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# Compensation of Strong Aberrations with a Time Reversal Virtual Array for Ultrasound Imaging

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**Summary:**
Ultrasound-based imaging represents an inexpensive and mobile alternative to x-ray-based techniques for medical diagnosis of stroke. However, skull-induced acoustical aberrations need to be compensated to maintain image quality. We propose a non-invasive calibration method that utilizes two independent acoustical accesses and a time reversal virtual array (TRVA). The proposed method is characterized in a model experiment and results in an improvement of the lateral resolution and the peak to background ratio by 35% and 10% respectively.

**Keywords:** ultrasound, time reversal, imaging, system identification

## Introduction

Strokes are one of the most frequent causes of death [1]. The prompt diagnosis and distinction between the ischemic and hemorrhagic subtype is extremely critical to a successful therapy and avoidance of long-term disabilities in patients. Mobile transcranial ultrasound imaging, available in the ambulance, could drastically reduce the time to diagnosis compared to x-ray-based imaging techniques, which are only available at a hospital. However non-invasive imaging of the brain with ultrasound is obstructed by the skull bone which induces significant aberrations that degrade the image quality [2].

It has been shown that strong aberrations induced in linear heterogenous media, for example a multi-mode wave guide [3], can be corrected by a time reversal virtual array (TRVA). This requires system identification by an acoustical point source [3] or reflector behind the aberrator and is therefore invasive. Here we propose a non-invasive method to calibrate a remote time reversal virtual array (RTRVA) utilizing a second acoustical access. An application of this method could reduce the effects of skull-induced aberrations degrading the image quality in context of transcranial imaging.

## Method

A TRVA is calibrated by identifying the system's impulse response between the virtual transducer elements of a TRVA and an ultrasound array. This is achieved by exciting a sound wave, ideally corresponding to a Dirac delta function, at the position of each virtual element which propagates through an aberrator, is then received with the ultrasound array (A1) and time reversed [3]. The proposed method excites the required calibration signal in a non-invasive manner by transmit focusing successively with a second ultrasound array (A2) on the element positions of the RTRVA as illustrated in Fig. 1. Based on the time invariant nature of sound propagation in linear media [4], convolving this received pattern with signals received at A1 during B-mode imaging estimates the signal at each element of the RTRVA free of aberrations.

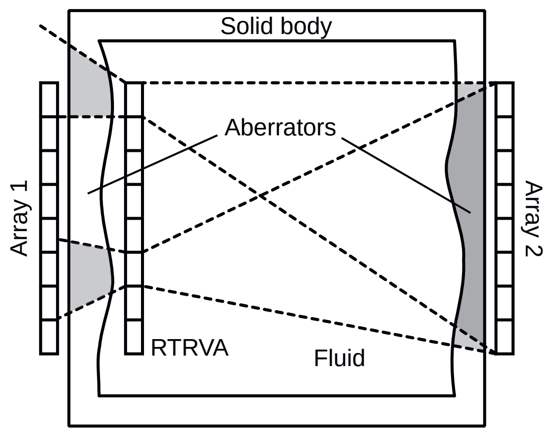


*Fig. 1 Focusing on virtual elements during RTRVA calibration. The shaded areas highlight the traversed parts of the solid body for two different focus points.*

Both arrays, A1 and A2, can access the region of interest only through aberrators. However due to the geometry of the arrays, different aberration-inducing parts of the solid body are traversed for different focus points during the calibration phase. Aberrations induced between A2 and the RTRVA do not contribute to the compensation when operating the calibrated RTRVA and represent an undesired calibration error inherent to the method. However, due to the relatively large distance between A2 and the RTRVA compared to the aperture of the latter, this calibration error is almost constant for all virtual elements. This mainly leads to an unknown positional offset of the RTRVA.

## Experimental Characterization

The proposed calibration method was evaluated inside a water-filled 3D printed resin model. The experimental setup was chosen similarly to Fig. 1 with two phased ultrasound arrays as described in Tab. 1. After calibration of the TRVA a copper wire with a diameter of 0.5 mm was placed as a point source between both real arrays.

*Tab. 1: Parameters of the experimental setup.*

| | |
|---|---|
| Sound frequency | 2 MHz |
| Sound speed in resin | 2700 m/s |
| Sound speed in water | 1497 m/s |
| Imasonic 1,5D Phased Array (A1) | |
| Element count (used) | 128 (64) |
| Element width | 0.26 mm |
| Pitch | 0.3 mm |
| Sonaxis SNX140623 ME128-LMP10 (A2) | |
| Element count (used) | 128 (64) |
| Element width | 0.4 mm |
| Pitch | 0.5 mm |
| RTRVA | |
| Element count | 64 |
| Element width | 2 mm |
| Pitch | 0.3 mm |

Utilizing the modular phased array ultrasound system described by Mäder et al. [5] conventional delay-and-sum beamforming with A1 and the RTRVA yielded the results shown in Fig. 2. The RTRVA can compensate the aberrations induced by the uneven wall thickness and significantly reduces the intensity of artifacts in the lateral direction. For the utilized resin model, the RTRVA can reduce the lateral half-width of the point-spread function by up to 35% while increasing the axial half-width by 133%. The latter is likely caused by the calibration signal transmitted by A2 which is only an approximation of a Dirac delta function and therefore leads to a temporal widening of the estimated impulse response. This propagates to the axial beam width during focusing and the axial resolution.

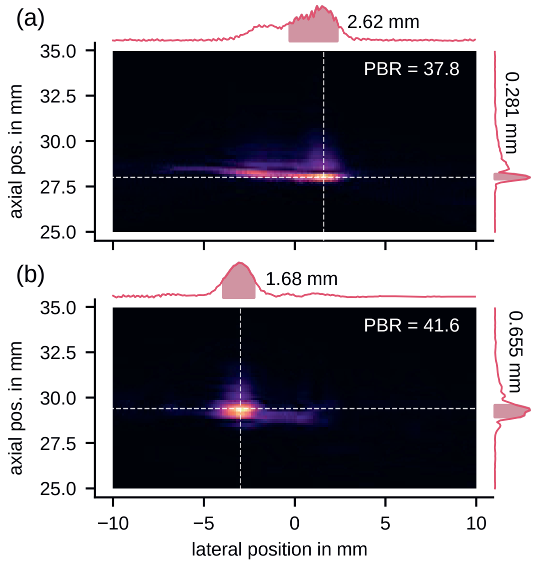


*Fig 2. Resolution and half-widths of a sub-wavelength point source (a) without correction and (b) with a RTRVA.*

## Conclusion and Outlook

The experimental characterization has shown that the proposed novel calibration method clearly improves the signal quality. In the future, the method can be applied to a skull phantom to examine the effects on image quality in detail.

## Acknowledgement

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