

MOWHARP: MULTI-ORIENTED WINDOWED HARP RECONSTRUCTION FOR ROBUST STRAIN IMAGING

Lucilio Cordero-Grande¹, Javier Royuela-del-Val¹, Marcos Martín-Fernández¹, and Carlos Alberola-López¹

¹Universidad de Valladolid, Valladolid, Castilla y León, Spain

Target audience. MR tagging enables to track material points through time. This is of special relevance, for instance, in the analysis of myocardial local motion, whose anomalies are directly related with impaired cardiac function. The HARP method for MR tagging makes possible a dense reconstruction of the deformation gradient tensor \mathbf{F} , from which measures of the myocardial strain can be computed. Nevertheless, without a proper reconstruction scheme, the strain estimation accomplished by HARP is prone to be corrupted by outliers caused by phase interferences and the application of a gradient operator.

Purpose. The objective is to establish the first application on real data (to the best of our knowledge) of the method introduced in ², Multi-oriented HARP (MOHARP), for reconstructing a robust measurement of the myocardial strain and its combination with the method proposed in ³, Windowed HARP (WHARP), for improving the precision of the strain estimation.

Methods. The commonly used SPAMM technique for MR tagging is based on the application of a spatial modulation with wave vector $\mathbf{k}_i = k_i \mathbf{u}_i$, with k_i its wave number and \mathbf{u}_i its orientation. For simplicity, we focus on the reconstruction of 2D HARP images, the 1-1 SPAMM and the stripe pattern case. Nevertheless, applications of the proposed methodology to other scenarios are straightforward. In ² it was proposed an extension of the HARP formulation for reconstructing the deformation gradient tensor (in which 2 wave vectors are used) to those cases in which one acquires an overdetermined set of $I > 2$ wave vectors. This extension was validated on a synthetic model of motion where it proved to enhance the robustness of the results. On the other hand, in ³, the computation of the local phase involved in the HARP method was performed by using the Windowed Fourier Transform (WFT). For the validation of the combination of the proposed approaches on real data, we have acquired a medial slice of a MR SPAMM SENSE TFE sequence on a Philips Achieva 3T scanner. The image has a spatial resolution of 1.33×1.33 mm and a slice thickness of 8mm. The acquisition parameters are $T_E = 3.656$ ms, $T_R = 6.027$ ms and $\alpha = 10^\circ$. Regarding the tagging parameters, we fix a tag spacing of $k_i = k = 2\pi/\lambda$, with $\lambda = 7$ mm and compare the results of acquiring different number of orientations $\mathbf{u}_i = (\cos(\theta_i), \sin(\theta_i))$ for the stripes. Namely, we consider four cases: (1) $I = 2$ with $\theta_0 = 0^\circ$ and $\theta_1 = 90^\circ$ (corresponding to the original HARP method); (2) $I=3$ with $\theta_0 = -60^\circ$, $\theta_1 = 0^\circ$ and $\theta_2 = 60^\circ$; (3) $I=4$ with $\theta_0 = -45^\circ$, $\theta_1 = 0^\circ$, $\theta_2 = 45^\circ$ and $\theta_3 = 90^\circ$; and (4) $I=6$ with $\theta_0 = -60^\circ$, $\theta_1 = -30^\circ$, $\theta_2 = 0^\circ$, $\theta_3 = 30^\circ$, $\theta_4 = 60^\circ$ and $\theta_5 = 90^\circ$. Therefore the wave vectors span the plane uniformly. The target of the proposed procedure is to estimate the material deformation gradient tensor \mathbf{F} at the end systolic phase. Once this tensor is estimated, we can compute the radial and circumferential components of the Green-Lagrange ejection strain tensor, $\mathbf{E} = 0.5(\mathbf{F}^T \mathbf{F} - \mathbf{Id})$, with \mathbf{Id} the identity matrix. As for the MOHARP method, we have used a least absolute deviation based reconstruction ². Regarding the WHARP method we have resorted to an analysis Gaussian window of size 32×32 ³.

Results. Due to the lack of a ground truth of the myocardial deformation, we evaluate the stability of the estimation of \mathbf{F} against different bandwidths of the HARP k -space filter. The normalized radius of the filter is defined as $r = \rho/k$, with ρ its radius. The results are included in Fig. 1, where we have computed the mean and median values (among all the pixels in the myocardium) of the Fréchet norm of the difference between the two estimations of \mathbf{F} obtained with radii $r-d$ and $r+d$ (the y axis is shown in a logarithmic scale for a better visualization). In addition, in Fig. 2 we include the results of the estimation of the radial (RR) and circumferential (CC) components of \mathbf{E} for the HARP, WHARP, MOHARP and MOWHARP methods. The radius of the HARP filter has been selected by visual inspection and we have observed that it coincides with the optimal values obtained by simulation in [3], respectively $r = 0.3$ and $r = 0.4$ with and without windowing. The number of stripes in the multi-oriented case is $I = 6$. We also include in Fig. 2 the entropy (H) and excess kurtosis (eK) of the distribution of strain values for each case.

Discussion. The major comments about the results in Fig. 1 are (1) the mean values decrease by increasing I , which reflects that the presence of outliers is accordingly reduced; (2) the median values generally decrease by increasing I except for the case of $I=3$ and $I=4$ orientations, which could be explained by the fact that the acquisitions with patterns oriented along the image information encoding directions (0° and 90°) are of less quality in order to estimate the deformation; and (3) the WHARP method tends to be more stable than the HARP method for small and medium bandwidths and the opposite occurs for large bandwidths. Regarding Fig. 2, the main conclusions are (1) the HARP and WHARP results present more outliers as given by the presence of values outside the realistic ranges, the large values of eK and the larger values of H with respect to their multi-oriented counterparts, which indicates a poorly concentrated distribution of strain; and (2) comparing the MOHARP and MOWHARP methods, the results of the radial component of the strain are better distributed through the realistic range of strain values in the MOWHARP case than in the MOHARP, which seems unable to recover those zones in which this parameter takes large values.

Conclusion. We have reported the first results on real images of a new method for myocardial strain tensor reconstruction. We believe that the proposed methodology brings new opportunities in the design of SPAMM acquisition sequences for strain imaging, especially when combined with modern acquisition protocols ⁴. The overload introduced by gathering an overdetermined set of stripes can be compensated by the acquisition of a reduced subset of the k -space in order to reconstruct the local phase ⁵. Consequently, new families of acquisition protocols can potentially be designed for motion sensitive MR imaging, which could simultaneously improve the resolution, robustness and precision in the analysis of motion.

References. 1. Osman, N.F., McVeigh, E.R., Prince, J.L., *IEEE Trans. Med. Imag.*, 19(3):186-202; 2000. 2. Cordero-Grande, L., Alberola-López, C., *ISMRM*: 458; 2012. 3. Cordero-Grande, L., Vegas-Sánchez-Ferrero, et al., *IEEE ISBI*: 520-523; 2011. 4. Rutz, A.K., Ryf, S., et al., *Magn. Res. Med.*, 59:755-763; 2008. 5. Sampath, S., Derbyshire, et al., *ISMRM*: 111; 2001.

Acknowledgements. This work was partially supported by the MICIIN and the FEDER under grant TEC2010-17982, by the ISCIII under grant PI11-01492, by the Junta de Castilla y León under grant VA136U13 and by the UVa under a FPI-UVa-2012 grant. The authors also acknowledge the EC for grant FP7-223920.

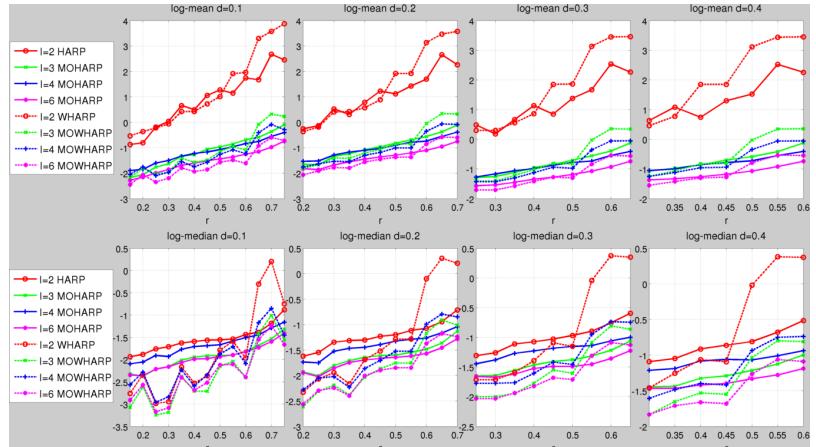


Fig. 1. Stability of the deformation gradient tensor against the radius of the HARP filter.

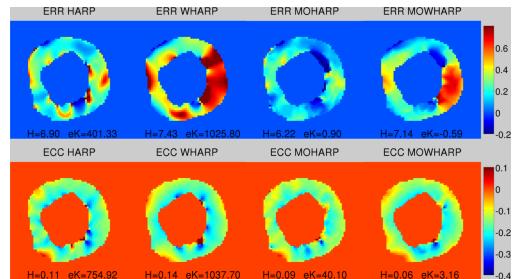


Fig. 2. Estimation of the Green-Lagrange ejection strain by the proposed methodology.