Acceleration Techniques for Acoustic Holography

UK Therapy Ultrasound Interest Group

David Sinden, Piero Miloro, Stéphane Chrétien & Adam Shaw

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Medical Ultrasound, Acoustics and Ionising Radiation, National Physical Laboratory

david.sinden@npl.co.uk

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Context

Acoustic Holography

Near field acoustic holography is a powerful, versitile and robust metrological tool for characterising medical ultrasound sources and fields

In applications of therapeutic ultrasound, in which focal pressures may be difficult to measure directly, either because of high pressures or due to material constraints, holography, used as an input to a propagation scheme may be the only option.

Holographic data can be projected backwards as a quality assurance check to ensure functionality of a device

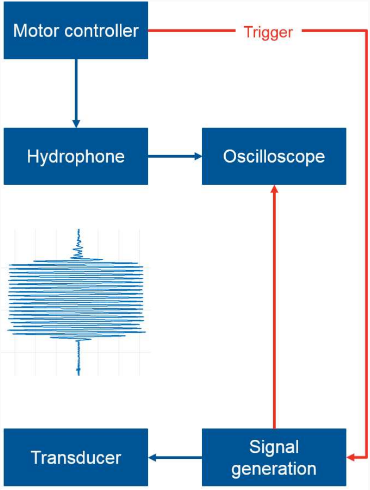
Acoustic Holography

In addition to the expense, holography can be time-consuming, which in many clinical cases may be prohibitively so.

Experimental Advances

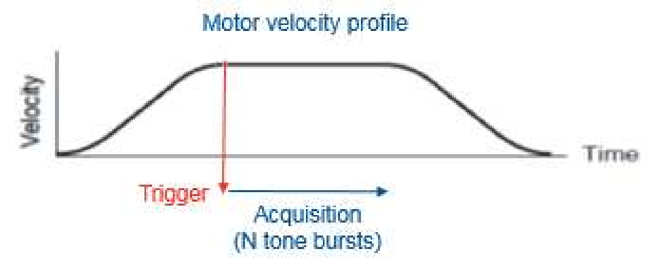
Experiments

Schematic diagram of experiment



Experiments

Parker ViX 250IM	stepper motor
Onda HMA-0200	backed membrane hydrophone
Transducer	single element sonic concepts focused 1.1 MHz
Signal generator	square wave generator + sinusoidal wave generator + amplifier
Oscilloscope	Agilent DSOX-3024A



Experiments

Moving scan

Hydrophone velocity: 10 mm/s

Pulse repetition rate: 50 Hz

$\Rightarrow$ Step size: 0.2 mm

Static scan

Average of 20 cycles

Settling time: 100 ms

Pulse repetition rate: 200 Hz

	10mm line scan	30mm line scan	90mm line scan
Moving:	$\sim$2s	$\sim$4s	$\sim$10s
Static:	$\sim$35s	$\sim$70s	$\sim$300s

Results

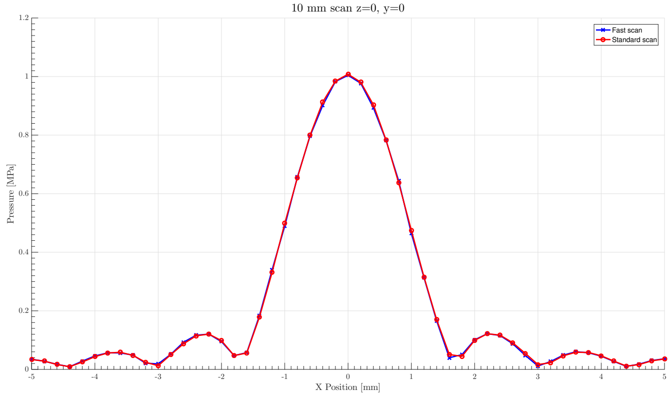


Figure 1: Static and moving line scans

Results

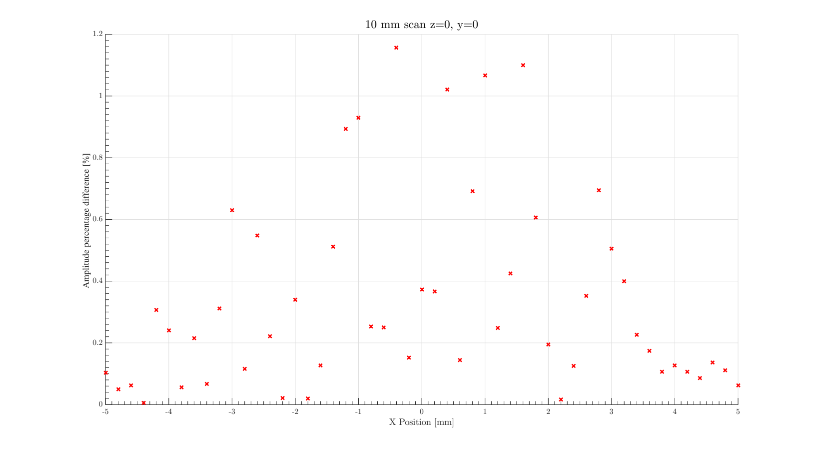


Figure 2: Difference in amplitude between static and moving line scans

Results

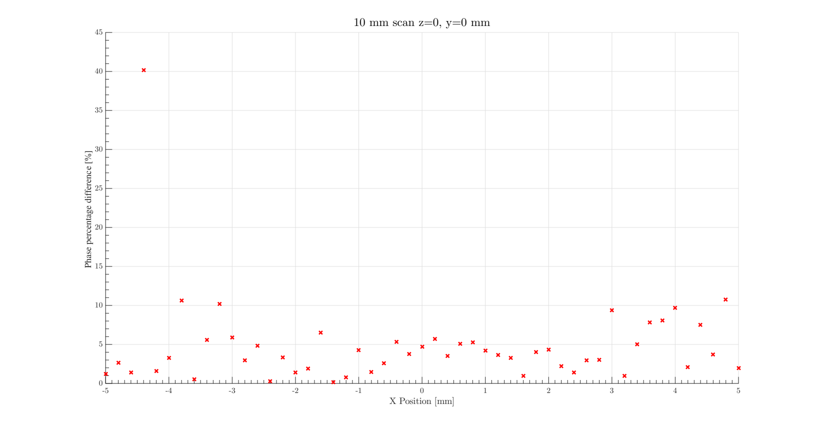


Figure 3: Phase difference between static and moving line scans

Results

- Peak positive pressure at the focus: $\sim$1MPa
- Amplitude difference normalized with respect to focal pressure of static scan
- Phase difference taken modulo 2π
- Focus $(0, 0, 0)$
- At $y = 0$, scans for $x \in [-5, 5]$, $[-15, 15]$, and $[-45, 45]$
- Also scans for $x \in [-5, 5]$ and $y = 1, 2, 3$

Discussion 1

- Currently only tested on membrane hydrophone: yet to test with needle hydrophone
- Limited to 1000 segments due to internal memory of the oscilloscope
- Potentialy limited by transfer rate of oscilloscope – a picoscope would be significantly better
- Phase difference is non-neglible: yet to test on nonlinear propagation models to see how this effects focusing . . .

Theroetical Advances

Image as matrix

Do we need to sample all the data? Inverse beamforming approaches seek to reconstruct holograms from partial information. This is an application of a technique called regularisation.

Compressive sensing[1] is a modern technique which can sometimes also be applied to solve these types of problems

Consider the hologram as a digital image, i.e. a (complex) matrix

The matrix, which contains information about the entire field, has some structure, which can be exploited . . .

[1] Compressive Sampling, E. J. Candés, *Intl. Cong. Math.*, Madrid 2006.

Caveat

This is not a method which can apply super-resolution type techniques to overcome the Nyquist limit.

All data which is acquired must still be acquired at the appropriate spacing

Structure of the hologram

The holography data, $\boldsymbol{M}$ can be decomposed into (real) phase and magnitude matrices

- Magnitude data is data-sparse, and exists on a semi-infinite domain $a \in (0, \infty)$.
- Phase data is bounded with $\varphi \in (0, 2\pi)$

- Both matrices can be decomposed in low-rank and sparse components ...

Matrix Decomposition

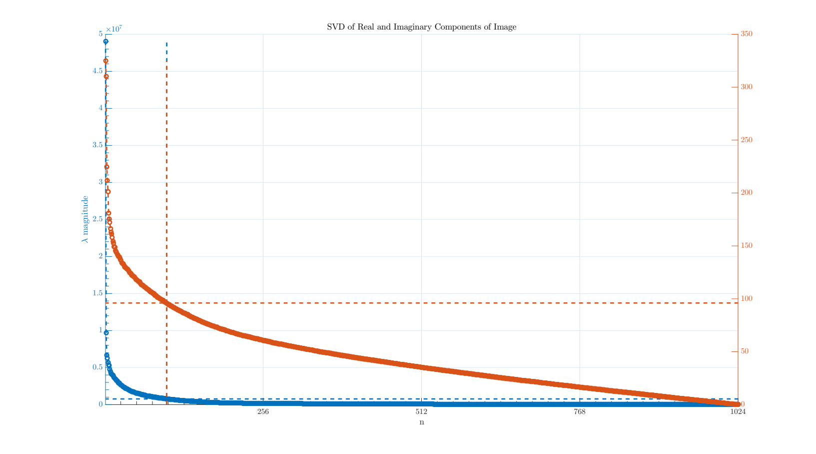


Figure 4: Singular-value decomposition of magnitude and phase matrices

Matrix Completion

Matrix completion is a regularisation scheme which recovers the system $\boldsymbol{M} = \boldsymbol{L} + \boldsymbol{S}$, from a smaller set of compressive measurements, $\boldsymbol{y}$

$$\min \left|\boldsymbol{y} - \mathcal{A}\left(\boldsymbol{L} + \boldsymbol{S}\right)\right|_2$$

where $\mathcal{A}\left(\cdot\right) \in \mathbb{R}^{K \times N}$, subject to

$$\text{rank}\left(\boldsymbol{L}\right) \leq r \quad \text{and} \quad \left|\text{vec}\left(\boldsymbol{S}\right)\right|_0 \leq K$$

The scheme[1] implemented decomposes in such a way that 'outliners' may be identified

[1] `SPaRCS`: Recovering low-rank and sparse matrices from compressive measurements. A. E. Waters et al. *Advances in Neural Information Processing Systems*, Eds. J. Shaw-Taylor et al., pp. 1089–1097, 2011.

Single Element Transducer

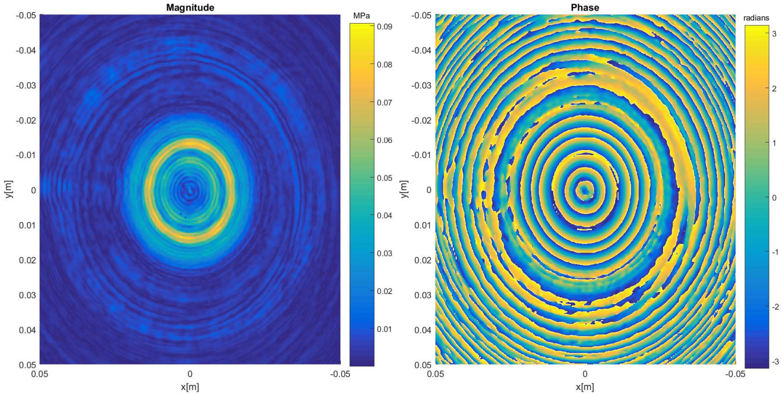


Figure 5: Holography data from single element transducer

Single Element Transducer

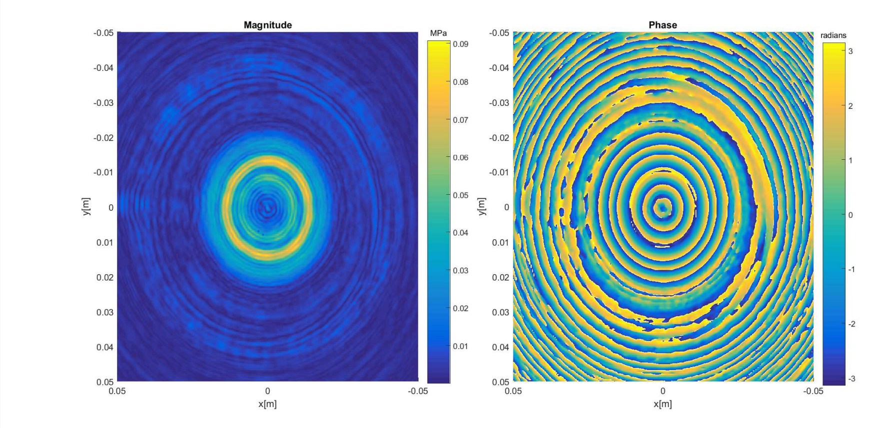


Figure 6: Reconstruction based on random sampling on 70% of data

Single Element Transducer

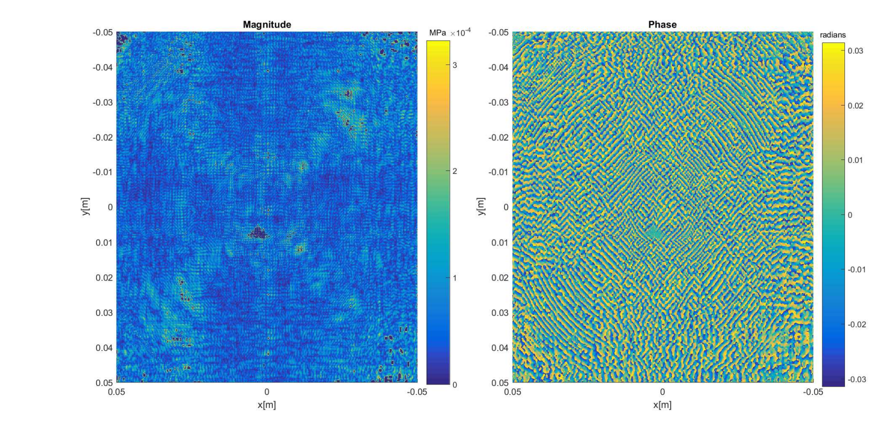


Figure 7: Difference between experimental and reconstructed data

Convergence of Scheme

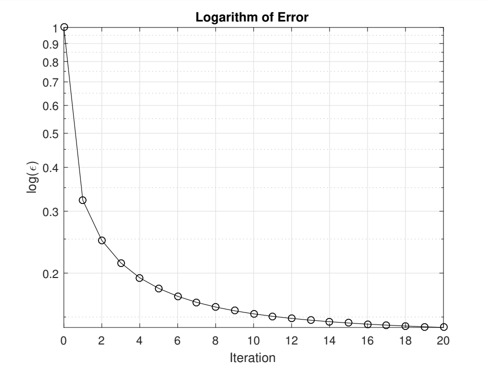


Figure 8: Exponential convergence of scheme: recovery of 512^2 matrix, sampled at 75% takes just over a minute on a powerful desktop computer

Phased Array

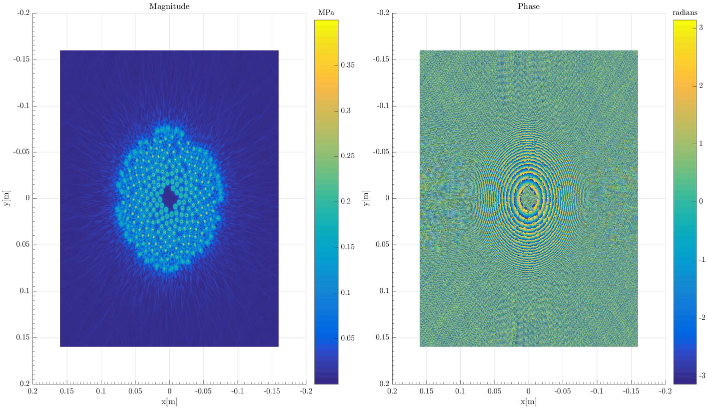


Figure 9: Holography data (Image courtesy of V. Khokholova)

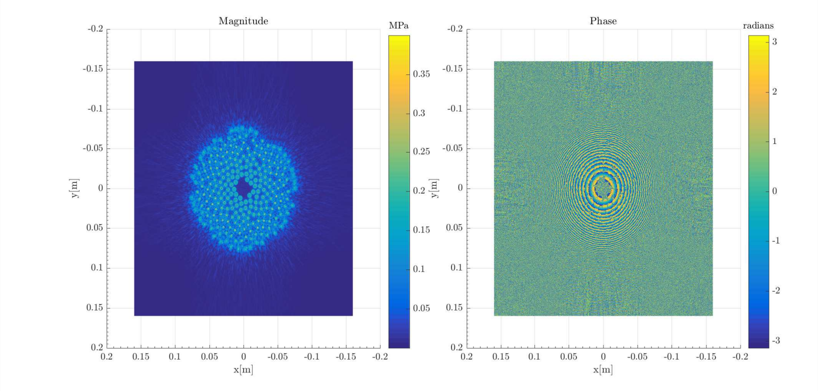


Figure 10: Recovered Data

Phased Array

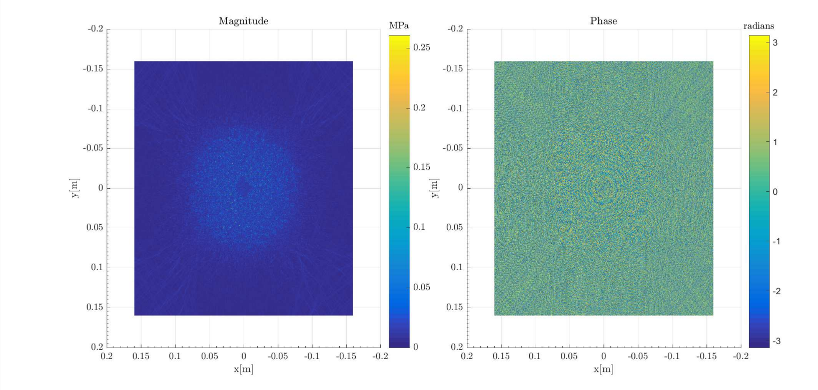


Figure 11: Difference between experimental and reconstructed data

Phased Array

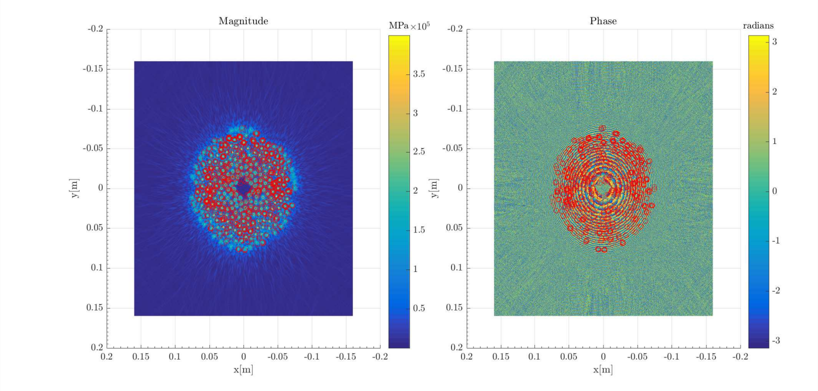


Figure 12: Data with sparse points assigned

Discussion 2

- Method is robust to random sampling. Implemented a few cases of random, connected, intersecting lines which converges
- Limited by the imposition of conditions imposed by reconstruction of phase data. If concerned with back-projection this is less of an issue
- At present only considered focal and on-axis differences between original and reconstructed data
- Uncertain whether data is always low rank and sparse at all distances from focused transducers
- Yet to test on diagnostic transducers or other transducers
- Care is needed in that convergence criteria must be strict as system can converge to a solution based on extremely small data sets: 15% data acquisition can be reconstructed but hologram does not yield an satisfactory input condition to a propagation scheme.

Conclusion

Conclusion

Both experimental and numerical techniques have are being developed to accelerate the acquisition of holography data.

Preliminary results point towards significant speed-ups in both cases.

And finally . . .

NPL is reformulating it work in therapeutic ultrasound

If you have any specific measurement challenges which you think we can help with, we can look at working in this area for your benefit

Thank you for your attention

Thanks for your time, and thanks to colleagues for their input

Any questions?

david.sinden@npl.co.uk

@david_sinden