Fast 3D Dense Tracking of Cardiac Material Points Using ZHARP: In-vivo Validation and Comparison with 3D SF-HARP

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Introduction: Three-dimensional imaging and quantification of myocardial function are essential steps in the evaluation of cardiac disease. It is essential for that purpose to fully determine the myocardium displacement field and to model the myocardium. Primary limiting factors to date are the lengthy image acquisition protocols and tedious postprocessing procedures required. The tracking of arbitrary points in 3D can be done using a 3D CSPAMM technique combined with harmonic phase (HARP) image analysis methods [1]. However, the method requires relatively long acquisition and processing time. SF-HARP has been proposed to yield 3D MR marker motion for a collection of points on the intersection between the imaged slices [2,3]. SF-HARP needs one SA and one LA to generate tracking of one line through the myocardium which is inefficient and sensitive to heart rate variations. ZHARP is a recently developed imaging methodology that encodes both in-plane and through-plane motion in a single image plane without affecting the acquisition speed. In this study, we extend zHARP to multi-slice SA acquisition and tracking with the objectives of 3D dense displacement mapping throughout the heart without the need of extra LA acquisitions. We also compare the performance of zHARP to 3D SF-HARP. Phantom experiments show strong accordance between the two methods while in-vivo results show the zHARP 3D tracking is less sensitive to heart rate variations.

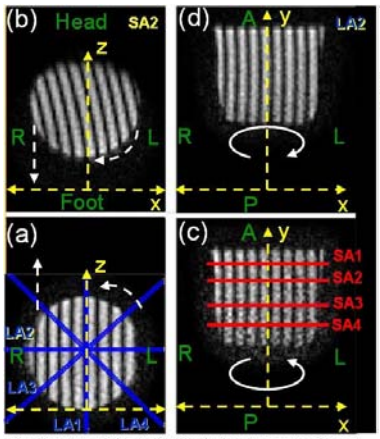

Fig.1 Setup of the cylindrical phantom experiment. (a),(c) The short-axis (SA) and the long-axis (LA) original location at time = t_0 . The object moves along the z-direction and rotates around the axis of symmetry. Maximum z-displacement is 1". Max. rotation is 16° .
(b), (d) SA, LA slices location at t_1 after maximum displacement and rotation.

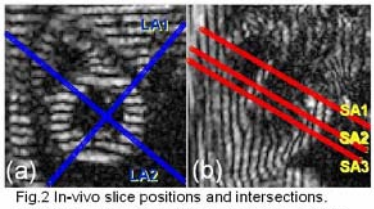

Fig.2 In-vivo slice positions and intersections.
(a) SA slice #2 and the intersection lines in blue.
(b) LA slice #2 and the intersection lines in red.

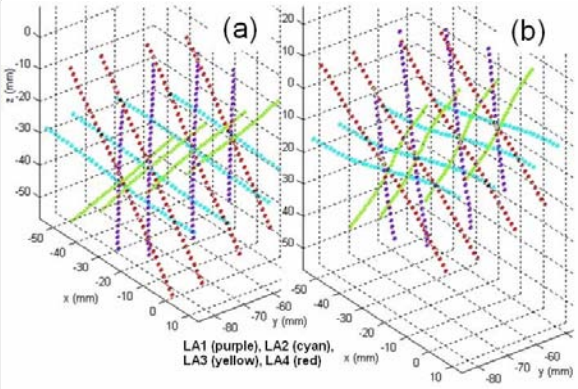

Fig.3 Phantom intersection-lines tracking results using zHARP

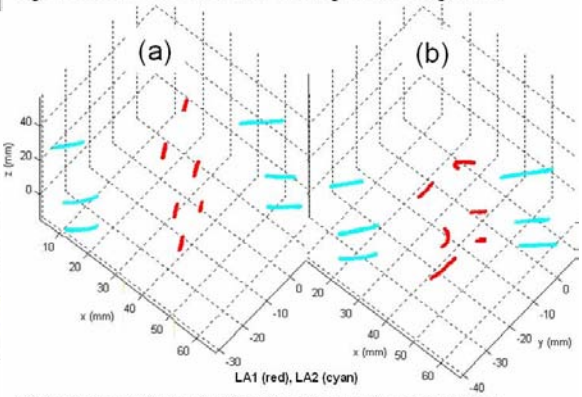

Fig.4 Phantom intersection-lines tracking results using zHARP

Methods: The zHARP pulse sequence was implemented on a Philips 1.5T-Intera full body system. Image processing was performed off-line on a personal computer. Two validation studies were conducted. For all the acquired slices, vertical and horizontal tagging was applied separately. SF-HARP processing[3] was applied on the HARP phases extracted from zHARP data.

Phantom validation: The pulse sequence and the algorithm were tested first in a rotating gel-phantom multi-slice experiment with 10ms acq. window, 20 spirals, Res.=256x256, FOV =320mm, slice thick.=8mm, tag spacing=8mm, TE=1.1ms, TR=30ms. Four parallel SA slices and four radial LA slices were acquired. The phantom was moving forward and backward in a direction parallel to the main magnetic field at a rate of 30rpm; simultaneously, the phantom was rotating around its axis of symmetry. Fig.1 shows the motion directions and some images acquired using this experimental setup.

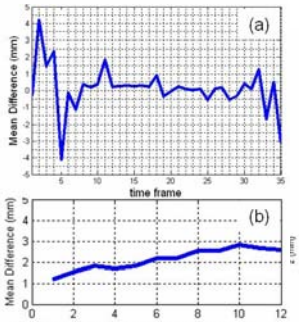

Fig.5 Mean difference between zHARP and SF-HARP tracking in both (a) phantom and (b) in-vivo

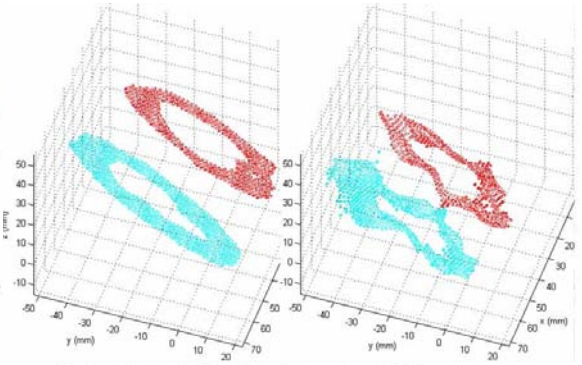

Fig.6 In-vivo multi-slice 3D tracking using zHARP

In-vivo validation: A healthy 26 years old male was scanned with zHARP using 15ms acq. window, 12 spirals, FOV =350mm, slice thick.=6mm, TE=4ms. Three parallel SA and two orthogonal LA slices were acquired as shown in Fig.2. The heart rate varied naturally during the scan from 76 to 91 cpm.
Processing: In both experiments, the lines of slice intersections were obtained, sampled and tracked in 3D using 3D SF-HARP and using zHARP. ZHARP was used again for 3D tracking of the whole SA slices without the need for LA slices.

Results: The zHARP line-tracking results are shown in Fig.3 and Fig.4 for both the phantom and the human subject, respectively. The mean difference in tracking between zHARP and SF-HARP is plotted in Fig.5. For the phantom, except for the first few time frames in which the flip angle was too small and the initial low SNR, the difference between the two tracking methods was randomly within 1mm. As for the human subject, the mean difference in tracking is starts close to zero and increases to 3mm at the end-systole time frame. The reason for that is that SF-HARP needs both LA and SA slices. Because of heart rate variations, LA and SA slices are not temporally aligned and thus giving an inaccurate tracking. ZHARP, on the other hand, extract the z-displacement directly from the same slice and therefore, less sensitive to heart rate variations.

Conclusion: We have demonstrated true 3D dense tracking of material points using zHARP and compared it with SF-HARP in both phantom and in-vivo experiments. Results show good agreement between the two methods while zHARP surpass SF-HARP by the ability to track the whole slice not only the slice-intersection lines and without the need for any additional LA slice acquisition saving more than 50% of scan time and gaining a higher density 3D tracking. Using zHARP for 3D tracking of material points is potentially useful clinically and for myocardium modeling.

References: 1) Ryf: JMRI'02, 2) Li Pan: ISMRM'05, 3) Sampath: ISMRM'04, 4) Abd-Elmoniem: IPMI'05