

IMPACT OF WAVELET DECOMPOSITION SCALE AND SIMPLEX THRESHOLDING ON IMAGE DENOISING

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Abstract: Image denoising is a pivotal problem in many image processing applications (segmentation, denoising, feature extraction, compression and so on). An effective wavelet-based image denoising mainly depends on the selection of an appropriate wavelet basis, decomposition to the appropriate scale, estimation of an optimal threshold, and function over the wavelet coefficients. Therefore, in this paper, at first, we report in detail the potential trends, such as the choice of wavelet basis and wavelet decomposition to the proper scale. Orthogonal, biorthogonal and reverse biorthogonal classes of various discrete wavelet filters are treated with different structured benchmark test images at various additive Gaussian noise levels. Also, we analysed the impact of PSNR in dB between each decomposition scale, which discloses the choice of resolution levels. Finally, we proposed a simple exponential (simplex) thresholding strategy to preserve the image features well. Our method is tested

with a Bayesian framework and compared with state-of-the-art thresholding methodologies involving traditional and hybrid wavelet coefficient thresholding. Experiments show that our system is feasible in terms of simplicity and outperforms the state-of-the-art filtering techniques.

Keywords: Wavelets, Decomposition, Simplex Thresholding, Image Denoising

I. INTRODUCTION

The multi-scale transforming ability of wavelets will process the signal at different scales or resolutions. They are very useful to isolate the discontinuities and transients; hence, it is convenient to handle and to conserve the prominent part of the time varying non-stationary signals [1]. Using the benefit of energy compaction and sparsity characteristics, DWT has been proven to represent most of the information can be represented in very few coefficients [2]. Also, simplicity and non-redundancy factors motivate the wavelet transform to occupy many fields of research and industry-based real-time applications, for instance, signal compression [3 - 4], noise suppression [5 - 6]. A corrupted image is an evil for compression, analysis, photography or publishing. Therefore, the degraded images basically need to be denoised before any kind of image processing. A vast literature has reported on the DWT-based image denoising techniques in which researchers have processed the wavelet coefficients with a variety of algorithms to improve the quality of reception. The three aspects in wavelet-based image denoising: wavelet transformation, coefficient modification and inverse wavelet transformation to the original domain, which include choice of wavelet type, choice of the shrinkage technique and applying a suitable threshold function to the wavelet coefficients [7].

Wavelet analysis. A finite energy 2D signal can be decomposed into a real-valued scale function (low pass filter) and three subbands in horizontal, vertical and diagonal orientations of wavelet function (high pass filter). Scale function measures the average fluctuations of the signal at different resolution levels; hence, it is less sensitive to the noise. While the wavelet function measures the difference fluctuations, hence it is more sensitive. On the other hand, the decomposition levels, in which each resolution level demands downsampling the separable analysis filters by a factor of two and up-sampling the synthesis filters by a factor of two. Hence, the choice of decomposition scale with the choice of wavelet basis plays a major role in wavelet-based denoising.

The desirable properties of wavelets: compact support – ensures the time frequency representation in terms of filter length and vanishing moments – bounds the ability of wavelets to represent information of a signal by reflecting the orthogonality to the lower order polynomials (that reduces the computational load). Also, it requires a trade-off between vanishing moments and the length of the filter to achieve significant reconstruction of the signal. Stationary wavelets from the Daubechies family are maximally flat, orthogonal and have high compact support; in turn, multi-resolution analysis is superior [8]. Biorthogonal, reverse biorthogonal, discrete Haar and Meyer wavelets are also analysed.

Conventional thresholding approaches. Thresholding functions need to shrink or scale the wavelet coefficients such that the noise is maximally suppressed while image features are preserved. Soft threshold produces smooth denoising but introduces wider bias [5], and keep or kill rule of hard threshold creates oscillations in the image due to discontinuous thresholding. Using these two basic approaches well-known threshold methods Visushrink, Rigsure,

Heysure, Minimax, SURE shrink, Bayeshrink, [9 - 11] have been deployed. Sub-band adaptive soft threshold is derived in [11] using a Bayesian framework. Bayes estimators are estimated from the observed data so that their risk functions minimise the Bayesian risk; performance with soft threshold is not only nearly optimal but also has an intuitive appeal compared with [5 - 10].

Non-conventional thresholding approaches. A non-negative garrotte shrinkage presented in [13] offered the advantages of both hard and soft shrinkage techniques in terms of risk and sensitivity to small disturbances in the input. To compromise the merits and demerits of soft and hard threshold, a general case [14] is proposed as a trimmed threshold, in which more turning provisions of parameter α create bias. Firm threshold [15], semisoft [16] revealed that the discontinuity behaviour of the hard threshold tends to have large variance and shrinks all large wavelet coefficients towards zero by the soft threshold that tends to have wider bias. Further, to improve the effectiveness of the shrinkage, a hybrid threshold technique is presented in [17], smooth sigmoid soft function in [18] practices to compromise the component is compared with a pre-set threshold value, in order to decide whether the coefficient is a part of the original signal or noisy, so that it does the best compromise between the noise content and the image structure.

II. Proposed System

The image of size $M \times N$, is corrupted by AWGN assumed to be stationary, independent, and zero mean,

$$\text{can be represented as, } y(i, j) = x(i, j) + \sigma n(i, j), \quad (1)$$

Where, $i = 0, 1, 2, \dots, M-1$, $j = 0, 1, 2, \dots, N-1$, and $y(i, j)$ = noisy image, $x(i, j)$ = original image, $n(i, j)$ = independent normal random variable, is considered as a high frequency signal added to the original signal and σ is the intensity of noise in $y(i, j)$. For simplicity, we write equation

$$(1) \text{ as } y = x + \sigma n \quad (2)$$

The aim here is to estimate $x' = y - n \approx x$, from the noisy observation y . This is achieved by transferring y into the wavelet domain by decomposing it into the proper levels and applying an optimal thresholding procedure. Selecting an appropriate threshold value is the prime step in the thresholding. Because, if the threshold value is too small, the restored image will still be noisy, and if it is too large, significant image characteristics will be lost along with the noise. That means, the coefficients of small magnitude are considered as pure noise and should be equated to zero [12]. The role of the threshold function is crucial, by which each component is compared with a pre-set threshold value, in order to decide whether the coefficient is a part of the original signal or noisy, so that it does the best compromise between the noise content and the image structure. We proposed a low complexity exponential-based simplex thresholding strategy and tested it with a Bayesian framework. The algorithm steps are as follows:

Step 1: Noisy image y of size N^2 is decomposed into scale $j=1, 2, \dots, J$ using DWT. Then the available subbands $s=LL_j, LH_j, HL_j, HH_j$. Note that LL_j is an approximation subband not to be modified.

Step 2: Using coefficients of HH_j , calculate the threshold value τ as

$$\tau = \begin{cases} \beta \frac{\sigma_s}{\sigma_n} & \text{if } \sigma_s^2 \leq \sigma_n^2 \\ \max(|\omega|), & \text{otherwise} \end{cases} \quad (3)$$

$$\text{Where, } B = \sqrt{\log(L_j)},$$

$$\sigma_s = 1.4828 \cdot \text{median}(|HH_j|) \quad (4)$$

σ_s = noise standard deviation of diagonal subband (HH)

under scale j ,

$$\sigma_s^2 = \frac{1}{L_j} \sum_{i=1}^{L_j} \omega_i^2 \quad (5)$$

$$\sigma_n = \sqrt{\max((\sigma_s^2 - \sigma_s^2), 0)} \quad (6)$$

σ_s^2 = noise variance of subband under consideration,

ω_i = wavelet coefficient in each scale J ,

L_j = Length of the j^{th} subband.

Step 3: Compute the subband-dependent threshold function using our proposed method

$$t = \exp\left(-\frac{|\omega_j|}{\tau}\right) \beta \in (0,1), \quad (7)$$

The modified coefficients of detail subbands is given by

$$\hat{\omega}_j = f(\omega_j, \tau) \quad (8)$$

Step 4: Inverse the wavelet transform to obtain the reconstructed image x' .

A. Equations

Number the equations consecutively. Equation numbers, within parentheses, are to position flush right, as in Eq. 1, using a right tab stop. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in

$$A = \pi r^2 \quad (1)$$

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "Eq. 1" or "Equation 1", not "(1)", especially at the beginning of a sentence: "Equation 1 is . . ."

III. FIGURES AND TABLES

Figure captions should be below the figures; table captions should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1” in the text, and “Figure 1” at the beginning of a sentence. Use 8 point Bookman Old Style for figure labels. Use words rather than symbols or abbreviations when writing figure-axis labels to avoid confusing the reader

TABLE 1 Table caption

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Fig. 1 Example of a figure caption

IV. CONCLUSION

Due to the advantage of less complexity over the shortcomings of poor directionality and less shift invariance of DWT, it has still attracted many researchers for further improvements in the area of image denoising. As observed from the recent survey, the success of wavelet-based image denoising depends on these factors: file format and category of the image, amount of noise added, threshold function and method, decomposition levels, and type of wavelet filter (orthogonal or biorthogonal) incorporated in the algorithm. In this regard, we conducted a comparative study of the wavelet-based many approaches to understand the nature of the wavelet basis and the satisfactory level of decomposition scale. Then, our proposed simplex thresholding scheme outperforms by compromising between denoising ability and computational cost when compared with the popular methods.

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