



King Saud University
**Journal of King Saud University –
Computer and Information Sciences**

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Restoration of stained old manuscripts via a hybrid wavelet and bilateral filtering system



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Received 6 May 2016; revised 10 August 2016; accepted 17 September 2016
Available online 23 September 2016

KEYWORDS

Wavelet;
Multi-scale analysis;
Bilateral filter;
Restoration;
Stained manuscripts

Abstract The conservation and restoration of old stained manuscripts is an activity devoted to the preservation and protection of things of historical and personal significance made mainly from paper, parchment, and skin. We present in this paper a hybrid implementation for de-noising and restoration of old degraded and stained manuscripts. This implementation is based on the statistical dependence of the wavelet coefficients of type Ortho-normal Wavelet Thresholding Algorithm based on the principle of Stein's Unbiased Risk-Estimate Linear Expansion of Thresholds (OWT SURE-LET) and the synergy with bilateral filtering. First, the non-biased quadratic risk Stein estimator is applied to de-noise images corrupted by white Gaussian noise. In a second step, an improved bilateral filter is introduced to smooth and eliminate unnecessary details with the advantage of preserving edges between image regions. Obtained results show the effectiveness of the proposed synergy compared to separated approaches both on gray scale images and stained old manuscript.

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1. Introduction

In many scientific fields, noise plays a fundamental role; it is the source of many difficulties. The noise in an image is the result of electronic noise from sensors and the quality of the digitizer in addition to long time degradation due to natural attacks. To fight against the effects of noise, it is necessary

to make the changes that take into account all image pixels during restoration process.

Recently Luisier and Blu (2007) have taken the principle of linear parameterization which they called LET and generalized it to the SURE-LET method. Donoho and Johnstone (1995) introduced the operator of wavelet coefficients soft thresholding to estimate and minimize the mean square error. This method is now known as Sure-Shrink. The current functions of soft and hard thresholding have proven their effectiveness in many denoising applications. They have been improved by considering non-linear estimators based on linear combinations of elementary functions (Pesquet and Leporini, 1997; Raphan and Simoncelli, 2007). Many works on SURE approaches were conducted in the context of multivariate

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Peer review under responsibility of King Saud University.



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denoising (Benazza-Benyahia and Pesquet, 2005; Chaux et al., 2008) and set-estimation (Combettes and Pesquet, 2004).

Bilateral filtering, which is a denoising technique added to the previous methods for smoothing and removing unnecessary details, is non-linear. It has been proposed in Aurich and Weule (1995) for image smoothing. It found its success in several applications such as image denoising (Tomasi and Manduchi, 1998; Liu et al., 2006), texture manipulation (Oh et al., 2001) compression (Durand and Dorsey, 2002) and photography enhancement (Eisemann and Durand, 2004; Petschnigg et al., 2004). It is also used in other areas such as mesh fairing (Fleishman et al., 2003), volumetric denoising (Wong et al., 2004), optical flow and motion estimation (Xiao et al., 2006), and video processing (Bennett and McMillan, 2005). Authors of Huang et al. (2016) made a quantitative comparison between five denoising algorithms for Chinese calligraphy images filtering.

In paper (Hedjam and Cheriet, 2013), they used multispectral imaging system to restore historical documents for the purpose of their recognition. The author of Alajlan (2010) introduced A novel recursive Algorithm for detail-preserving impulse noise removal.

In this work, the quality of noisy and stained old manuscript images is improved by taking advantages of bilateral filtering and a denoising algorithm based on the combination of the bilateral filter and OWT SURE-LET is proposed. The SURE-LET de-noising approach with ortho-normal wavelets and dependencies between scales (OWT SURE-LET) proposed by Luisier and Blu is used.

2. Denoising based on SURE-LET

Consider a real time signal x , with lengths L and L' before and after transformation respectively. This signal is perturbed by a white Gaussian noise centered real b with variance σ^2 independent of x . The actual observed signal is denoted: $y = x + b$. The conventional method for reconstructed signal \hat{x} quality assessment is the study of signal to noise ratio (SNR) defined as follows:

$$\text{SNR}(x, \hat{x}) = 10 \times \log_{10} \left(\frac{\|x\|}{\|\hat{x} - x\|} \right) \quad (1)$$

with $\|\hat{x} - x\|$ the square error. It is supposed that $G(y)$ estimates x such that the expectation $E(|\partial g_n(y)/\partial y_n|) < \infty$ for $1 \leq n \leq L$ (Blu and Luisier, 2007). Then we have:

$$E \left(\sum_{n=1}^N g_n(y) x_n \right) = E \left(\sum_{n=1}^N g_n(y) y_n \right) - \sigma^2 E \left(\sum_{n=1}^N \frac{\partial g_n(y)}{\partial y_n} \right) \quad (2)$$

The function is written as: $G = R\Theta D$ with D , R and Θ are the decomposition, reconstruction and thresholding operators, respectively. The components of G function are written, for all $y \in R^L$ and $1 \leq n \leq L$. In the other hand, the random variable is given by Blu and Luisier (2007):

$$\varepsilon = \|G(y) - y\|^2 + 2\sigma^2 \text{div}(G(y)) - L\sigma^2 \quad (3)$$

with: $\text{div}(G(y)) = \text{diag}(\text{DR})^T \Theta'(Y)$

$$\Theta'(Y) = \left(\frac{\partial \theta_l(Y_l)}{\partial Y_l} \right) \quad \text{for } L \leq l \leq L'.$$

In addition, by definition:

$$Y_l = (Dy)_l = \sum_{m=1}^L D_{lm} y_m \quad \text{for } L \leq l \leq L'.$$

2.1. SURE-LET denoising algorithm

Now, consider that the estimation function G can be written as a linear combination of K elementary functions G_k :

$$G(y) = \sum_{k=1}^K a_k G_k(y) \quad (4)$$

Writing G as a linear combination of elementary functions; each one is being introducing a thresholding function which is a LET part as it is used in Wong et al. (2004). The advantage of this formulation is allowing us to formulate the denoising problem as an optimization problem relatively simple to solve. To get the best possible noise reduction (in the sense of mean square error), it is sufficient to minimize the estimator e . To do so, each estimator is considered as a function of the parameter vector $a = (a_1, \dots, a_K)^T$. Differentiating this function with respect to each a_k , it is possible to rewrite the problem as a linear system to be solved.

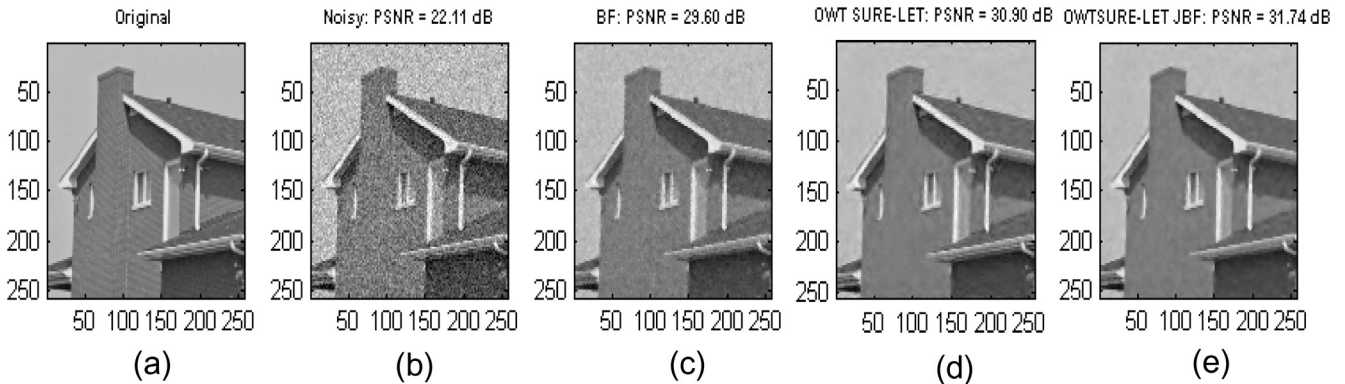


Figure 1 (a) Original image house, (b) noisy image, denoising by: (c) bilateral filtering (d) OWT-SURELET (e) OWT-SURELET JBF.

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