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A new speckle filtering method for ultrasound images based on a weighted multiplicative total variation

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ABSTRACT

Ultrasound images are corrupted by a multiplicative noise – the speckle – which makes hard high level image analysis. In order to solve the difficulty of designing a filter for an effective speckle removing, we propose a new approach for de-noising images while preserving important features. This method combines a data misfit function based on Loupas et al. model and a Weighted Total Variation (WTV) function as a multiplicative factor in the cost functional. The de-noising process is performed using a multiplicative regularization method through an adaptive window whose shapes, sizes and orientations vary with the image structure. Instead of performing the smoothing uniformly, the process is achieved in preferred orientations, more in homogeneous areas than in detailed ones to preserve region boundaries while reducing speckle noise within regions. Quantitative results on synthetic and real images have demonstrated the efficiency and the robustness of the proposed method compared to well-established and state-of-the-art methods. The speckle is removed while edges and structural details of the image are preserved.

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1. Introduction

Ultrasound (US) is a widely used, safe medical diagnostic technique, due to its noninvasive nature, low cost, capability of forming real time imaging and the continuing improvements in image quality [1]. However, the main weakness of medical ultrasound image is the poor quality which interferes with multiplicative speckle noise that degrades the visual evaluation. This phenomenon is common to laser, sonar and synthetic aperture radar (SAR) imagery [2,3]. Speckle pattern is a form of a multiplicative noise. It depends on the structure of imaged tissue and various imaging parameters. Speckle has a negative impact on medical US images. It tends to reduce the image contrast to make obscure and blur image details which affect the human ability to identify normal and pathological tissue. It also degrades the speed and accuracy of ultrasound image processing tasks such as segmentation and registration. The macroscopic properties of studied biological tissues demonstrate that speckle noise tends to mask important details, consequently confusing the diagnosis. The speckle noise is a random process. It does not provide enough information which lead to a wide subject of investigations [2,4–11]. In order to improve the quality of US images, it is imperative to reduce this speckle without destroying the image features. Recently, it has been demonstrated that Total Variation (TV) methods are relevant models for de-noising images in different cases [12–16]. Accordingly, in this paper a variational model to deal with speckle noise in real ultrasound images is proposed. To eliminate the choice of the artificial

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regularization parameter, the energy functional is chosen as the product of a data fidelity term and a TV regularization term. The multiplicative TV regularization was proposed by van den Berg et al. [17] to solve contrast source inversion problem. In this work, we propose an adaptation of the multiplicative regularization to a dedicated US noise model [11] using a locally adaptive energy minimization based on weighted total variation model. To de-noise US images, the challenge is to enhance and preserve important features; the proposed method is applied on a locally adaptive window, where shapes, sizes and orientations varying with image structures [18]. This proposed Adaptive Weighted Multiplicative Total Variation Regularization method is denoted as AWMTVR.

This paper is organized as follows: in Section 2, we give an overview of speckle filters and related methods. Section 3 describes our adaptive weighted multiplicative Total Variation Filter. Quantitative results on artificial and real US images are presented in Section 4; Section 5 concludes our contribution and describes the future works.

2. Speckle filtering: related works

The need for image processing methods to suppress speckle noise has been proven to enhance image quality and increase diagnostics potential for medical ultrasound images. Therefore image de-noising problem has been studied widely. A number of locally adaptive statistic filters based on multiplicative speckle noise were developed. The typical filtering methods include Lee filter [19], Kuan filter [20], Frost filter [21], enhanced Lee filter and enhanced Frost filter [22]. These filters reduce the speckle noise by adjusting the size of the filtering window. They also decrease the image resolution inside this latter, which makes image edges and linear targets blurry. Some edge information is saved well, but speckle is not fully smoothed. Recently, inverse problems such as image restoration appeared in many applications like remote sensing, medical imaging, astronomy and digital photography [23]. Most of inverse problems are nonlinear and highly ill-posed. In order to solve this problem, a large number of techniques have been developed. One of the most well-known techniques is the Total Variation minimization and regularization. Total variation (TV) is a powerful concept for robust estimation [24]. It was first introduced for regularization in image restoration [25]. It has been extensively used with great success for inverse problems, because the TV has the ability of smoothing noise in flat image areas and at the same time preserves finer image details such as edges and texture, due to the piecewise smooth regularization property of the TV norm. It received many theoretical research attention. It has been used in many signal and image processing applications [16,26–32]. Nevertheless, TV- based image restoration has some drawbacks. One of them is the regularization parameter selection. For this purpose, numerous studies were conducted [33–38]. A solution is to use the multiplicative type of regularization of inverse algorithms, eliminating the choice of the artificial regularization parameters [17]. However, most of existing multiplicative regularization is applied on electromagnetic problems [39–45]. To our knowledge, multiplicative regularization approach has not been applied for speckle reduction in US images. In this aim, we implement the multiplicative regularization within the framework of speckled image de-noising. We combine the data misfit function based on the Loupas et al. noise model [11] and a weighted total variation function as a multiplicative factor in the cost functional. The computation of the appropriate parameter is controlled by the minimization process itself. The minimization is achieved through local adaptive windows. Experiments have proven the excellent performance of the proposed method which constitutes a robust approach for speckled images.

3. Proposed method

Several multiplicative regularization techniques have been developed in different fields, but there are none specific to speckle suppression. Therefore, a new Speckle reduction technique – an Adaptive Weighted Multiplicative Total Variation Regularization method, AWMTVR method – is instituted to reduce the speckle. We first determine the noise model used for US images with a new formulation of the proposed method.

3.1. Notations

The notations below are used.

$d(x,y)$	observed noisy image
$\bar{d}(x,y)$	mean image
$f(x,y)$	original image
$\hat{f}(x,y)$	approximative solution
$b(x,y)$	zero-mean Gaussian noise
$J_{TV}(f,\Omega)$	weighted total variation function
$W(f)$	weight function
$J_R(f,\Omega)$	regularization function
$J(d,f,\Omega)$	cost function
η_R	normalization factor of the regularization function
δ^2	positive steering parameter
ζ	conjugate gradient update image
g	cost function gradient
g_{TV}	gradient of the total variation function
g_R	gradient of the regularization function
Ω	a bounded domain $\Omega \subset \Re^2$
N_Ω	area of the domain Ω

3.2. Noise model in US images

A relevant noise model for US image de-noising cannot be easily described. Generally, complex image formation process is considered. Recent research in the US image domain proves that multiplicative speckle noise distribution can be approximated by a Gamma distribution [46] or a Fisher–Tippett distribution [47]. Consequently, the general speckle noise model should be chosen as follows:

$$d(x,y) = f(x,y) + f(x,y)^m \cdot b(x,y) \tag{1}$$

$f(x,y)$ is the original image, $d(x,y)$ is the observed image, $b(x,y) \sim \aleph(0,\sigma^2)$ is a zero-mean Gaussian noise. This model

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