

# An iterative denoising system based on Wiener filtering with application to biomedical images



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## ABSTRACT

Biomedical image denoising systems are important for accurate clinical diagnosis. The purpose of this study is to present a simple and effective iterative multistep image denoising system based on Wiener filtering (WF) where the denoised image from one stage is the input to the next stage. The denoising process stops when a particular condition measured by image energy is adaptively achieved. The proposed iterative system is tested on real clinical images and performance is measured by the well-known peak-signal-to-noise-ratio (PSNR) statistic. Experimental results showed that the proposed iterative system outperforms conventional image denoising algorithms; including wavelet packet (WP), fourth order partial differential equation (FOPDE), nonlocal Euclidean means (NLEM), first order local statistics (FOLS), and single Wiener filter used as baseline model. The experimental results demonstrate that the proposed approach can remove noise automatically and effectively while edges and texture characteristics are preserved.

## 1. Introduction

Image enhancement and denoising are usually used to better visualize and interpret the content [1–6]. In this regard, several effective denoising systems for enhancement of biomedical images corrupted with noise during acquisition process have been proposed in the literature. The main goal of biomedical image denoising is to suppress noise from acquired image while preserving as much as possible its meaningful edges or texture details. Indeed, the accuracy of clinical diagnosis depends mainly on visual quality of acquired images. For instance, wavelet-based approach was adopted in [7], partial differential equation was employed in [8,9], adjusted empirical mode decomposition in [10], nonlocal means in [11], and Wiener filter was used in [12]. As a suitable filter to reduce the effects of non-stationary noise, Wiener filter was successful in denoising one and two dimensional biomedical signals [13,14], and also in image processing in general [15].

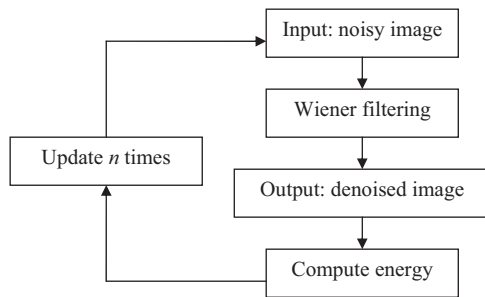
Recently, several iterative approaches were proposed in the literature to denoise images. For instance, an iterative method based on fuzzy sub-pixel fractional partial difference was proposed in [16]. The proposed iterative method was successful in enhancing contrast of noisy image. However, it is a computationally complex method [16]. An iterative generalized cross-validation and fast translation invariant approach for image denoising was proposed in [17]. The approach is based on wavelet thresholding algorithm and found to be fast and effective as it reduces the computation cost of the standard generalized

cross-validation method and efficiently suppresses the Pseudo-Gibbs phenomena. However, it yields to slight blurring due to simplicity of the soft-threshold function which is necessary to accelerate computation. The authors in [18] proposed a noise adjusted iterative low-rank matrix approximation method. For instance, a patchwise randomized singular value decomposition is first applied to denoise the image. Then, an iterative regularization technique based on low-rank matrix approximation is employed to further separate the signal and noise. The proposed algorithm requires an appropriate stopping parameter to be pre-determined along with number of iterations. More recently, the authors in [19] proposed an automatic filtering convergence method using PSNR checking and filtered pixel detection for iterative impulse noise filters by defining an adaptive stop criterion to filter a corrupted image within finite steps. However, the improved iterative impulse noise filters fail to discriminate both impulse noise and high-frequency signal contained in high-frequency image.

In this paper, a simple and effective multistep system for image denoising based on Wiener filtering is presented. The Wiener filter is chosen as the basis of our proposed multistep denoising system for three reasons. First, it is effective in reducing the effects of non-stationary noise [14]. Second, it incorporates both the degradation function and statistical characteristics of noise into the restoration process [15]. Third, it can remove the additive noise and invert the blurring simultaneously [15].

The proposed multistep system for image denoising based on Wiener filtering is described as follows. In the first step, the Wiener

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**Fig. 1.** Block diagram of the proposed multistage denoising system. The procedure is repeated until there is a decrease in energy of the denoised image.

filter is applied to the noisy image. In the second step, the obtained denoised image in previous step is processed by Wiener filter for improving image quality by removing the remaining noise. The resulting denoised image in second step is further processed by Wiener filter in third step. In other words, the proposed denoising system is composed of several stages/steps where each obtained denoised image is further processed with Wiener filter. The process continues until obtaining a better quality of the image. For instance, the multistep processing stops when a given condition is automatically satisfied.

In order to evaluate the proposed multistep denoising system, a set of three biomedical images is considered. In particular, the real clinical test images are degraded by various levels of Gaussian noise. In addition, the effectiveness of the proposed multistage denoising system is compared with that of conventional existing methods; including wavelet packet (WP) [20], fourth order partial differential equation (PDE) [21], nonlocal Euclidean mean (NLEM) [22], and first order local statistics (FOLS) [23]. Finally, the performances of all algorithms will be evaluated in terms of the well-known peak-signal-to-noise ratio (PSNR).

The remainder of this paper is organized as follows: Section 2 presents our proposed multistep denoising system along with comparison techniques. Section 3 presents the experimental results. Finally, Section 4 concludes our study.

## 2. Methods

In this section, our multistep denoising system and comparison methods are presented. In addition, the peak-signal-to-noise ratio used as main performance measure is presented.

### 2.1. Proposed multistep system based on Wiener filtering

In order to provide a good quality of denoised biomedical image, we build a multistage denoising system based on several iterations of Wiener filter. Indeed, the goal is to iteratively apply Wiener filter to obtained denoised images until expected denoising performance stops improving. For instance, the Wiener filter is applied to the initial noisy

image in the first iteration. The obtained denoised image in previous iteration is filtered by Wiener filter in the second iteration. The resulting denoised image in second iteration step is further processed by Wiener filter in third iteration; and so on. The number of iterations is not fixed, but is adaptive as the overall denoising process automatically stops when energy of the denoised image in iteration  $n$  is smaller than that in iteration  $n-1$ . In this regard, there is no further improvement in the denoising outcome.

The algorithm of the proposed Wiener-based system for image denoising is described as follows:

- Apply Wiener filter to noisy image.
- Compute energy ( $E_1$ ) of the denoised image.
- Apply Wiener filter to denoised image obtained in (b).
- Compute  $E_2$  of the denoised image in (c).
- If  $E_2 > E_1$  then apply Wiener filter to denoised image obtained in (c) and continue to next stage  $n$ ; else stop. This is the update stage.
- Repeat (b) to (e)  $n$  times until  $E_n < E_{n-1}$

For illustration purpose, the proposed multistep (iterative) denoising system based on Wiener filtering is summarized in Fig. 1:

The Wiener filter [24] is an adaptive technique based on local mean ( $\mu$ ) and variance ( $\sigma^2$ ) around each pixel of a noisy image  $a(n_1, n_2)$ . In particular, Wiener filter creates a pixel wise filtering using estimated mean and variance to obtain an estimated or denoised image  $b(n_1, n_2)$  given by:

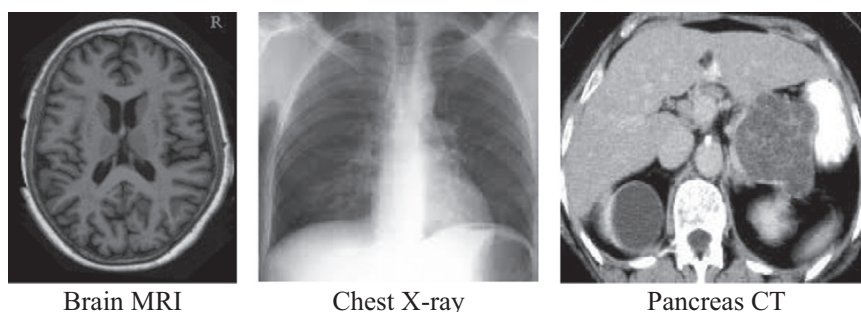
$$E(u) = \int_{\Omega} f(|\nabla^2 u|) dx dy. \quad (1)$$

where  $v^2$  is the noise variance that could be estimated as average of all local estimated variances.

The methods used for comparison purpose; namely the wavelet packet (WP) [20], fourth order partial differential equation (PDE) [21], nonlocal Euclidean means (NLEM) [22], and first order local statistics (FOLS) [23]; are described next.

### 2.2. Comparison methods and performance measure

Following the classical approach for image denoising based on wavelet transform, the noisy image is decomposed by using discrete wavelet transform (DWT) [25] to decompose it into low-low, low-high, high-low, and high-high sub-band coefficients. The denoised signal is obtained by thresholding the obtained wavelet coefficients. Then, an inverse DWT is performed to recover the denoised signal. In this paper, wavelet packet transform (WPT) [20,26] that performs a complete analysis of the image at all subbands including both approximation and detail coefficients; is employed for denoising purpose. For the WPT thresholding technique, we employ the Daubechies-4 as mother wavelet at third level of decomposition. The optimal threshold value is determined by minimizing Stein's unbiased risk estimator (SURE) [25]. Indeed, denoising by wavelet transform is usually performed by thresholding where coefficients smaller than a specific threshold are



**Fig. 2.** Original images used for experiments.

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