Estimation of Speed-of-Sound for the correction of compound imaging

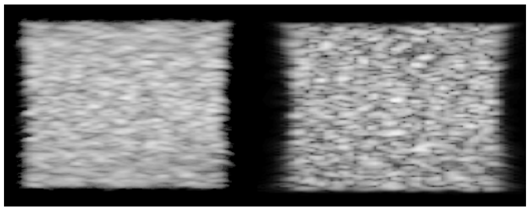
Georg Schmitz
RheinAhrCampus Remagen, S¸dallee 2, 53424 Remagen
Schmitz@rheinahrcampus.de

Introduction

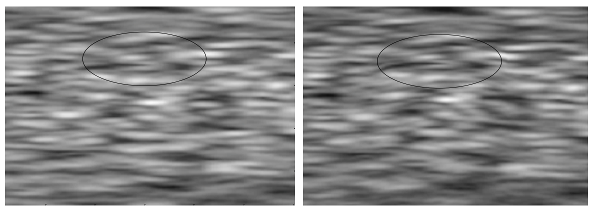
The superposition of ultrasound images of the same object acquired from different directions to reduce speckle and improve image quality is well known since more than 20 years. However, only recently this technique has been implemented in real-time in standard ultrasonic equipment. Philips/ATL were the first to overlay up to nine images using a phased linear array with different steering angles. When the new technique is used on standard ultrasonic test phantoms, image quality suffers from the speed of sound of the phantom material being 6% lower than the velocity of 1540 m/s assumed by ultrasonic scanners. It has been shown that similar situations may arise in anatomical imaging and image quality can be improved considerably by estimating the speed of sound [1]. In this paper, average sound speed estimation based on a compound image quality criterion is discussed. Additionally, the criteria presented are evaluated for a simple case of local speed of sound estimation.

Simulation Method

To have full control over the imaging and tissue parameters, phased array imaging of a speckle phantom was simulated using the Field II program of J.A. Jensen [2]. The phantom consists of 20000 point scatterers with normal distributed amplitudes of expectation 1 and random positions within a volume of 20 x 20 x 10 mm≥ at a depth of 30 mm centered in respect to the array. It was imaged with a 192 element linear 3.5MHz array with 64 apodized active elements and an element width of 0.9 λ. The images were steered at angles from ñ17 to +17 degrees in 4.25 degree steps. Dynamic focusing in 2 cm intervals was used. This resulted in 9 images with 100 scanlines each. For the beamformer and the timescale a sound velocity of 1540 m/s was assumed. For compound the frames were first added, then a Log-transform was applied.
Fig. 1 shows an unsteered image of the speckle phantom together with a compound image reconstructed at the correct speed of sound of 1540 m/s. In the compound algorithm different global speeds of sound c_1 ranging from 1380 m/s up to 1700 m/s (±10%) were used for transforming the time coordinate to a length scale.


a b
Figure 1: compound image (a) and unsteered single frame (b) of the 20 x 20 mm speckle phantom area. The transducer is at the top, 30 mm from the phantom surface.

In general, refraction due to local velocity variations was neglected because calculating the real ray path through the medium is a three-dimensional problem and cannot be solved satisfactorily in the 2D image. The only deviation from the linear approximation is the use of corrected beam angles: the beamformer calculates delay times for focussing and beam steering from the standard speed of sound of 1540 m/s. A different global velocity leads to a shift in focal depth and a deviation from the assumed beam steering angle according to $\alpha_{real} = \arcsin(c_1 / c_0 \cdot \sin\alpha_0)$, with the index *real* for the actual angle and the index 0 for angle and sound speed as assumed by the system. The shift in focal depth is uncritical and not corrected. The angle correction is made because errors can lead to severe detail loss.


a b
Figure 2: Comp. Image without (a) and with (b) local deviation of 1380 m/s from 1540 m/s background in the marked region.

To take also local velocity variations into account, a circular area with 5 mm diameter was centered 5.5 mm from the phantom surface and could take a different sound speed in compound calculation. A slowness map with the reciprocal velocity was used in the compound algorithm to account for the effect of local deviations. The simulation assumed also 1540 m/s for this region. In compound calculation the velocity c_2 of the region varied independently

by ±10% in steps of 40 m/s. Although this situation of a localized deviating area is rather simple the results already show differences in the criteria used.
The slowness map for local correction was assumed to be available in time coordinates in axial direction. This is because the typical origin of such a map would be an image segmentation of the unsteered frame with a fixed and most probably wrong speed of sound setting. The correct velocities for the segmented regions have then to be found by optimizing a compound quality criterion. Thus, in a first calculation step, the slowness-map is corrected by its own entries and by this transformed to axial spatial coordinates.

Criteria

Criteria for correct matching have to be rather simple, since eventually they should work in real-time for on-line correction. Two criteria for homogeneous speckle regions are investigated here: signal-to-noise-ratio (SNR) and lateral correlation (LC):
SNR is the ratio of the regions mean and its standard deviation. For fully developed speckle it is constant. Since speckle are still correlated in the differently steered frames, the lowest gain in SNR will be realized for the correct compound, i.e. speckle will be reduced less.
LC is based on a similar idea. The correlation coefficient of speckle in lateral direction will decrease faster if steered frames are correctly overlaid. For wrong overlay, correlated speckle of other frames are displaced and lead to a slower decorrelation. Both criteria have been evaluated for independently varying c_1 and c_2.

Results

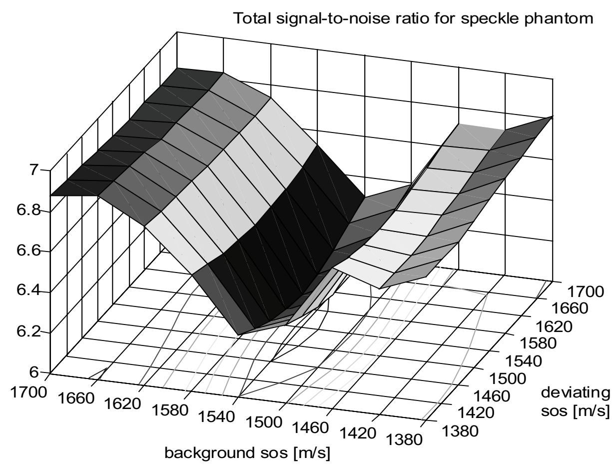


Figure 3: SNR results in dependence of background velocity c_1 and deviating velocity c_2

Fig. 3 shows the SNR results which have a minimum at the correct speed of 1540 m/s for both velocities. The minimum is more pronounced for the global correction while the flat optimum for the local deviation may be difficult to find in real images.
In contrast, the LC results of Fig. 4 show only a minimum for the global variation, while the criterion fails for local deviations. This is due to the fact that local variations cause additional speckle curvature (see Fig. 2) leading to a decay of lateral correlation.

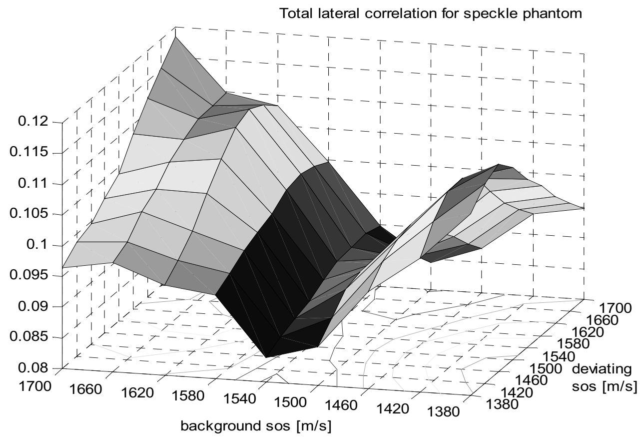


Figure 4: LC results in dependence of background velocity c_1 and deviating velocity c_2

Testing the same criteria with the compound of logarithmic images failed in both cases. Thus, one must take care to use images without non-linear processing.

Conclusions

On simulated images of a pure speckle phantom two criteria of compound quality were tested for the detection of correct global and a simple local sound speed variation. The SNR seems suitable to detect both variations while the lateral correlation fails for the detection of local changes. Thus, a global correction with an SNR measurement in speckle regions seems a feasible approach for compound image improvement, while for the detection of local variations also the SNR might not be sensitive enough.

References

[1] Jago, J.R. and Whittingham, T.A.: A practical system for the application of ultrasound computed tomography to medical imaging. *Proc. of Acoustic Sensing and Imaging,* pp. 257-265, 1993.

[2] Jensen, J.A.: Users Guide for the Field II Program, Release 2.86, 8/2001. http://www.es.oersted.dtu.dk/staff/jaj/field/