h_{p,q} \psi_{p,q}(x,y). \tag{4}$$

The 2D projection method can be represented as a composition of 1D cases. Hence, for the sake of simplicity, we consider the Hermite projection method along the x axis only:

$$f_y(x) = \sum_{p=0}^{\infty} h_p \psi_p(x), \tag{5}$$

where $f_y(x) = f(x,y)$ holds for a fixed y, while the coefficients of Hermite expansion are calculated according to:

$$h_p(x) = \int_{-\infty}^{\infty} f_y(x) \psi_p(x) dx. \tag{6}$$

The Hermite expansion coefficients can be defined by using the Hermite polynomials, as follows:

$$h_p = \frac{1}{\alpha_p} \int_{-\infty}^{\infty} e^{-x^2} \left(f(x) e^{x^2/2} \right) H_p(x) dx, \tag{7}$$

where $Hp(x)$ is the Hermite polynomial:

$$H_p(x) = (-1)^p e^{x^2} \frac{d^p(e^{-x^2})}{dx^p}, \tag{8}$$

while α_p represents the Hermite normalization constant defined as:

$$\alpha_p = \sqrt{2^p p! \sqrt{\pi}}. \tag{9}$$

Note that each coefficient calculated using the Hermite expansion method contains the information about the whole image row. Since the even and odd Hermite functions tend to cosine and sine functions respectively, when $p \to \infty$, the Hermite series expansion provides the "frequencies" that are analogues to the Fourier frequencies.

3 IMAGE WATERMARKING USING HERMITE EXPANSION COEFFICIENTS

The watermarking procedure based on the Hermite expansion coefficients is proposed in this Section. The Hermite projection method is applied to image rows. In this way, an image can be represented by using a set of Hermite functions and Hermite coefficients as follows:

$$I(x,y) = \sum_{p=0}^{K-1} h_p \psi_p(x), \quad for \ y = 1, ..., M, \tag{10}$$

where I denotes an image of size $N \times M$, while K is the number of employed Hermite functions. A perfect image reconstruction can be achieved when the number of Hermite functions is equal to N (the length of x). However, it has been shown that the image can be efficiently reconstructed even by using a smaller number of Hermite functions, i.e., if $K < N$ holds. Hence, the image can be represented by using $K \times M$ Hermite coefficients. Additional savings can be achieved by applying the Hermite projection method over both coordinates.

In order to provide an efficient method for calculating the Hermite expansion coefficients, the simplified Gauss-Hermite quadrature formula is considered. Hence, the Hermite coefficients are calculated as follows:

$$h_p \approx \frac{1}{N} \sum_{m=1}^{N} \frac{\psi_p(x_m)}{(\psi_{N-1}(x_m))^2} I_y(x_m), \tag{11}$$

where x_m are zeros of Hermite polynomials.

3.1 Watermark embedding procedure

In the sequel, a set of Hermite coefficients, calculated for image rows, is used to embed the watermark. Usually, in order to avoid image quality degradation, it is preferable to omit a certain number of Hermite coefficients Q that correspond to the lower order Hermite functions. Namely, they can be observed as a low-frequency part of the image, which contains most of its energy. Altering these coefficients may lead to serious image quality degradation, especially having in mind that the watermark should be strong to assure successful detection in low-frequency region.

The results obtained in several experiments show that an appropriate number Q of coefficients that should be omitted from watermarking is equal to the third part (1/3) of the total number of coefficients per image row.

Therefore, the watermarked Hermite coefficients are obtained as follows:

$$\begin{aligned} h_{iw} &= h_i + \alpha w_i, \\ i &= \{Q+1, Q+2, ..., K-1\}, \end{aligned} \tag{12}$$

where α controls the watermark strength.

The set of Hermite coefficients used for image reconstruction can be written in the form:

$$h_{pw} = \begin{cases} h_{iw}, & for \ p = i, \\ h_p, & otherwise. \end{cases} \tag{13}$$

Finally, the watermarked image is reconstructed as:

$$I_w(x,y) = \sum_{p=0}^{K-1} h_{pw} \psi_p(x), \quad for \ y = 1, ..., M \tag{14}$$

3.2 Watermark detection procedure

A blind watermark detection procedure is done using the standard correlation detector, applied to the watermarked Hermite expansion coefficients:

$$Det(w) = \sum_i h_{iw} w_i. \qquad (15)$$

Note that for any wrong trial (wrong key), $Det(w) > Det(wrong)$ should hold.

The detection performance can be evaluated by using the detectability index from signal detection theory. Firstly, the detection is performed for all right keys and wrong trials and the mean values of detector responses are calculated: $\overline{D}(w)$ for watermarks (right keys) and $\overline{D}(wrong)$ for wrong trials. The standard deviations of detector responses (σ_w^2 for right keys and σ_{wrong}^2 for wrong trials) are calculated, as well. Considering these parameters, the measure of detection quality is obtained as:

$$R = \frac{\overline{D}(w) - \overline{D}(wrong)}{\sqrt{\sigma_w^2 + \sigma_{wrong}^2}}. \qquad (16)$$

The measure R is further used to calculate the probability of error P_{err} according to:

$$P_{err} = p_{Dw_w} \int_T^\infty P_{Dw_w}(x)dx + p_{Dw_r} \int_{-\infty}^T P_{Dw_r}(x)dx, \qquad (17)$$

where the indexes w_r and w_w have the same meaning as in the previous relation, T is a threshold, while equal priors $p_{Dw_w} = p_{Dw_r} = 1/2$ are assumed. By considering normal distribution for P_{Dw_w} and P_{Dw_r}, and $\sigma_{w_r}^2 = \sigma_{w_w}^2$, the minimization of *Perr* leads to the following relation:

$$P_{err}(R) = \frac{1}{4}erfc(\frac{R}{2}) - \frac{1}{4}erfc(-\frac{R}{2}) + \frac{1}{2}. \qquad (18)$$

By increasing the value of R the probability of error decreases. For example, $P_{err}(R = 2) = 0.0896$, $P_{err}(R = 3) = 0.0169$, while $P_{err}(R = 4) = 0.0023$.

4 EXPERIMENTAL RESULTS

In the sequel, the advantages of the proposed watermarking procedure are demonstrated on the examples. The procedure has been tested on a set of natural test images such as Sphinx, Airplane F16, Boat, Bridge and Lena. An original, a corresponding compressed and compressed-watermarked sample images are illustrated in Fig. 2a-c, respectively. The achieved PSNR after compression and watermarking is approximately 38-40 dB, indicating good image quality and watermark imperceptibility. The Hermite expansion method is performed along the image rows.
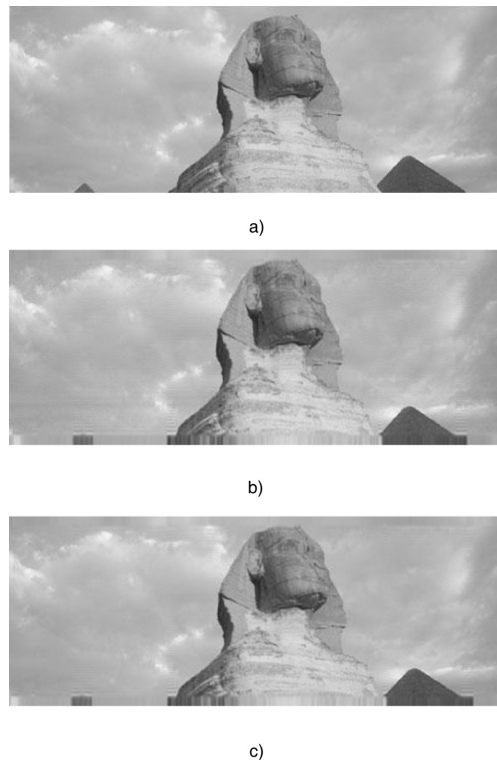

Fig. 2. a) original image, b) compressed image, c) compressed and watermarked image

The ratio between the number of Hermite coefficients used for the reconstruction and the number of original image coefficients is approximately:

$$\frac{K}{N} = 0.6.$$

Therefore, the compression ratio is approximately 60%.

The robustness of the procedure is tested under the following attacks: image darkening and lightening, JPEG compression with different quality factors (*QF*), impulse noise, Gaussian noise, image resize using nearest-neighbor interpolation, rotation including the cropping operation. The average measures of detection quality and the corresponding probabilities of errors, calculated according to (18), are given in Table 1.

Table 1. Measures of detection quality and probabilities of error

The detection is done for 100 watermarks. For each of them, 100 wrong keys (trials) are considered. The proposed procedure provides low probability of error, for most of the tested attacks, although strong attacks are applied in the experiments, as shown in Fig. 3.

The geometrical attacks are realized as follows. Image size is reduced approximately for 30%, and then increased
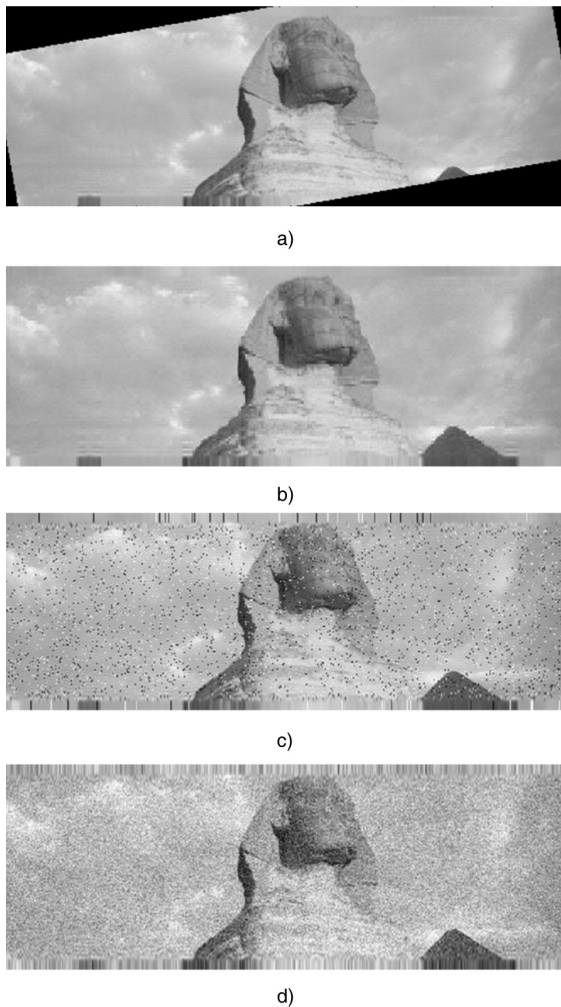
Fig. 3. Watermarked images after attacks: a) rotation and crop, b) resize to original dimensions, c) impulse noise, d) Gaussian noise

to the original size by using nearest-neighbor interpolation. Image is rotated for 10 degrees in one direction, cropped and interpolated, and then rotated for 10 degrees in the opposite direction, cropped and interpolated again. The detection results (for right and wrong keys) under the attacks considered in Table 1, are presented in Fig. 4a-f. Note that, in order to provide better readability of results, the detection is illustrated only for 30 watermarks (right keys) and 900 wrong trials.

Robustness to JPEG compression

The robustness has been tested for different JPEG quality factors, which defines the degree of loss in the compression process (it is specified on a scale between 0 and 100 where a factor of 100 represents the best image quality i.e., the least quantization). The quality factor is used to define

Table 1. Measures of detection quality and probabilities of error

TYPE OF ATTACK	R	P_{err}
No attack	9.8	10^{-13}
Darkening	9.3	10^{-11}
Lightening	9.35	10^{-11}
JPEG QF=80%	4.4	10^{-4}
JPEG QF=70%	3.5	10^{-3}
Image resize with nearest neighbor interpolation	6	10^{-5}
Image rotation for 10 degrees including cropping	3.66	10^{-3}
Impulse noise (density 0.05)	7	10^{-7}
Gaussian noise (variance 0.01)	7.2	10^{-7}

quantization matrices for different compression degrees as follows:

$$Q_{QF} = round(Q_{50} \cdot q),$$

where Q_{50} is the experimental quantization matrix (Fig. 5) defined for $QF = 50$, while q is defined by:

$$q = \begin{cases} 2 - 0.02QF, & for \quad QF \geq 50 \ , \\ \frac{50}{QF}, & for \quad QF < 50 \ . \end{cases}$$

The detection results for different QFs are given in Fig. 6, in terms of the probability of error. It is interesting to observe that the proposed method provides robustness to JPEG compression up to the quality factor of 70%. However, for higher compression degree (lower QF), the detection becomes unreliable. It is important to emphasize that the concept applied in this procedure is rather different than in the standard watermarking procedures. Namely, the watermarked image is already compressed (e.g., at 60% of the original one), and thus, additional JPEG compression significantly affects the image quality, and watermark as well. Consequently, we may say that any additional JPEG compression degree acts as a strong attack.

Robustness to noise

Additionally, in order to emphasize the robustness to noise, the watermark detection has been tested under Gaussian and impulse noise with different values of variance and pulse density. Namely, as a consequence of the Hermite functions expansion, the proposed procedure provides high level of noise robustness, as depicted in Fig. 7 and Fig. 8.

Hence, the proposed procedure provides low probabilities of errors even when the variance of Gaussian noise
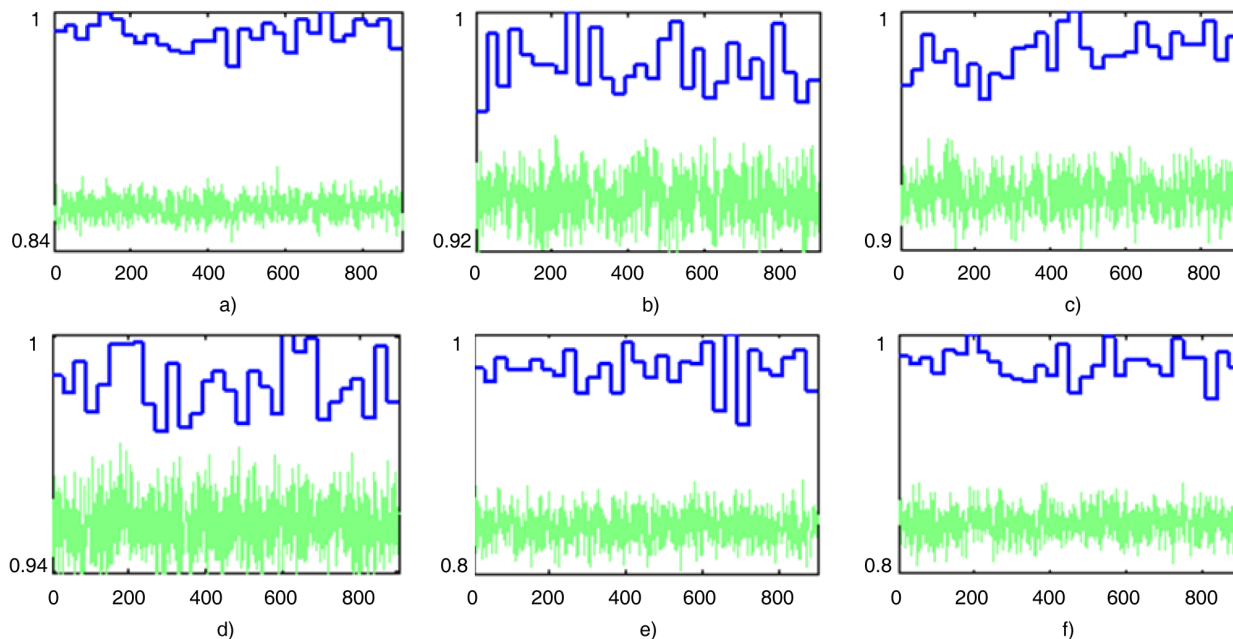
Fig. 4. Detection results for a set of right keys- watermarks (blue color) and wrong trials (green color): a) without attacks, b) JPEG 70%, c) image resize, d) image rotation, e) impulse noise, f) Gaussian noise

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Fig. 5. Coefficients of the quantization matrix Q_{50}

Fig. 6. Detection results under JPEG compression attack for different quality factors

and the density of impulse noise are above 0.01, which is not the case with the DCT-based procedure, where lower amounts of noise are acceptable (e.g. $\sigma=0.003$) [10]. Additionally, unlike the DCT based procedures, the proposed approach provides robustness to certain geometrical attacks, as well.

Comparison and calculation complexity

For the comparison, we consider a watermarking method from the literature which is also based on Hermite polynomials [17]. Therein, the Hermite transform was used instead of the Hermite expansion method applied in our approach. The Hermite transform provides multiscale image representation obtained as a polynomial transform with a Gaussian function. When compared to the proposed one, the method [17] does not consider the ad-
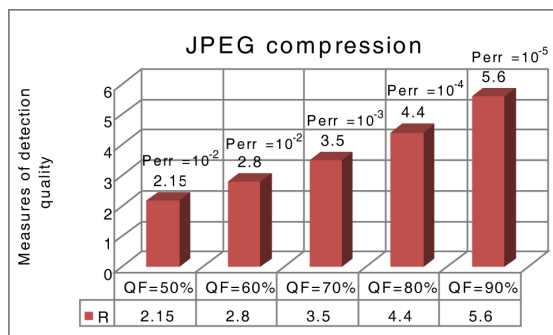
vantage of combined image compression and watermarking. Furthermore, the watermarking in the Hermite transform domain is fragile to geometric distortion [17]. Thus, it has to be combined with moment-based image normalization to provide robustness to affine transforms. However, when using image moments, the computational complexity becomes the major issue and difficulty for real-time implementation in software [18]. On the other hand, in our case, the computationally efficient fast Hermite projection method is available for realization of the Hermite expansion (more details could be found in [13]). Note that, the computational time for Hermite expansion in Matlab im-
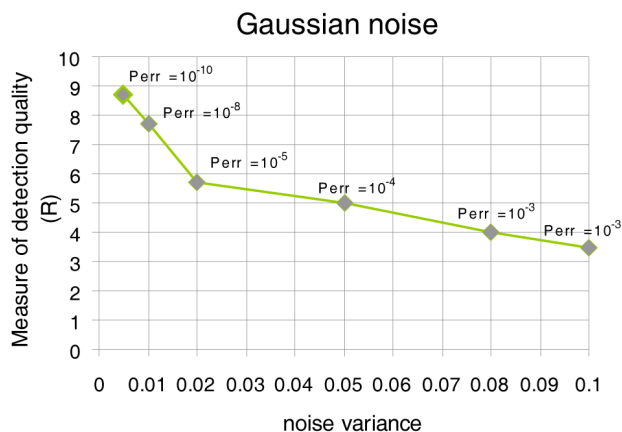
Gaussian noise

Fig. 7. Detection results in the presence of Gaussian noise
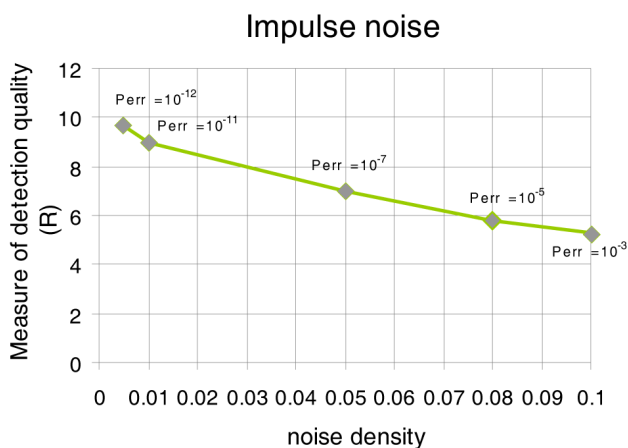
Impulse noise

Fig. 8. Detection results in the presence of impulse noise

plementation (Windows 7, Intel Processor 2.7 GHz, for 500 image rows and 120 Hermite functions) is 0.28s. In parallel realization (each image row is processed in parallel) the total computational time for the Hermite expansion reduces even to 0.003 s.

The rest of the procedure is the same as in other watermarking methods (additive watermark embedding and correlation detection) and requires only addition and multiplication operations.

5 CONCLUSION

A combined robust watermarking and compression procedure for image protection is proposed. By using the Hermite projection method, the image is expanded into set of Hermite functions and corresponding coefficients, used for watermark embedding. In the same time, the Hermite expansion method provides savings in terms of the number of coefficients required for signal reconstruction. It has been shown that the proposed method provides high robustness in the presence of attacks such as image darkening, lightening, JPEG compression, Gaussian and impulse noise, as well as some geometrical attacks. We may emphasize that the proposed combined approach provides a good trade-off among the robustness, transparency and compression ratio, which recommends it for a variety of applications that require both the compression and copyright protection, such as Internet applications, satellite imaging, remote sensing, art work preserving, etc.

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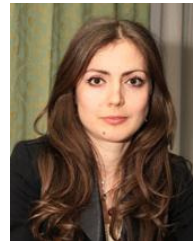
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