CSPAMM Real-Part Reconstruction using an Internal Phase Reference

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Purpose: To improve the contrast-to-noise ratio (CNR) in tagged MR cine imaging, as acquired for DENSE or HARP strain analysis.

Introduction: Complementary Spatial Modulation of Magnetization (CSPAMM) images are computed by subtracting two 1-1 tagged images I_+ and I_- that have the tag phase inverted. A simple model of the acquisition is given by the following expressions:

$$I_+ = (1-a) + a\cos kx; \quad I_- = (1-a) - a\cos kx; \quad I_{CSPAMM} = I_+ - I_- = 2a\cos kx$$

where $a$is the normalized tagging modulation depth, related to the total tagging excitation angle $\alpha = 2\arcsin\sqrt{a}$. A straightforward implementation is achieved by acquisition of tagged images with α=90° (a=0.5), a regular magnitude reconstruction of both tagged images, followed by subtraction. To increase the tagging contrast, α can be increased up to 180° (a=1.0), though this requires a real-part reconstruction of the images. The reference phase map needs to be free of tag modulation, or at least free of inverted signal to avoid a sign ambiguity. It is typically obtained in a separate acquisition (see e.g. [1]). In this scenario the gain in CNR is roughly twofold, with (in case of CSPAMM imaging) only 50% increase in scan time. In this abstract we propose to obtain the reference phase map from the tagged images themselves, aiming to improve CNR without increasing scan time.

Methods: In the sum image $I_{sum} = I_+ + I_- = 2(1-a)$, the tag modulation is cancelled, and therefore I_{sum} is in principle suitable as phase reference. However, in case a=1.0, the sum signal is zero, which means that the sum image cannot be used as phase reference unless the tag modulation is reduced. Simulated 1-1 tagged images (SNR=18, matrix 256x76, FoV=300mm, tag distance d_{tag}=7mm, low-frequency phase errors, and circle with inverted phase in centre to mimic fatty tissue) were used to evaluate the effect of the following methods to improve SNR of the sum image: 1) reduction of the tag modulation depth, 2) adding horizontal and vertical tagged images and 3) spatial filtering: 3a) low-pass and 3b) median. Scanning a healthy volunteer, the tagging modulation depth was optimised for a given protocol (Siemens Sonata, SSFP cine imaging [2], BW=850Hz/pix, TR=3.6ms, 3k-lines per heart beat, temporal resolution 10.9ms, multiple breath-holds, FoV=300mm, d_{tag}=7mm, matrix 256x76, interleaved acquisitions.

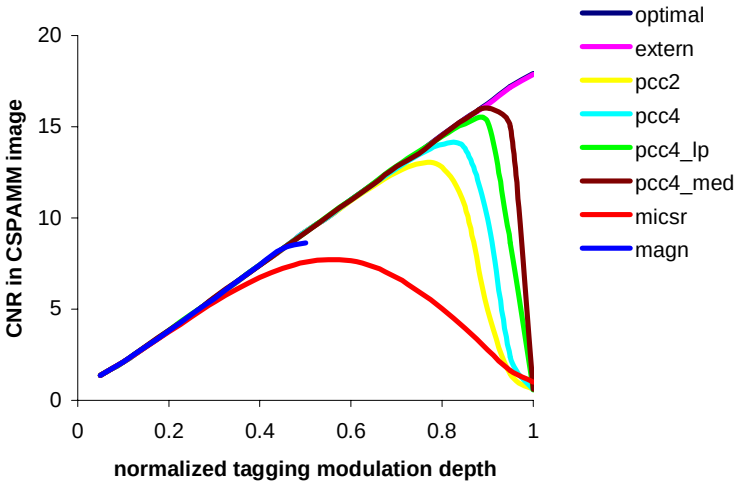

Figure 1: Results of simulations of CSPAMM CNR as a function of tag modulation depth a and the method of phase correction applied: "optimal" = corrected using imposed phase errors, "extern" = separate phase correction scan (SNR=18), "pcc2" = sum image, "pcc4" = sum image of all four tagged scans, "pcc4_lp" = ppc_4 plus low-pass filtering, "ppc4_med" = ppc_4 plus 5x5 median filter, "micsr": see [3] and "magn" = the straightforward implementation.

Results: Figure 1 shows the simulated CNR for various reconstruction methods. For completeness, we also included the MICSR [3] reconstruction. Figure 1 clearly reveals a breakdown of SNR in the sum image for large modulation depth. Efforts to improve SNR of the sum image appear effective (more overlap with the "optimal" curve). Summing all four tagging acquisitions and using a median filter gave best results in the simulation. Figure 2 shows an example of the simulated CSPAMM images at a=0.9. The volunteer scans were phase-corrected using "pcc4_med". Choosing α=140° (a=0.88) resulted in artefact-free images. Figure 3 shows the first image (acquired during SSFP start-up) and an end-systolic image. In a simulation with a=0.88, the CNR efficiency (CNR per √time) was equivalent to that of tagging with a=1.0 and phase correction by a reference scan.

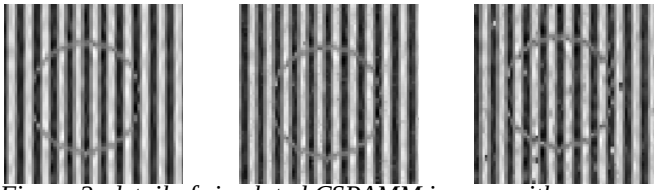

Figure 2: detail of simulated CSPAMM images with reference phase maps "extern", "ppc4"and "ppc2".

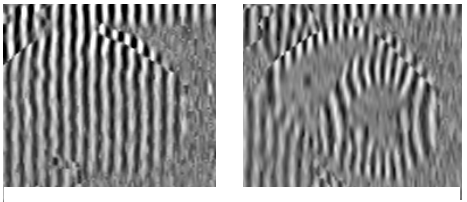

Figure 3: detail of acquired images.

Conclusion: Real-part CSPAMM images can be constructed by deriving a phase reference from the tagged images. The CNR efficiency is similar to that of a real-part reconstruction with reference scan. Compared with subtraction of magnitude images (a=0.5), the CNR was improved with a factor 1.7 at identical scan time.

References: [1] D.Kim *et al*, ISMRM 11, 1795 (2004) [2] J.J.M.Zwanenburg *et al*, MRM 49:722–730 (2003) [3] M.NessAiver *et al*, MRM 50:331-342 (2003).