REVISITING ITERATIVE TIME REVERSAL PROCESSING APPLICATION TO DETECTION OF MULTIPLE TARGETS.

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Abstract

The iterative time reversal processing represents a high speed and easy way to self-focus on the strongest scatterer in a multitarget medium. However, finding weaker scatterers is a more difficult task that can be solved by computing the eigenvalue and eigenvector decomposition of the time reversal operator, the so-called DORT method. Nevertheless, as it requires the measurement of the complete inter-elements response matrix and time consuming computation, the separation of multiple targets may not be achieved in real time. In this study, a new real time technique is proposed for multitarget selective focusing that does not require the experimental acquisition of the time reversal operator. This technique achieves the operator decomposition using a particular sequence of filtered waves propagation instead of computational power. Due to its simplicity of implementation, this iterative process can be achieved in real time.

Introduction

Over the past decade, acoustic time reversal mirrors [1] (TRM) have been studied widely in medical imaging, non-destructive testing and underwater acoustics. A Time reversal mirror is an array of transducers able to work both in transmitting and receiving mode. When a TRM receives the signal coming from an acoustic source or reflector, it time-reverses the received signals and re-emits them into the medium. The resulting wavefront focuses back on the acoustic source or reflector location. When the medium contains several reflectors, the time reversal process can be iterated in order to focus on the brightest target [2].
The main limitations of the iterative time reversal process are the impossibility of finding weaker targets and the progressive monochromatization of the signals. In order to achieve selective detection and focusing on each scatterer inside an unknown multitarget medium, another approach was developed by Prada et al. As it is demonstrated in ref [3], the echoes of a single target are an eigenvector of the time reversal operator. Using this basic idea that each target is associated to an eigenvector of the time reversal operator it is possible to record the whole time reversal operator and compute its eigenvector decomposition. Thanks to this numerical eigenvector decomposition, a selective focusing on each target can be achieved. Using this technique, known as the DORT method. However, the DORT method is not a real time method because it requires the measurement of the N×N inter-element impulse responses and the computation of the eigenvectors decomposition is quite time consuming.
Here, we propose a new real time technique for multitarget selective focusing that does not require the experimental acquisition of the time reversal operator and its numerical decomposition. This technique achieves the operator decomposition simply by using a particular sequence of filtered waves instead of computational power. The general idea of this new approach is use the time reversal iterative process in order to focus on the brightest target. These signals are then used to derive a broadband cancellation filter which allows to cancel the echoes of the found target. The selection of the next brightest target is done by iterating the time reversal plus the cancellation filter. This process can be extended to the following of multiple targets detection using the cancellation filter that cleans up the targets already detected

The iterative decomposition

In order to explain the iterative decomposition method, we consider a simple homogeneous medium containing three scatterers made with a steel wire of 0.4mm diameter.
The experiments are conducted in the ultrasonic range in a water tank. The acoustic waves are emitted and received with a standard linear array made of 120 elements working at a 1.5 MHz central frequency. This array is connected to a multi-channel system made of 120 independent electronic channels containing A/D and D/A converters (50 MHz sampling, 20 MHz bandwidth). We acquire the

signals in a window of 25 µs . The experimental setup is presented in Fig. 1.

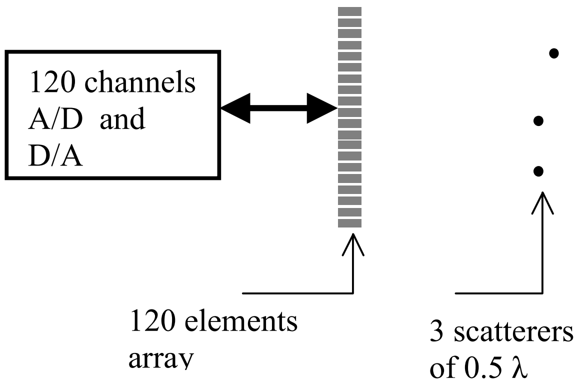

Figure 1. Configuration of the example. The TRM is composed of an array of 120 elements and an electronic able to send and receive the signals.3 targets were placed in this example.

The process identifies each target step by step beginning from the most reflective one to the weakest one. The selective identification of a new target is made in three steps.

1 Time-reversal processing:

A plane wave is emitted in this medium. The backscattered signals are composed of three wavefronts of different amplitudes corresponding to each target (Fig. 2.a). If these signals are time reversed and reemitted through the medium, the resulting wavefronts focus on each target and the brightest target is more illuminated than the others. Consequently, its contribution in the backscattered echoes is more important. After a few iterations this time-reversal process permits to select the most reflecting scatterer. However, at each iteration the signals are filtered by the limited bandwidth of the transducers and it results in a progressive temporal spreading of the emission signals. In figure 2.b we can see the received signal after 8 iterations of the time-reversal process, the strongest scatterer was selected but the bandwidth was clearly reduced. The second step of the process allows to overcome this problem.

2 Building an "eigenpulse" signal by pulse compression:

The bandwidth narrowing suffered during the time reversal process is a real drawback in most applications. An easy solution consists in reconstructing a wideband wavefront at each iteration by detecting the arrival time and amplitude law of the signals received on each transducer. These arrival time and amplitude law is then used to reemit a wideband pulsed signal identical on each transducer with the corresponding amplitudes and time delays on each of them. It allows to avoid the bandwidth spreading of the signals during the iterative process (fig. 2.c).

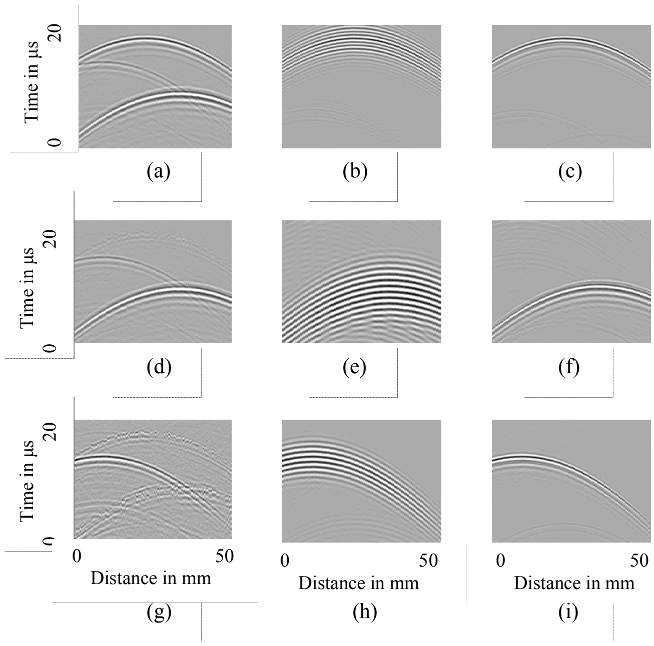

Figure 2. The iterative process. a) Signals of the 3 scatterers after a plane wave emission. b) Detection of the strongest scatterer by iterative time reversal. c) Eigenpulse of the first scatterer. d) Signals of the two scatterers after filtering the first one. e) Detection of the second scatterer by time reversal and filtering . f) Eigenvector of the second scatterer. g) Signal of the 3rd scatterer after filtering the first and second. h) Detection of the 3rd scatterer by time reversal and filtering. i) Eigenpulse of the 3rd scatterer.

3 Cancelling the detected scatterer and selecting a new one:

The basic idea for selecting a new scatterer is to apply a "cancellation operator" able to clear up all the signals coming from the previous detected target. If we start with a backscattered signal containing the echoes of the three scatterers (Fig. 2.a), after applying the cancellation operator we obtain the filtered signals shown in Fig. 2.d. As we can see, the echoes of the strongest scatterer have been cancelled. This new set of filtered signals is now used as initial illumination for the iterative time reversal process. The cancellation filter is applied at each step during the iterative time reversal process. Consequently the first target is not illuminated, the second target generates the brightest echoes and it is progressively selected by the iteration process (Fig. 2.e).

The signals backscattered by the second target are temporally spread and can be "pulse compressed" as described in step 2 (Fig. 2.f). Finally, the cancellation filter permits to cancel the first and second targets and selects the third target by iterating the time reversal process. Figures 2.g, 2.h and 2.i, describe the final eigenvector decomposition that was found for the third and weakest target.

The complete process does not require any hard numerical computation. The speed of detection is directly linked to the travelling time of the waves in the medium. For short distances as in the human body, this method can be implemented for real time selective focusing. For example with a propagation distance of 15-cm a step of iterative time reversal process takes only 1-ms, the maximum detection and the cancellation filter can be done in 3-ms. Running the complete detection of the three targets of figure 1 takes nearly 50-ms. With this short time of detection it is possible to track moving multiple targets.

We will demonstrate experimentally that this process is robust not only in a noisy environment (like speckle noise for medical applications) but also through an aberrating medium. For this purpose, this technique can also be seen as a phase aberration correction technique using the bright spots embedded in the medium.

Examples of detection in inhomogeneous media

An example of application is to find 9 nylon wires of half wavelength diameter (0.4mm) in a biological phantom with an important “speckle noise” structure.

Figure 3.a shows the echoes of the phantom when it is illuminated with a plane wave. We can see the echoes of some targets superposed to a structural speckle noise coming from a random distribution of small scatterers. The iterative method is able to identify the 9 echoes as it is shown in figure 3.b.

Due to the speckle noise a standard echographical image is not able to resolve the first 3 scatterers of the left side of the image (figure 3.c). Using the time delays detected by the iterative method we can calculate the position of each scatterer. Figure 3.d shows the calculated positions, the positions given by the furnisher and the ones obtained taking the maximum of the B scan of Fig 3.c.

The maximum detection in the B-scan image can be applied to the last 6 scatterers where the resolution is enough to isolate each target. However, for the first 3 scatterers it is impossible to give the good number of targets and their respective positions directly from the clasical B-scan image.

A possible application could be the identification of micro calcifications in the breast, if a suspicious area is detected by a conventional image, an automatic detection of punctual scatterers could give an extra information to detect the calcifications.

Conclusion

A new real time technique has been proposed for selective focusing on multiple targets. It is based on the combination of the iterative time reversal process with very simple operations like maximum detection and signal subtraction. This method enables to find and auto focus in real time on multiple targets using two intermediate operators. The cancellation operator permits to cancel the echoes coming from targets already detected and the iterative time reversal process achieves the adaptive focusing on a new target. A pulse compression operator based on the use of a maximum detection algorithm serves to overcome the problem of signal temporal spreading induced during the iterative time reversal process. Theoretical similarities with the DORT method have been highlighted. Instead of achieving the eigenvector decomposition using time consuming computational power, the new approach builds it experimentally in real time by simply using wave propagation. This high speed selective focusing technique has a potential application in micro-calcification detection in breast, non destructive testing and underwater acoustics. For all these topics the real time capability could be interesting for tracking moving multiple targets.

References

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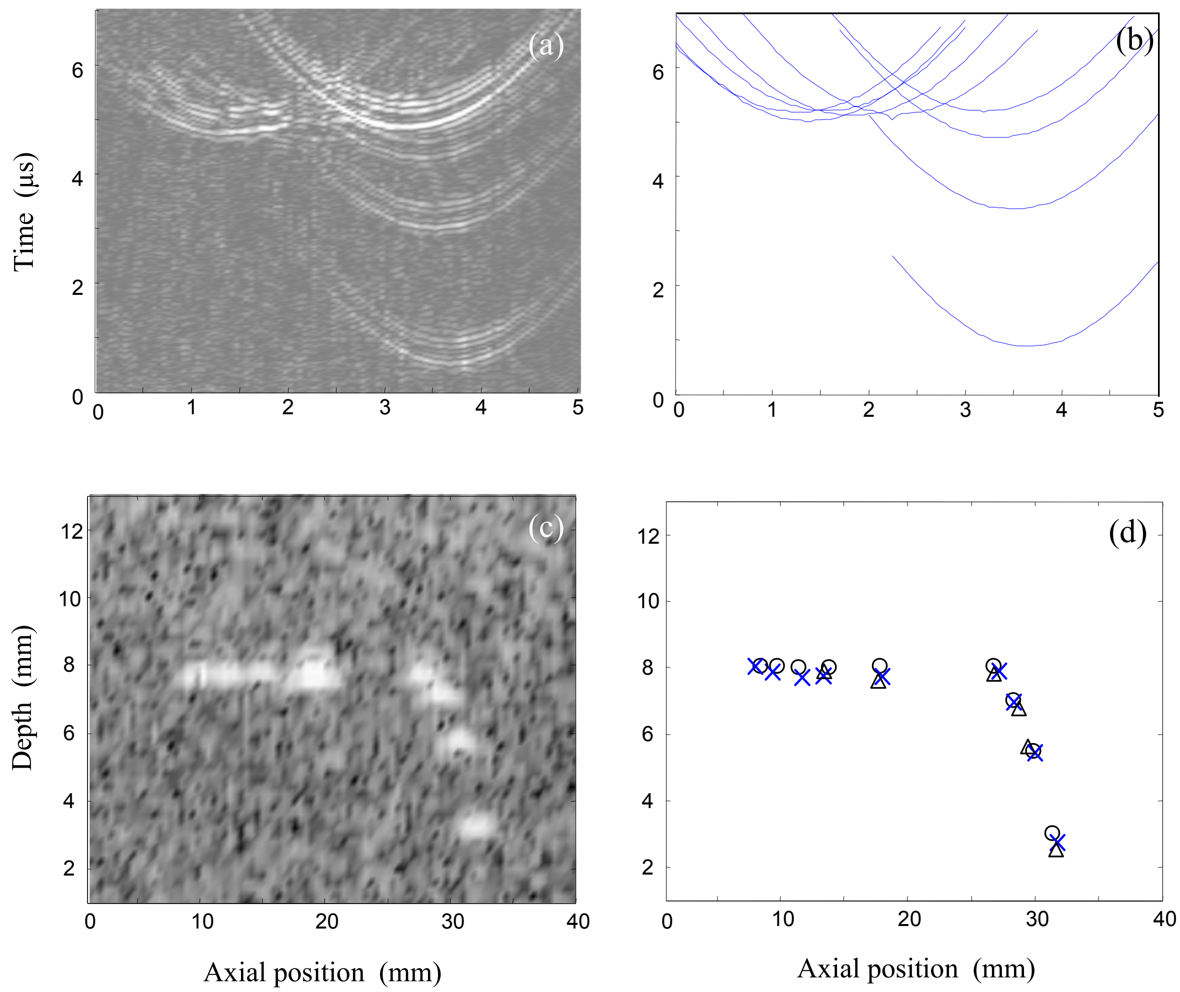

Figure 3. Target detection in a biological phantom. a) Signal received after a plane wave illumination , we can see some echoes of the target with an important noise of the structure of the phantom. b) Detection of the echoes the 9 targets. c) Echographic image of the phantom due to the speckle noise. The first for targets are difficult to resolve. d) Calculation of the targets position from the detected echoes. The x are the measured positions and the circles are given by the furnisher of the phantom .