Analyzing Rapid Flow from SEA-Tagged MR Images Using Harmonic Phase (HARP)

Y. Jiraraksopakun[1], S. M. Wright[1], and J. X. Ji[1]

[1]Electrical Engineering, Texas A&M University, College Station, TX, United States

Introduction

Single-Echo Acquisition (SEA) imaging is a totally parallel imaging method that can be used to image rapid flow. Earlier, it was shown that SEA imaging can image and visualize turbulent flow at frame rates as high as 200 frames per second [1]. As a result, an algorithm that can analyze and help visualize the flow is needed. HARmonic Phase (HARP) MRI provides a promising tool to track 2D apparent flow for tagged MR images in a rapid fashion [2, 3]. In this study, the HARP algorithm was adopted and applied to tagged data sets to quantitatively analyze the flow motion. Preliminary results from HARP analysis are demonstrated and compared with direct visualization of the component images. Challenges for improved flow analysis are discussed.

Method

Tagged images from a turbulent flow phantom were acquired using SEA imaging with a highly localized 64-channel receiver. SEA imaging was performed at 200 frames per second, and spin-tagging were performed using modified DANTE RF pulse trains [1]. After tagging, a modified spoiled gradient echo sequence was successively applied for 64 acquisitions, with TR = 5 ms.; TE = 3 ms.; FOV = 14×14 cm^2; matrix size (N_p×N_f) 64×128. Final images were interpolated to 256×256. Different flow velocities were then imaged successively with 3 second delay to allow tag-spin decay. Flow velocity was increased during the delay.

HARP algorithm [2] was implemented and initially verified with cardiac simulator data sets [4]. To analyze flow motion, HARP analysis was applied on the tagged images. Two first harmonic phase images must be extracted from a tagged image pair for sufficient description of 2D apparent motion. An elliptic bandpass filter described in [3] was used to obtain the HARP images (r_A = 1.35 rad/cm, r_B = 2.24 rad/cm, σ = 0.2). Due to diagonal tag alignment, the central frequencies of the bandpass filters were set to the two first harmonic peaks at ±45º. Velocity field **v** at a spatial coordinate **y** at time t_n is estimated from the change in HARP angles between two tagged images

$$\mathbf{v}(\mathbf{y},t_n) = -\frac{1}{\Delta t}\nabla^{*}\mathbf{a}^{-1}(\mathbf{y},t_{n+1})W\left[\mathbf{a}(\mathbf{y},t_{n+1}) - \mathbf{a}(\mathbf{y},t_n)\right]$$

where Δt is the time separation between an image pair; **a** is the wrapped harmonic phase vector; and the wrapping function W and the spatial derivative of **a** are defined in [2]. The estimate is valid under a small motion assumption, i.e. displacement is within half of the tag period.

Results & Discussion

Figure 1a-d shows overlaid flow fields on a series of tagged images. To clearly visualize the motion field, 5 to 95 percentile magnitude truncation was applied on magnitude histogram of motion vectors, and their vector lengths were scaled accordingly. Fig. 1e–g are zoomed in on different motion field areas of Fig. 1a. The results demonstrate a number of interesting characteristics. At the inlet, retrograde flow is observed on the right. The eddy flow is clearly seen at the left of Fig. 1f. And the flow is minimal at the shadow region immediately above the center boundary. These are consistent with comments in [1].

HARP analysis provides promising results for characterization of rapid flow, yet several improvements are needed. Image tags that contain phase information were severely degraded in later frames and/or were lost due to high flow, resulting in unrealistic motion fields for some areas in Fig. 1b-d. For choice of optimal filter, adaptive algorithms (in stead of using fixed parameters) to find filter parameters are possibly improve the results. Noise effects on motion vector field resulted from HARP can be reduced by peak combination on k-space data or vector restoration and/or Kalman filtering on the motion field. In case of real tagged images, peak combination might be out of interest because of the symmetry property in Fourier domain. Furthermore, the flow analysis needs to be extended to obtain 3D motion information. These challenges are on investigation for our future work.

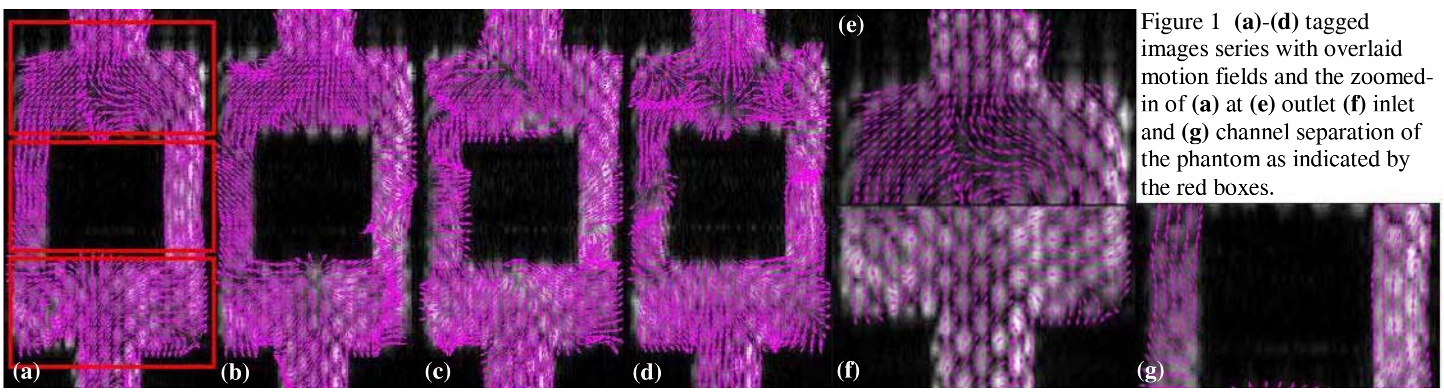

Figure 1 **(a)**-**(d)** tagged images series with overlaid motion fields and the zoomed-in of **(a)** at **(e)** outlet **(f)** inlet and **(g)** channel separation of the phantom as indicated by the red boxes.

Acknowledgements

Support from NIH (1R21EB003296-01A1 and 1R21EB005695-01A1) is gratefully acknowledged.

References

[1] Wright S.M. etl. al. IEEE EMBC 2006: 4877-4880

[2] Osman N.F., et. al. PMB 2000 (45):1665-1682

[3] Osman N.F., et. al. IEEE TMI 2000 (19,3):186-202

[4] Waks E., et. al. MMBIA 1996: 182-191