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Periodic Noise Removal in Strain and Natural Images Using 2-D Fast Fourier Transform

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Abstract - This paper presents a 2-D FFT removal algorithm for reducing the periodic noise in natural and strain images. For the periodic pattern of the artifacts, we apply the 2-D FFT on the strain and natural images to extract and remove the peaks which are corresponding to periodic noise in the frequency domain. Further the mean filter applied to get more effective results. The performance of the proposed method is tested on both natural and strain images. The results of proposed method is compared with the mean filter based periodic noise removal and found that the proposed method significantly improved for the noise removal.

Keywords— *Priodic Noise Removal; 2-D FFT; Strain Images.*

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I. INTRODUCTION

A. Motivation

Digital images play an important role in daily life application such as television, ultrasound imaging, magnetic resonance imaging, computer tomography as well as in areas of research and technology. Image acquisition is the process of obtaining a digitized image from a real world source. Each step in the acquisition process may introduce random changes into the values of pixels in the image. These changes are called noise. Let F'(x, y) be the noisy digitized version of the ideal image, F(x,y) and n(x,y) be a noise function which returns random values coming from an arbitrary distribution. Then additive noise can be described by Eq. (1)

$$F(x,y)= F'(x,y)+ n(x,y) \qquad (1)$$

Elastography is a method for imaging the elastic properties of compliant tissues that produces gray-scale strain or elasticity images called elastograms. It is has been shown to be useful in differentiating cancers from non-cancers in the breast, identifying tumors in the prostate, imaging the myocardium, studying DVT, studying renal pathology, monitoring thermal changes, in intravascular applications, and in obtaining the mechanical structural properties of different tissue types.

S. Kaisar Alam and J. Ophir have proposed the effect of temporal stretching of the post-compression echo signal on the cross-correlation function will be investigated dong the same line. The applied compression is assumed to be uniform; the de-correlations introduced by the lateral and elevation& tissue movements are ignored. The theory predicts that if the post-compression echo signals are stretched before the TDE step, then for small strains, the cross-correlation function very closely resembles the autocorrelation function [1]. S. Kaisar Alam et al. introduce a novel estimator that uses the stretch factor itself as an estimator of the strain. It uses an iterative algorithm that adaptively maximizes the correlation between the pre- and post-compression echo signals by appropriately stretching the latter. They investigate the performance of this adaptive strain estimator using simulated and experimental data. The estimator has exhibited a vastly superior performance compared with the conventional gradient-based estimator [2]. Varghese et al. are reduced the artifacts by a combination of small compressions and temporal stretching of the post-compression signal. Random noise effects in the resulting elastograms are reduced by averaging several elastograms, obtained from successive mall compressions (assuming that the errors are uncorrelated). Multi-compression averaging with temporal stretching is shown to increase the signal-to-noise ratio in the elastogram by an order of magnitude, without sacrificing sensitivity, resolution or dynamic range [3]. Techavipoo and Varghese have proposed the Wavelet shrinkage denoising of the displacement estimates to reduce noise artifacts, especially at high overlaps in elastography. Correlated errors in the displacement estimates increase dramatically with an increase in the overlap between the data segments. These increased correlated errors (due to the increased correlation or similarity between consecutive displacement estimates) generate the so-called "worm" artefact in elastography. However, increases in overlap on the order of 90% or higher are essential to improve axial resolution in elastography. The use of wavelet denoising significantly reduces errors in the displacement estimates, thereby reducing the worm artefacts, without compromising on edge (high-frequency or detail) information in the elastogram. Wavelet denoising is a term used to characterize noise rejection by thresholding the wavelet coefficients. Worm artefacts can also be reduced using a low-pass filter; however, low-pass filtering of the displacement estimates does not preserve local information such as abrupt change in slopes, causing the smoothing of edges in the elastograms [4].

Furthermore, spatial-angular compounding techniques have been applied to strain imaging for reducing artifact noise [5], [6], [7], [8]. Angular sub-elastograms estimated at different insonification angles are appropriately weighted (depending on the insonification angle), then averaged to produce a spatially compounded elastogram. These are based from principles in speckle reduction from conventional 2D B-mode images [9], [10].

Periodic noise is noise which is created by machinery, engines and other types of cyclic processes. Because the periodicity of the noise patterns makes spatial frequency domain denoising methods applicable, a 2-D Fourier transform (FT) artifact suppression algorithm to be proposed that applies the 2-D FFT in the strain image to extract and remove the peaks which are corresponding to the artifacts in the frequency domain. The 2-D FFT can provide the information in one more dimension compared with the 1-D FFT from which we can be better to differentiate the real artifacts and some useful information.

B. Main Contribution

The 2-D FFT removal algorithm for reducing the periodic noise in natural and strain images is proposed in this paper. For the periodic pattern of the artifacts, we apply the 2-D FFT on the strain and natural images to extract and remove the peaks which are corresponding to periodic noise in the frequency domain. Further the mean filter applied to get more effective results. The performance of each filter is compared using parameter PSNR (Peak Signal to Noise Ratio).

The organization of the paper as follows: In section I, a brief review of image denoising and related work is given. Section II, presents a concise review of image artifact noise reduction. Section III, presents the noise removal algotithm and proposed system framework. Experimental results and discussions are given in section IV. Based on above work conclusions are derived in section V.

II. IMAGING ARTIFACT NOISE REDUCTION

The process of generating an elastogram can be viewed as a two-step process: the mapping of the elastic modulus distribution in tissue into a distribution of strains, and the mapping of the distribution of strains into elastogram.

In ultrasound elastography, motion tracking between two successive frames plays a key role for strain estimation. An iterative method involving calculating the zeros of phase using Newton’s method performs well in theory with two preconditions: motions are only along ultrasound scan line direction and only rigid motion exists [11, 12]. However, in real situations, neither of the two pre-condition holds. First of all, the motion is not ideal rigid shift. Secondly, in-plane and out of plane tissue motions cause an inherent change in speckle shape, which is called decorrelation. Moreover, electronic noises in real ultrasound system may make high number of Newton iterations unnecessary for converged solutions.

To make the strain imaging more stable visually and suppress errors in successive strain frames, post-processing methods are used, including smoothing, persistence and image enhancement.

In general, strains are generated when an external force is performed. Without external force, the estimated strain value is noisy and not reliable. The uniformity of force pressing/release is an important factor in generating good strain images.

A. Image Restoration in Frequency Domains

According to the principle of Fourier transform, a spatial image size in M*N will be stored as a 2-D array, with the size of M*2N where each column has 2N numbers of real and imaginary parts alternating.

Algorithms 1: Peak detection in the frequency domain.

1. Define a detection route such that the detected peaks are stored in an ascending order in terms of the distance to the origin (where the origin is the centre of the spectrum domain). Note that if only processes in the right half space of the centre because of the symmetry of the peaks (impulses) in the spectrum domain.
2. Define a local window of the size X*Y (where X and Y are odd) and find the maximum from the window pixels.
3. If the current pixel is just the same as the local maximum and also it is above a given threshold, it will be a new detected peak.

To remove the periodic pattern of an image, we can first take the 2-D FFT to the image and detect the positions of the impulses in spectrum, see Algorithm 1. The image is then restored by using a band-reject filter with a proper dimension around the impulses. The restoration algorithm for a single impulse is as follows:

Algorithms 2: Image restoration from frequency domain to spatial domain.

1. Define the position of the impulse as P (Δx, Δy) where Δx and Δy are the relative positions to the origin in the spectrum domain.

2. In the real/imaginary frequency domain, define the following four areas according to the sign of Δy (set a positive Δx due to the symmetric of the impulses):

a) D1: center at (Δx, 2Δy) with the dimension of $2\delta_x \times 4\delta_y$ only if $\Delta y > 0$.

b) D2: center at (X_{dim}- Δx, $2Y_{dim}$- 2Δy) with the dimension of $2\delta_x \times 4\delta_y$ only if $\Delta y > 0$. (The image will be stored as a 2-D array, with the size of dim dim $X_{dim} \times 2Y_{dim}$ after Fourier Transform)

c) E1: center at (Δx, $2Y_{dim}$+2Δy) with the dimension of $2\delta_x \times 4\delta_y$ only if $\Delta y < 0$.

d) E2: center at (X_{dim}-Δx, -2Δy) with the dimension of $2\delta_x \times 4\delta_y$ only if $\Delta y < 0$.

3. Set all the real and imaginary values to be zero in areas D1 and D2 if $\Delta y > 0$, or in areas E1 and E2 if $\Delta y < 0$.

Take the inverse 2-D FFT and back to the spatial domain.

III. NOISE REMOVAL ALGORITHM

A. Mean Filter

Igor Aizenberg and Constantine Butakoff have proposed the mean filter based periodic noise removal in frequency domain.

The idea behind this filter is to analyze the image spectrum amplitude using a scanning window of a size N×N. To choose the elements within the window for the comparison, a mask is defined. This mask can be defined as a binary matrix of a dimension N×N. The choice of the elements is organized in the following way. A local window has to be covered by the mask. If the element of the mask corresponding to the spectrum amplitude value in the local window equals to 1 then this value is included in the local mean calculation. The central element of the window, which is the amplitude of the spectral coefficient to be analyzed and filtered (the central coefficient within the window), must be excluded from the local mean calculation. It means that the corresponding element of the mask must be equal to zero. I.e.:

$$M = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad (2)$$

$$S_{kl} = \frac{\sum_{i=-\frac{N}{2}}^{\frac{N}{2}} \sum_{j=-\frac{N}{2}}^{\frac{N}{2}} M_{ij} \left| X_{k+i,l+j} \right|}{T} \quad (3)$$

where M is the mask, X is a spectrum amplitude, T is a number of nonzero elements in M, S_{kl} is a mean in a local N×N window around the $(k,l)^{th}$ spectral coefficient. The filtering criterion is the following:

$$\frac{K_{kl}}{S_{kl}} > Th \quad (4)$$

where Th is the threshold to identify the noise peaks. Further details about mean filter are available in [13].

B. Proposed Noise Removal Algorithm

Algorithm3:

1. Take a 2-D FFT to the processing image.
2. Use Algorithm 1 for local peaks detection in the frequency domain.
3. Compute the direction groups and define the set of deleted impulses.
4. Remove the selected impulses by using Algorithm 2, and then take the inverse 2-D FFT.
5. Apply the mean filter to suppress the peaks.
6. Apply the inverse 2D FFT for the spatial domain.

Normalize the updated pixels to obtain the same mean as the old.

C. Evaluation Measure

Removal of noises from the images is a critical issue in the field of digital image processing. The phrase Peak Signal to Noise Ratio, often abbreviated PSNR, is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupted noise that affects the fidelity of its representation. As many signals have wide dynamic. The MSE and PSNR is defined as:

$$PSNR = 20\log_{10}\left(\frac{255}{MSE}\right) \quad (8)$$

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left\| I(i,j) - k(i,j) \right\|^2 \quad (9)$$

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

The results of the proposed method are tested on two types of images (natural Lena image and strain images). The collected testing images are corrupted by periodic noise and then these are used for periodic noise removal.

Fig. 1 illustrates the relation between the periodic noise in spatial and frequency domains. Fig. 1 (a) and (c) are images having periodic noise. The spatial domain check type periodic noise is appearing as the white pixels in the frequency domain as shown in Fig. 1 (b) and (d) respectively. From this example we can conclude that the periodic noise is appearing as the peaks in the frequency domain.

Fig. 2 illustrates the periodic noise removal comparison between the proposed method and mean filter. The proposed method (PSNR=30.06) is outperforming the mean filter (PSNR=22.15). Fig. 3 shows the performance of proposed method in strain images and is clear that the proposed method (PSNR=19.19) is showing better performance compared to mean filter (PSNR=18.47) based periodic noise removal.

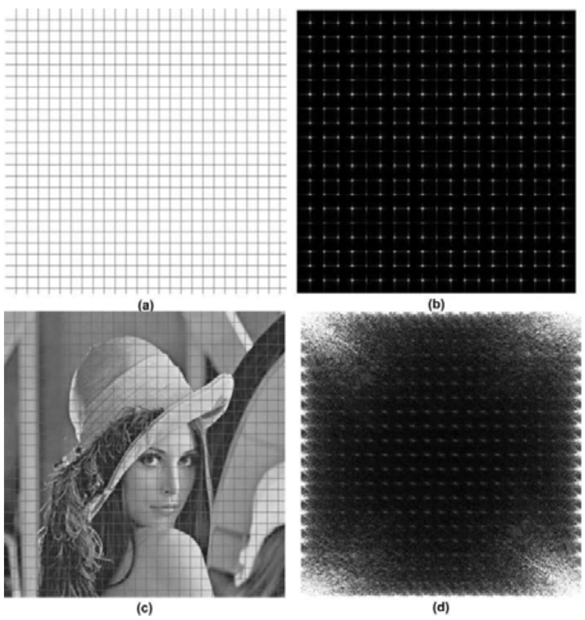

Fig. 1: (a) white image is corrupted with periodic noise, (b) frequency domain image of (a), (c) Lena image corrupted with periodic noise, (b) frequency domain image of (c).

Fig. 2: (top left) original Lena image, (top right) Lena image corrupted with periodic noise, (bottom left) filtered image by mean filter (PSNR=22.15), (bottom right) filtered image by proposed method (PSNR=30.06)

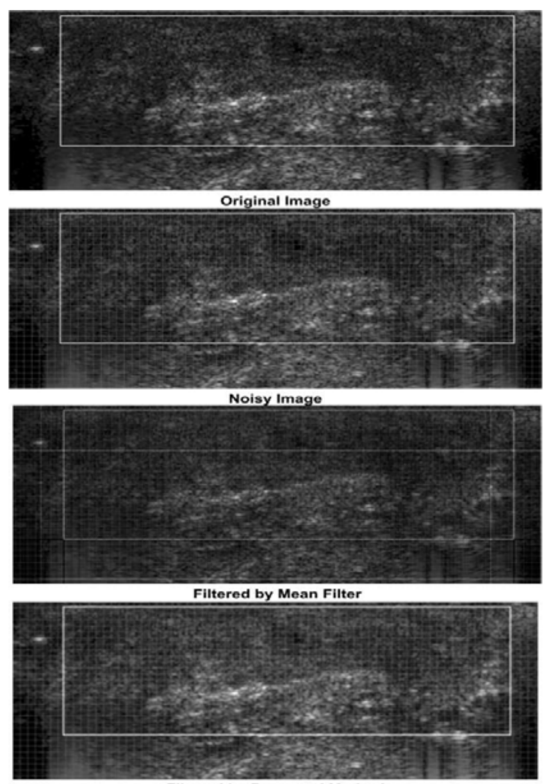

Fig. 3: Results comparison of proposed method with mean filter.

V. CONCLUSIONS

The 2-D FFT removal algorithm for reducing the periodic noise in natural and strain images is proposed in this paper. For the periodic pattern of the artifacts, we apply the 2-D FFT on the strain and natural images to extract and remove the peaks which are corresponding to periodic noise in the frequency domain. Further the mean filter applied to get more effective results. The performance of each filter is compared using parameter PSNR (Peak Signal to Noise Ratio). The performance of the proposed method is tested on both natural and strain images. The results of proposed method is compared with the mean filter based periodic noise removal and found that the proposed method significantly improved for the noise removal.

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