Speckle Noise Reduction in Medical Ultrasound RF Raw Images

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Abstract

Ultrasonography is the commonly used imaging modality for the examination of several pathologies due to its non-invasiveness, affordability and easiness of use. However, ultrasound images are degraded by an intrinsic artifact called 'speckle', which is the result of the constructive and destructive coherent summation of ultrasound echoes. This paper aims to generate B-mode images out of radiofrequency (RF) data following standard procedures, a series of steps such as envelope detection, log-compression and scan conversion. The best set of parameters of this pipeline will be selected in order to achieve B-mode images with high quality.

1 Introduction

Ultrasound imaging is one of the most important and cheapest instrument used for diagnostic purpose among the clinicians. However, the images obtained through this type of examination presents a characteristic noise type, known as speckle noise, which makes it difficult to analyze and diagnose [1,2].

Speckle reduction methods can be classified in two categories: image compounding and image filtering [3]. Image compounding is achieved by averaging a series of ultrasound images acquired from different viewpoints. The main drawback is the need of multiple acquisitions. Image filtering techniques include adaptive filters, anisotropic diffusion and wavelets [2].

Recently, new types of filters have been proposed to remove speckle noise from RF data. In [4], the authors used a low pass frequency-shift, followed by a least mean square adaptive filter. Al-Asad [5] proposed a Short Time Fourier transform applied to the envelope of each RF line before reconstruction, followed by its application to the lateral dimension of the 2D image after reconstruction.

In this paper we intend to filtering of the raw RF data to reduce noise and limit the signal to the working bandwidth. This will be done by the application of denoising filters individually to the one-dimensional RF envelopes that will constitute the B-mode image. By filtering RF data in the process of B-mode image construction, we expect to obtain images with less speckle noise.

2 Methods

In order to obtain an ultrasound image in B-mode, an RF signal is received which passes essentially through three signal processing phases, as shown in Fig. 1: IQ Demodulation, Envelope Detection, and Log compression.

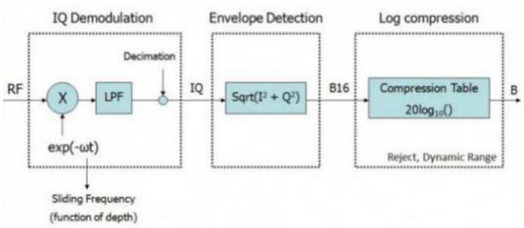


Figure 1: B-mode Signal Processing

IQ Demodulation: is a common and useful technique in RF signal processing. In the demodulation process for digital signals, the waveform is not important because it is already known. The problem comes down to whether the pulse is present or absent, so channel noise has no influence in that direction. However, channel noise may cause certain errors in decisions. The decision on the detection can be facilitated through the passage of the signal through filters that reinforce the useful signal and suppress the noise at the same time. This allows to greatly improve the signal-to-noise ratio by reducing the possibility of error.

Envelope Detection: is one of the simplest analog demodulation techniques in which an electronic circuit that receives a RF signal as input and provides an envelope of the input signal as an output.
Absolute and Hilbert transforms are common methods of envelope detection. It returns the absolute or Hilbert amplitude variation of the amplitude of a time wave.
Logarithmic compression: is the method by which the high amplitudes are compressed at the same time that the signal of the low amplitudes is amplified. This method allows you to view low-amplitude signals on the monitor that would otherwise not be seen.
After obtaining the B-mode image, it goes through a **scan conversion** (Fig. 2). It is a method that helps convert linear B-scan data into geometrically correct images, "fan-shaped" images.

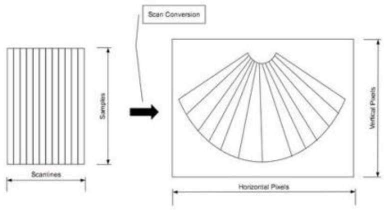


Figure 2: Scan Conversion

The RF signal processing is performed in the steps: IQ Demodulation and Envelope Detection. In these steps, we are allowed to filter the noise present in the RF signal, as shown in Fig. 3.

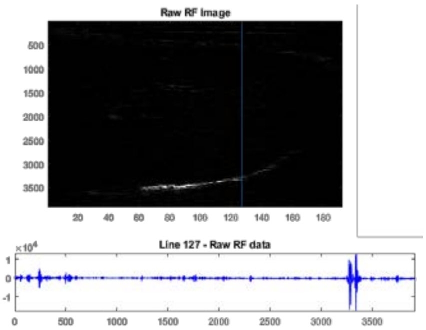


Figure 3: Raw RF Image

In the IQ Demodulation stage, it is possible to apply low pass filters (LPF), that attenuate or reduce the amplitude of the frequencies larger than the cutoff frequency. The amount of attenuation for each frequency varies from filter to filter. And the technique of **downsampling** or **decimation** it is also applied, which allows us to reduce the sampling rate. This is done by simply separating one sample at each N, which can cause signal distortion.
In the envelope detection step, you can apply one of the following options: *Hilbert* (discrete-time analytic signal using Hilbert transform) or *Absolute* (absolute value and complex magnitude).

3 Results

Figure 4 shows the influence of the different filters (*Butterworth, Bessel and, Chebyshev*) and envelope detection (*Hilbert or Absolute*) applied to the raw RF image. By comparing the images obtained and the corresponding signal representation, we can observe that the *Butterworth and Chebyshev* filters are the ones with the best results in noise reduction, along with the *Hilbert Envelope.*
To study the influence of decimation, it was used the combination ***Butterworth filter* + *Envelope Hilbert***. We considered that this was the combination that shows the best results for noise reduction when compared to the others in the study, as shown in Fig. 5.

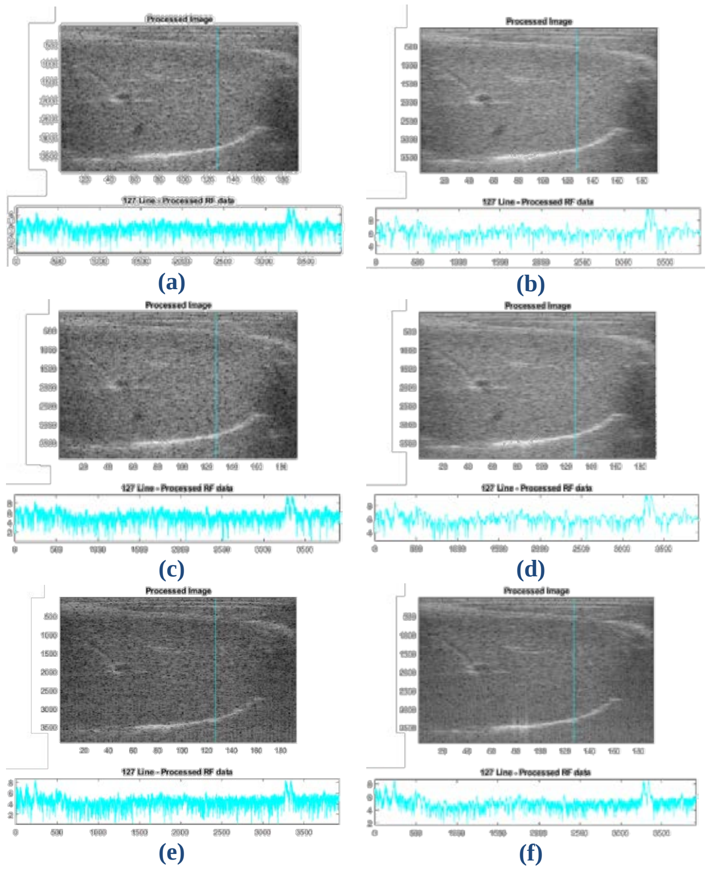


Figure 4: Results with downsampling = 1. **(a)** Butterworth filter, Absolute envelope, log compression **(b)** Butterworth filter, Hilbert envelope, log compression **(c)** Chebyshev filter, Absolute envelope, log compression **(d)** Chebyshev filter, Hilbert envelope, log compression **(c)** Bessel filter, Absolute envelope, log compression (d) Bessel filter, Hilbert envelope, log compression

Figure 5 shows the influence of different downsampling values in B-mode images. In this study, the downsampling assumes the values of 20, 30, 40 and 50.

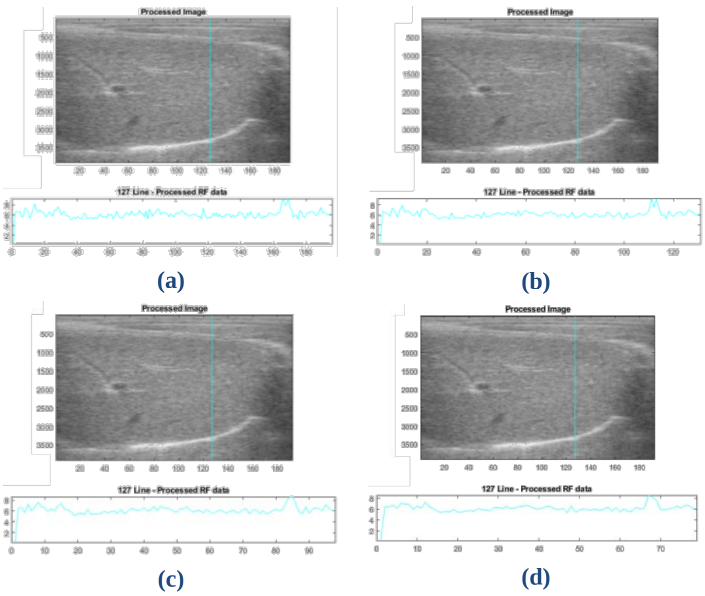


Figure 5: **(a)** Butterworth filter, Hilbert envelope, downsampling = 20, log compression, **(b)** Butterworth filter, Hilbert envelope, downsampling = 30, log compression, **(c)** Butterworth filter, Hilbert envelope, downsampling = 40, log compression, **(d)** Butterworth filter, Hilbert envelope, downsampling = 50, log compression

For downsampling values of 20 and 30, a major improvement in image noise is observed[1], however, for values greater than 30, an undesirable effect happens that causes image distortion, known as *blurring effect*. After testing different filters, downsampling values, and different Envelope detection, it was concluded that the following combination was the one with the best results in the processing of the RF image:

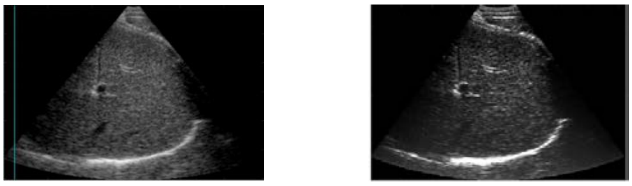
Butterworth filter + Hilbert envelope + downsampling = 30

To justify our choice, we use the image result from this combination as reference to calculate the peak signal-to-noise ratio for the images in Fig.4 and Fig.5. PSNR high means good quality and low means bad quality image. Table 1 shows that the best quality images are obtain with Butterworth filter combine with Hilbert envelope. And also shows the bigger the downsampling value the better quality. However, visually for downsampling value of 40 the image starts to become affected by the undesirable *blurring effect*. That's why we considered downsampling 30 the best option.

Filters	DownSampling	Envelope	PSNR
Butterworth	40	Hilbert	34,5883
	20		32,4544
	1		23,9061
Chebyshev			23,8879
Bessel			17,6883
Butterworth		Absolute	18,1407
Chebyshev			17,7704
Bessel			14,3964

Table 1 Peak signal-to-noise ratio

Median filter was applied to the B-mode image. This filter is one of the image processing techniques used for removing speckle noise. Figure 6 shows the RF and the B-mode processed images with contrast adjustment. By comparing this two images it is possible to affirm that RF signal processing shows to be equally efficient in noise reduction as the B-mode filtering.



(a) **(b)**

Figure 6: **(a)** Scan convert RF Image, Butterworth Filter, Hilbert Envelope, Downsampling=30, and contrast adjustment, **(b)** Scan convert B-mode Image filtered with Median filter and contrast adjustment.

4 Conclusions

In this paper we proposed and approach to reduce speckle noise in ultrasound images by filtering the raw RF data, before obtain the B-mode image. This was done by the application of denoising filters individually to the 1D RF envelopes that will constitute the B-mode image.

From the results we can conclude that filtering in RF mode, before the conversion to B-mode, reduce the speckle noise in B-mode image. This approach needs to be study in order to reduce even more the speckle noise.

References

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