Description of MRE phantom data

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The data are reported in

Papazoglou et al. Multifrequency inversion in magnetic resonance elastography. Phys Med Biol 2012;57(8):2329-2346.

and

Tzschatzsch et al. Tomoelastography by multifrequency wave number recovery from time-harmonic propagating shear waves. Med Image Anal 30, 1-10 (2016).

Phantom preparation

The phantom made from agar-based Wirogel (Bego Inc., Bremen, Germany) has a size of 0.135 x 0.135 x 0.1 m^3. There are four parallel cylindrical inclusions of a diameter of 12 mm. Gel/water ratios are 1:3, 1:1, 1:4, 1:3.5 and 1:2 in the matrix and inclusion 1 to 4 (see figure below), respectively. The viscoelastic parameters of inclusions and phantom matrix were determined by a torsional rheometry device (MCR 301, Anton Paar, Austria) on five disc layers of 60 mm diameter and 2 mm thickness and gel-water compositions corresponding to the phantom ingredients.

Phantom data acquisition

The data were acquired in a 1.5 T scanner using a single-shot spin-echo echo-planar-imaging (EPI) sequence with a sinusoidal motion-encoding gradient. The phantom was positioned inside the head coil of the scanner with the cylindrical inclusions parallel to the static scanner field (along the z-axis in the figure below). The actuator plate on top of the phantom was driven by a carbon fiber piston connected to a loudspeaker. The main vibration direction was parallel to the static B0-field direction, which was also parallel to the principal axis of the cylindrical inclusions. Thus, polarization of the shear waves was mainly parallel to the principal axis of the inclusions. Transversal image slices of 1.5 mm thickness were acquired in a cross-sectional view through the inclusions. Harmonic drive frequencies were 30, 40, 50, 60, 70, 80, 90 and 100 Hz with synchronized frequencies of the motion encoding gradient (MEG). Number of MEG cycles and MEG amplitudes (in mT/m, given in brackets) varied with 1 (25), 1 (20), 1 (25), 2 (10), 2 (25), 3 (20), 3 (10), 3 (10) from 30 to 100 Hz, respectively. Further imaging parameters: TR/TE = 227.6/86, 80x128 matrix size, 120x192 mm^2 FoV yielding 1.5 mm isotropic voxel size, 25 adjacent slices (no gap), eight dynamic scans per vibration period without toggled MEG polarity.

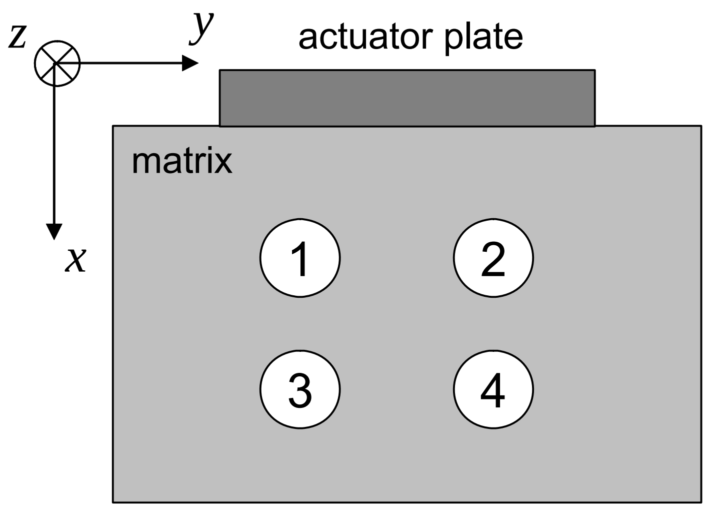


Table: Viscoelasticity values determined by shear rheometry (Papazoglou et al., 2012).

Parameter	Matrix (1:3)	Incl. #1 (1:1)	Incl. #2 (1:4)	Incl. #3 (1:3.5)	Incl. #4 (1:2)
springpot shear modulus μ in kPa	10.830	43.301	5.228	6.001	16.281
springpot powerlaw exponent α	0.0226	0.0460	0.0272	0.0247	0.0345
wave speed c in m/s*	3.18	5.94	2.21	2.38	3.80

*calculated from μ- and α-values using the relation $c = 1/N \sum_i \sqrt{2\mu^{1-\alpha}\omega_i^{\alpha}} / \sqrt{\rho(1+\cos[\alpha\pi/2])}$.

Phantom data

- phantom_raw.mat:
    - magnitude: MRE magnitude images
    - phase: raw phase data
    - info: meta data
- phantom_unwrapped.mat:
    - magnitude: MRE magnitude images

- phase_unwrapped: unwrapped phase data (Two-dimensional unwrapping based on Flynn's algorithm[1]. Each slice in a 4D x-y-z-t array has consistent phases with respect to adjacent slices. However, an offset of integer multiples of 2π may occur with respect to other x-y-z-t data)
- info: meta data

Coordinate system of the data set

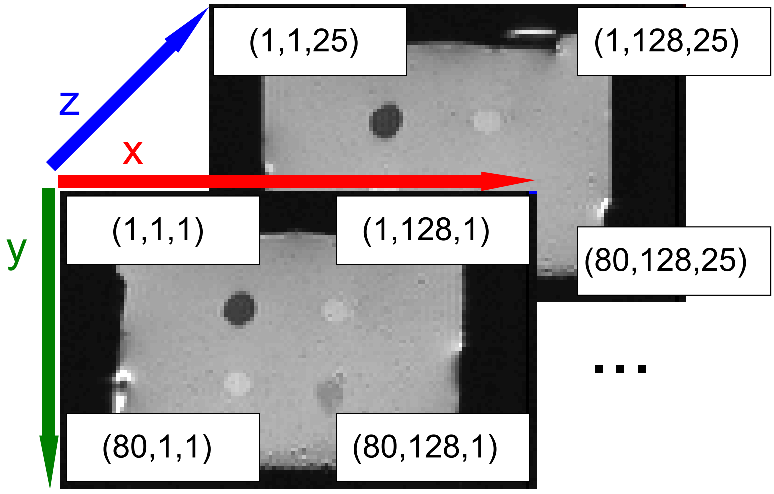
The raw / unwrapped phase phantom data and the corresponding magnitude images are six-dimensional Matlab cubes with the following index order:

Index	*Physical Meaning*	*Dimension length*	*Sorting*
1	y-coordinate (row index)	80	Ascending
2	x-coordinate (column index)	128	Ascending
3	z-coordinate (slice index)	25	Ascending
4	time step index	8	Equally distributed over one harmonic cycle
5*	motion encoding direction index	3	1: along positive y-axis 2: along positive x-axis 3: along positive z-axis
6*	frequency index	8	30, 40, 50, 60, 70, 80, 90, 100 Hz (ascending)

*please be aware that n*2π-phase offsets ($n \in Z$) may occur across that index.

A visualization of the first three (spatial) pixel coordinates is shown in the following figure:

[1] Ghiglia, D.C. & Pritt, M.D. Two-Dimensional Phase Unwrapping: Theory, Algorithms, and Software, (John Wiley & Sons, 1998).



The given pixel coordinates (y,x,z) correspond to the nearest corner pixel of the first and last slice, respectively.

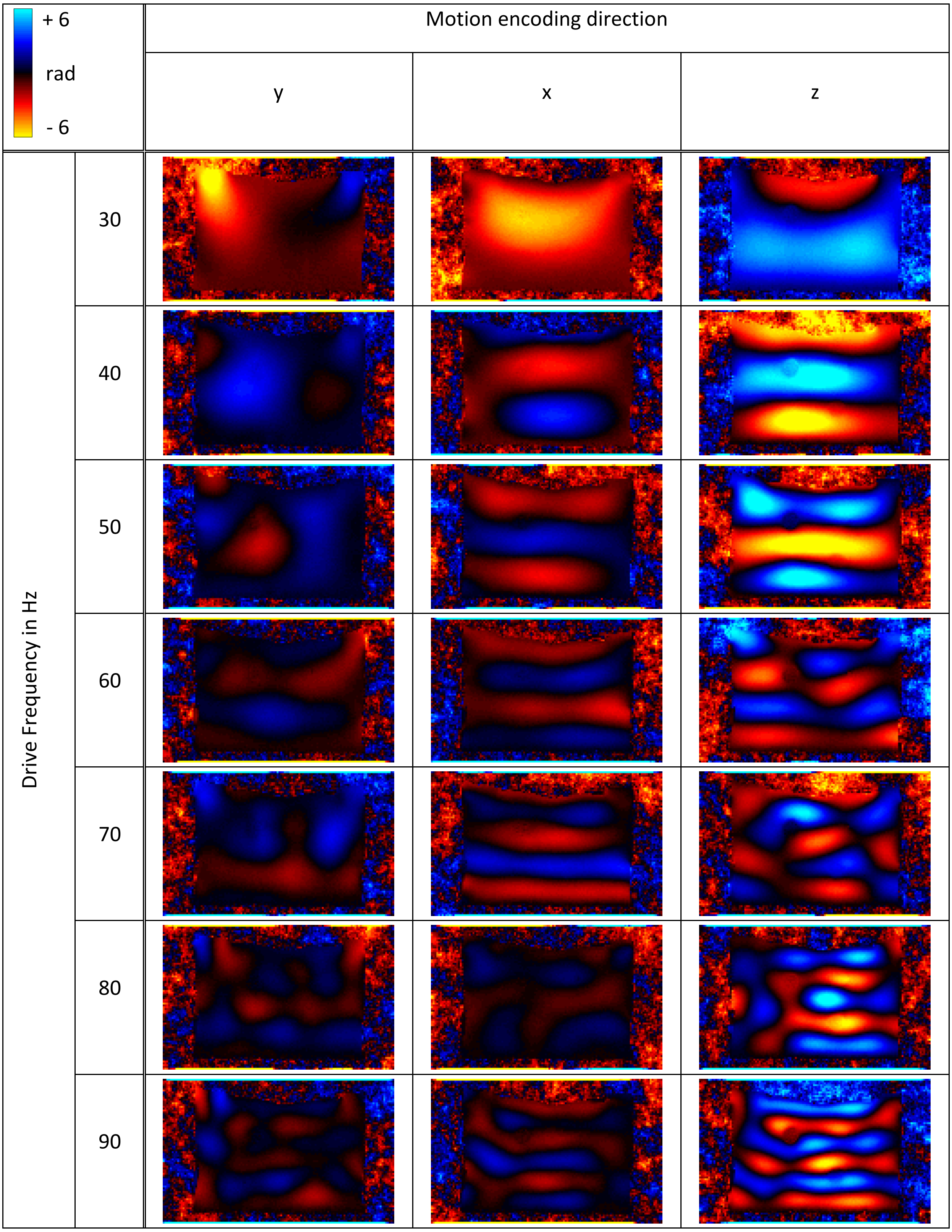
Example how curl and divergence wave fields can be computed from the unwrapped phase data

```
ft=fft(phase_unwrapped,[],4);
firstHarmonic=squeeze(ft(:,:,:,2,:,:));

[DX DY DZ]=gradient(firstHarmonic,info.dx_m,info.dy_m,info.dz_m,1,1);
div=squeeze(DX(:,:,:,2,:)+DY(:,:,:,1,:)+DZ(:,:,:,3,:));

cu(:,:,:,1,:)=DY(:,:,:,3,:)-DZ(:,:,:,1,:); % dz/dy - dy/dz
cu(:,:,:,2,:)=DZ(:,:,:,2,:)-DX(:,:,:,3,:); % dx/dz - dz/dx
cu(:,:,:,3,:)=DX(:,:,:,1,:)-DY(:,:,:,2,:); % dy/dx - dx/dy
```

Wave Images (first harmonic)



	100