

REVERBERATION REDUCTION USING 3D WIENER FILTERING

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ABSTRACT

One of the most common artifacts in ultrasound imaging is reverberations. These are multiple reflection echoes that register as coming from a deeper region than the depth of the interface that are causing them, and result in ghost echoes in the ultrasound image.

A method to reduce these unwanted artifacts using a three dimensional (2D + time) Wiener filter has been developed. Two sequences of iq-data, the least processed signal possible to retrieve from the ultrasound system (Vingmed System Five), have been used to test the method: One sequence on a tissue-mimicking agar gel phantom in which bars of glass simulating ribs give rise to reverberations, and one sequence on an open-chest pig with a strong reverberation from a water-filled rubber glove used as a medium between the heart and the transducer.

The procedure works as follows: In a graphic interface the operator is shown the image sequence. In one of the frames two areas must be marked out; One area which contains a typical reverberation artifact, and one area which will represent an artifact free signal. After creating the three dimensional Wiener filter post-processing of the sequence is performed.

The developed method significantly reduced the magnitude of the reverberation artifact in the tested sequences.

1. INTRODUCTION

One of the most common artifacts in ultrasound imaging is reverberations. In for example echocardiography one cause of this artifact is the fact that the operator is restricted to "acoustic windows"; the ultrasound beam has to fit between the ribs and avoid the lungs. It is therefore not unusual that a part of the beam is obstructed and reflected back. On their way to being registered these reflections are often reflected on the transducer surface and back into the body, where they are once more reflected and return to the transducer. These multiple reflection echoes originating from e.g. the ribs or pericardium will thus register as coming from a deeper region. The resulting ghost echo is called a reverberation artifact, and will appear at some integer multiple of the depth

of the interface that is causing it [4]. In a sequence of images a reverberation artifact is ideally stationary over time. However, in e.g. echocardiographic sequences a slight periodic variation with the respiration of the patient can be seen, and sometimes also variations caused by involuntary movements of the transducer.

2. MATERIAL AND METHODS

The inphase quadrature (iq) signal is the least processed signal that is possible to retrieve from the Vingmed System Five, which is the ultrasound system used to acquire the image sequences for this study. The iq-data is constructed from the radio frequency (rf) signal, see figure 1, which is the digital output from the system's beamformer. This process is called iq-demodulation [2] and includes three main steps:

1. The narrow banded, real valued rf-signal is shifted down in the frequency domain, so that the right part of the spectrum is approximately centered at origo after the shift is performed. The shift will make the previously real signal complex, but with the same energy content.
2. The signal is low-pass filtered in order to remove the part of the spectrum that was initially negative.
3. As the bandwidth of the signal is relatively small, sub-sampling without loss of information can now be performed. The signal is sub-sampled to a sampling frequency chosen so that no interpolation is required in order to form the new signal.

In figure 2 an example of an iq-demodulated rf-beam is shown.

The image shown on the ultrasound system display is saved in a format called tissue-data. The tissue- and the iq-data originate from different pulses; In normal scanning, one tissue-image is captured between each iq-image. Tissue-data is basically the envelope of the downsampled, rectified rf-signal, resampled to rectangular coordinates (in order to get the geometry right) and log-compressed to make the dynamic range of the data fit the human eye.

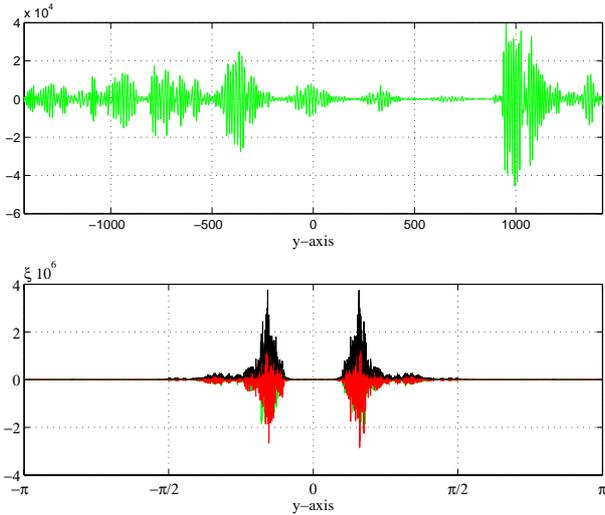


Fig. 1. An rf-beam from the output of the beamformer and its Fourier transform. In the plots the real part of the signals are shown in a light gray shade, the imaginary part in a darker gray, and the absolute value of the signal in black.

The tissue-data are thus amplitude images with no phase component, so that the major part of the signal energy is concentrated around zero and the lower frequencies. As the reverberation noise spectrum is also concentrated at low frequencies, the signal and noise are hard to separate in data of this format. Restoration of the sequence is thus more likely to be successful using iq-data.

2.1. Test sequences

Two 2D + time ultrasound iq-sequences were used to evaluate the algorithm: One sequence on a tissue-mimicking graphite in agar gel phantom [1], in which bars of glass simulating ribs give rise to reverberations, and one in vivo sequence on an open-chest pig with a strong reverberation from a water-filled rubber glove used as a medium between the heart and the transducer.

2.2. 3D Wiener filter

A number of filtering techniques attempting to improve the quality of the signal exists. One important classical approach is the Wiener filter. The Wiener filter is a global filter and produces an estimate of the uncorrupted signal by minimizing the mean square error between the estimate and the uncorrupted signal in a statistical sense. The two dimensional Wiener filter is mainly used to restore images corrupted by noise or blurring due to linear motion, additive noise or low resolution and contrast due to the imaging system [5].

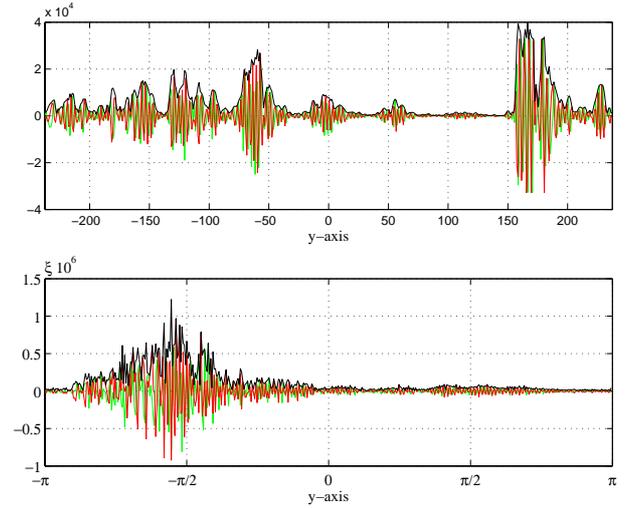


Fig. 2. The iq-demodulated version of one beam from the beamformer output, shown in the signal and Fourier domains. In the plots the real part of the signals are shown in a light gray shade, the imaginary part in a darker gray, and the absolute value of the signal in black.

In order to apply a Wiener filter one needs to know the point-spread function of the imaging device causing the blurring and/or addition of noise. Generally, this information is not available, and a model must be used. In the case of stationary signals corrupted by additive, uncorrelated noise the model may be stated as $\mathbf{g} = \mathbf{f} + \mathbf{n}$, where \mathbf{f} is the undegraded data and \mathbf{n} is the additive noise. It can be shown (see for example [5]) that the restoration filter that finds the optimum linear estimate is given by:

$$W(\mathbf{u}) = \frac{\|F(\mathbf{u})\|^2}{\|F(\mathbf{u})\|^2 + \|N(\mathbf{u})\|^2}, \quad (1)$$

Here $\|F(\mathbf{u})\|^2$ is the three dimensional spectrum of the signal or undegraded image and $\|N(\mathbf{u})\|^2$ is the three dimensional spectrum of the noise, i.e. the reverberation artifact.

2.3. Filtering process

In a graphic interface the operator is shown the image sequence. In one of the frames two areas must be marked out; One area which contains a typical reverberation artifact, and one area in which the artifact is not visible. This can be done in a frame shown in polar coordinates, as in the leftmost image in figure 3, or in the standard rectangular coordinates as shown in figure 4.

To define the noise and signal volumes the sequence is windowed with Gaussian functions in three dimensions. The width and height of each of the marked out areas are used as standard deviations of the Gaussian windows for

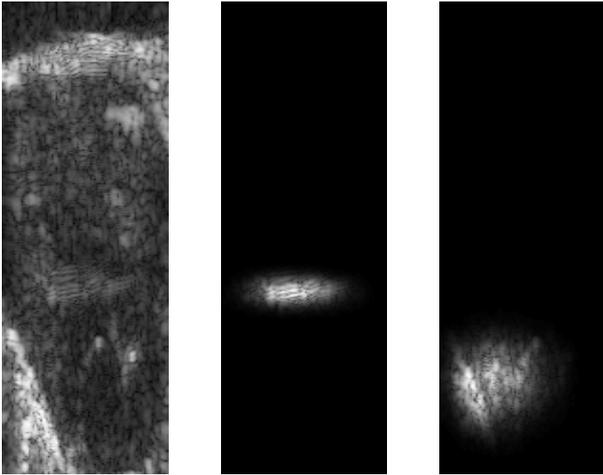


Fig. 3. One frame of the in vivo sequence, the noise area and the signal area (from left to right) in polar coordinates.

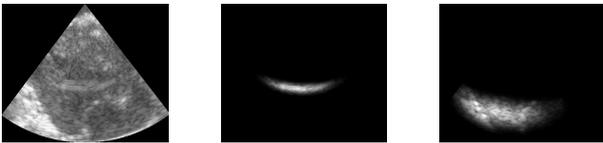


Fig. 4. One frame of the in vivo sequence, the noise area and the signal area (from left to right) in geometric coordinates.

the angular and depth directions of the data. In the time dimension the standard deviation of the Gaussian window may also be specified by the operator.

Three dimensional FFT for the volumes is computed, and an estimate of the spectra of the respective signal and noise volumes are acquired by squaring the magnitude of the Fourier transformed volumes and smoothing the result with a 3D Gaussian kernel. The smoothing is necessary to keep the filter from getting too large spatially.

The Wiener filter is computed by the formula in equation 1. The data sequence is filtered by multiplication in the Fourier domain, and, lastly, the result of the filtering is transformed to the spatial domain.

3. RESULTS

The developed method significantly reduced the magnitude of the reverberation artifact in both test sequences. To illustrate this one frame from the phantom sequence is shown in figure 5, and one frame from the in vivo sequence is shown in figure 6. In both figures the magnitude of the results from the filtering procedure is shown resampled to geometric coordinates.

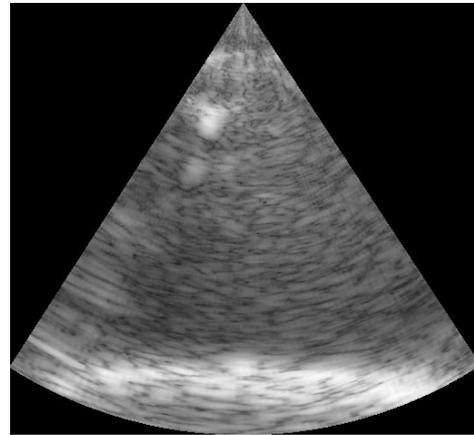
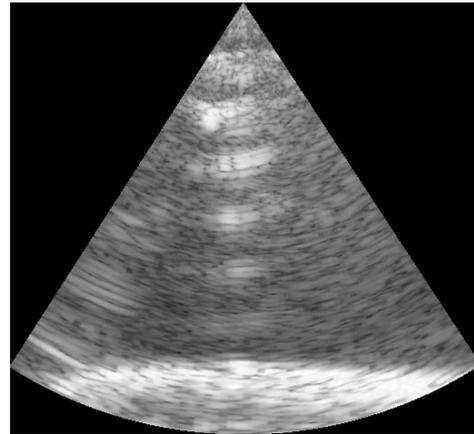


Fig. 5. One frame from the phantom sequence, before and after filtering.

4. DISCUSSION

Traditionally processing of ultrasound data have been one dimensional. To remove the stationary reverberation originating from the ultrasound pulse bouncing back and forth between the fatty tissue interfaces under the skin and the transducer surface, Nickel [3] has proposed a 1D-highpass filtering scheme along time. Each pixel of a echocardiographic rf-sequence is processed from frame to frame in real time. With this approach there is a risk of removing stationary structures in the sequence. Also, the respiration and involuntary movements of the transducer may make the reverberation less stationary, which decreases the chances of a successful removal.

With an increased number of dimensions the degrees of

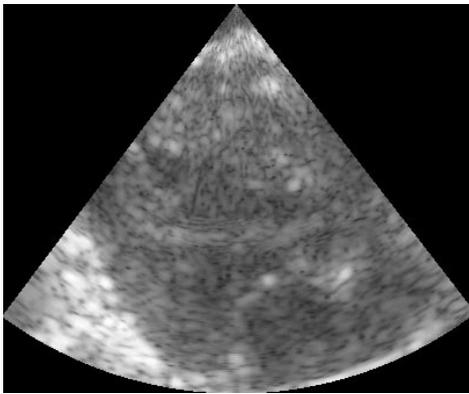
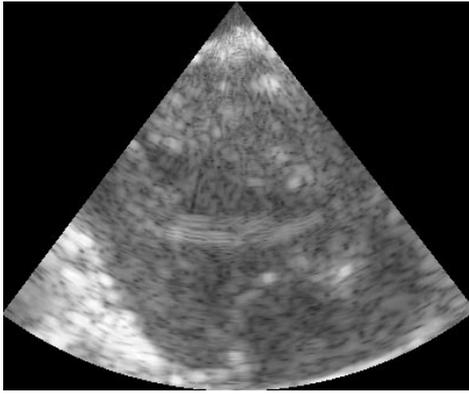


Fig. 6. One frame from the in vivo sequence, before and after filtering.

freedom of the filter is increased. One dimensional global filters will not be able to reconstruct a signal where noise has a spatial distribution. Using a 2D filter the correlation between adjacent frames is not exploited. As is the case in this study where a volume consisting of several beams in a time-sequence is to be reconstructed, movements from e.g. respiration gives the reverberation artifact a periodic pattern, which can be better handled with a three dimensional filter as this can be given a much more selective description.

No effort has been put into producing eye-pleasing tissue sequences from the filtered iq-data. The ultrasound system manufacturers have put a great deal of work into displaying nice images on the screen. As our intention is to produce images that are as revealing as possible we have not concentrated on mimicking what has already been done, and the images presented here can be seen as reverberation reduced data right before this last eye-pleasing processing step.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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