Improving the accuracy of 2D phase unwrapping using a triplanar approach.

Simon Daniel Robinson[1], Barbara Dymerska[1], and Siegfried Trattnig[1]
[1]*Department of Biomedical Imaging und Image-guided Therapy, Medical University of Vienna, Vienna, Vienna, Austria*

Introduction: MR phase values outside a 2π range are aliased, causing phase images to show discontinuities or "wraps". Phase wraps generally need to be removed before use in phase imaging[1], Susceptibility-Weighted Imaging (SWI)[2] and Quantitative Susceptibility Mapping (QSM)[3]. The most widely used unwrapping methods are region-growing approaches which work either in 2D[4,5] or 3D[4]. 2D phase unwrapping is nearly universally performed in the axial plane, the most common acquisition plane for phase imaging. Images unwrapped in 2D often show artifacts where there are abrupt changes in phase (e.g. close to large veins) and where there is no continuity of signal between areas of the image (e.g. between the inferior temporal lobes). These problems are less common in 3D, which can exploit circuitous connections between voxels, although 3D unwrapping can be very slow. In this study we examine the potential to decrease 2D unwrapping errors by unwrapping in planes other than the axial, and propose a hybrid 'triplanar' approach in which the results of 2D unwrapping in the axial, coronal and sagittal planes are combined to eliminate errors.

Materials and Methods: Unwrapping was applied to 7 T human in-vivo brain data and simulated data (to provide ground truth phase). To simulate realistic phase, ΔB_0 phase variations were added to the MNI template according to the average of fieldmaps measured for 8 healthy subjects at 7 T, 5% Gaussian-distributed white noise was added and the wrapping operator applied (Fig 1, top row, first two columns). High resolution in vivo data was acquired in the axial plane with a 7 T Siemens scanner with isometric voxels of 0.65 mm side length and T_E=15 ms (Fig 1, bottom left).

Analysis: For coronal and sagittal unwrapping, data were reformatted to the required planes prior to 2D unwrapping with PRELUDE[4] and PHUN[5]. The results for these two unwrapping methods were assessed separately. Residual integer jumps of 2π between slices were corrected as in Ref 6. Unwrapped images in the coronal and sagittal planes were then reformatted to the axial plane. The median of the results from 2D unwrapping in the axial, coronal and sagittal planes was calculated for the triplanar approach. 3D unwrapping (available in PRELUDE only) was additionally applied to both data sets. For simulated data, the mean error (% of voxels incorrectly unwrapped) was calculated for in-brain voxels.

Results: Errors were apparent in 2D unwrapping results for both simulated and in-vivo data (red arrows in Fig. 1; errors are also apparent in perpendicular planes at yellow arrows). PHUN was faster than PRELUDE, but more prone to errors (see Table 1). There were far fewer errors unwrapping in the sagittal plane than the axial plane. Errors were practically eliminated (fewer than 0.01% of voxels) in the triplanar approach.

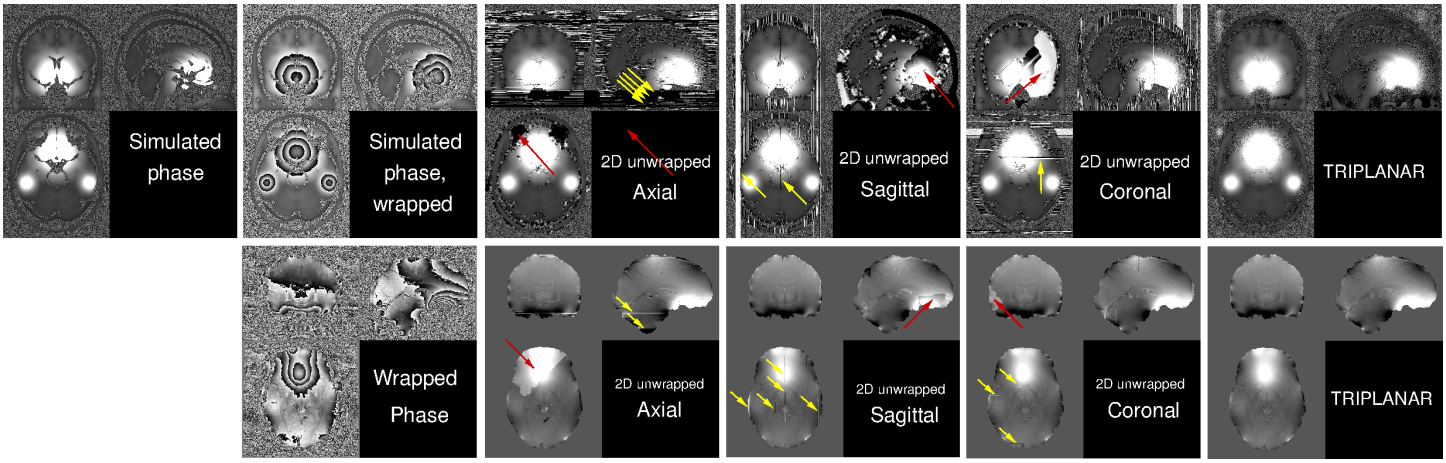

Fig 1: Demonstration of unwrapping errors encountered with 2D unwrapping in the axial, sagittal and coronal planes, and the elimination of these with the Triplanar approach (right). The top row is simulated data, the bottom row in-vivo data.

Table 1		Axial	Coronal	Sagittal	3D	Triplanar
PHUN	**Time (s)**	95.1±0.2	40.9±0.8	38.3±0.1	Not Available	238±2
	Accuracy (% errors)	7.02	1.14	0.30	Not Available	0.01
PRELUDE	**Time (s)**	349±3	266±2	429±2	131783 (>36 hrs)	1070±7
	Accuracy (% errors)	0.88	1.40	0.07	0	0

Discussion and Conclusion: If performed in one plane only, 2D phase unwrapping should be carried out in the sagittal plane to take advantage of the continuity of signal between the temporal lobes and the rest of the brain. Unwrapping results were improved, with errors being reduced to close to zero, by combining the results of unwrapping in all three planes. Triplanar unwrapping was over 100 times faster than 3D unwrapping. Triplanar unwrapping has been demonstrated for PHUN and PRELUDE, but can be applied to all 2D unwrapping methods.

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