PURE PHASE ENCODING ACQUISITION FOR CALIBRATION OF HIGH GEOMETRIC FIDELITY INTERVENTION APPLICATIONS

S. Crijns[1], B. Raaymakers[1], and J. Lagendijk[1]
[1]Radiotherapy, UMC Utrecht, Utrecht, Netherlands

Purpose

In MR-guided interventions, it is desirable to establish a solid relationship between the imaging coordinate system and world coordinates.
This is generally beneficial in applications that put high demands on geometric accuracy such as biopsies, stereotactic neurosurgery and multimodal imaging, but it is particularly important in MR-guided radiotherapy, as radiation cannot be visualized on MR images. Lagendijk et al. [2] presented the benefit of using MR imaging, not only as a position verification system, but as a treatment guidance modality. On-line MR images provide superior soft-tissue contrast and enable development of new treatment strategies, even for patient groups that were not eligible for radiotherapy so far (e.g., renal cancer patients [2]). Recently, we have reported on a prototype integrated MRI-accelerator and demonstrated good image quality irrespective of the radiation beam [3]. There must be a highly accurate connection between the treatment and imaging coordinate systems here.
In general, there are discrepancies between the two coordinate systems. When frequency encoding is used, diffusion, field inhomogeneities chemical shift, etc., influence each point in k-space along a frequency encoding line in a different way, which manifests itself as image distortions. Furthermore, non-linearity of the gradient magnetic fields that are used for position encoding cause local coordinate distortions as well. The latter effect can be effectively dealt with by careful calibration [4. We propose here to deal with the former category of effects by using phase encoding in all directions [5. This approach minimizes frequency dependent distortions. Furthermore, we suggest to reduce the inherently long acquisition times of this type of acquisition, that are prohibitive for use in current interventional procedures, using random under-sampling strategies combined with total variation (TV) regularized iterative reconstruction as proposed in [6].

Methods and materials

We perform our experiments on a 1.5T whole body Achieva scanner (Philips Medical Systems, Best, The Netherlands). Spin echo (SE) images are acquired with FOV 128x128 mm^2, acquisition matrix 128x128 pixels, T_E/T_R 30/150 ms, acquisition time 20 s. Purely phase encoded images are acquired with the same FOV, acquisition matrix 64x64 pixels, T_E/T_R 30/150 ms, acquisition time 6.1 min. Images are acquired of two phantoms using a quadrature head coil. Phantom I is a plastic cylinder filled with copper-sulfate doped water. Phantom II is a co-axial glass cylinder, where the inner cylinder is filled with a) air and b) sunflower oil and the outer cylinder with copper-sulfate doped water. Both of the phantoms are positioned in the geometrical center of the scanner, with the long axis of the phantom perpendicular to the magnetic field.
Total variation regularized iterative reconstruction is implemented in Matlab (The Mathworks, Natwick, USA) as outlined in [6]. K-space data obtained from a purely phase encoding experiment is retrospectively under-sampled with factors 10, 20, 30, 40 and reconstructed using zero filling with simple density compensation and the TV regularized iterative approach respectively.

Results and discussion

Figure 1 shows phase encoding only images (bottom) and corresponding SE reference images for phantom I and II. The left column is a reference situation where the resonance frequency is determined by the scanner and no field inhomogeneities are present. Subsequently, a 500 Hz offset is applied to the resonance frequency and the acquisition is repeated. The SE image, in the second column shows translation that is to be expected from the conventional encoding, whereas the purely phase encoded image is unaffected. Next, phantom IIa is examined. The air/water transition in the phantom constitutes field inhomogeneity that produces image distortions, as can be seen in the upper image of the third column. Finally, in a SE image of phantom IIb we see a field inhomogeneity induced image distortion together with a chemical shift artifact (upper image of fourth column). The latter two artifacts are completely absent when using only phase encoding (columns 3 and 4, bottom row). In Figure 2, results for zero-filled and TV regularized reconstructions from retrospectively under-sampled data are shown. The reconstruction from fully sampled data is shown in Figure 1 (bottom row, 3rd column). Images remain very clear, especially for calibration purposes, even at very high under-sampling factors.

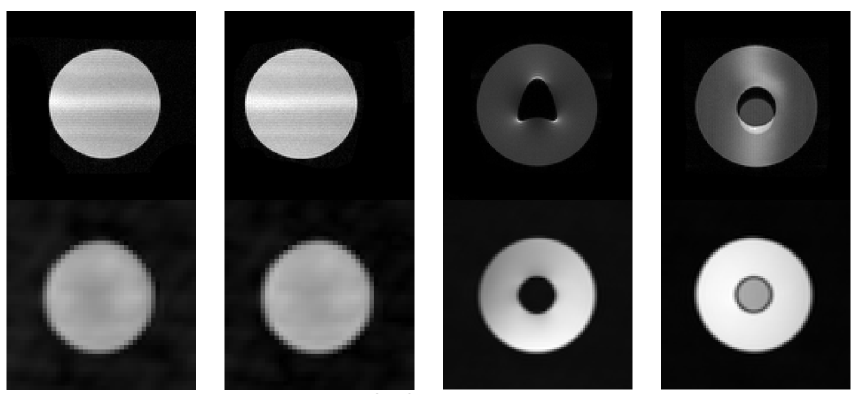

Figure 1 Upper row: SE frequency and phase encoded images. Bottom row: purely phase encoded images.

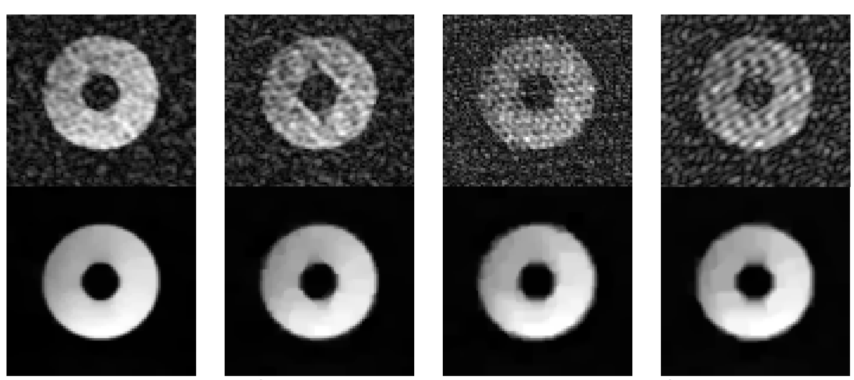

Figure 2 Reconstructions from under-sampled data. Upper row: zero-filled reconstruction. Bottom row: TV regularized iterative reconstruction (from left to right reduction factor 10, 20, 30, 40).

Conclusion and outlook

Pure phase encoding acquisition methods can be used to effectively avoid image distortions due to resonance frequency related phenomena. High acceleration factors can be achieved using random under-sampling in combination with compressed sensing reconstructions, especially for sparse objects such as shown here. We expect to be able to reach even higher under-sampling factors when combining the current approach with sensitivity encoding and aim to speed up the acquisition process using techniques like SPRITE [7], making pure phase encoded acquisition a tractable approach in imaging scenarios that put high demands on geometric fidelity.

References: [1] Lagendijk, Radiother. Oncol. 86 25–29 (2008) [2] Kerkhof, Brit. J. Urol. Int. (2010) EPub ahead of print [3] Raaymakers, Phys. Med. Biol. 54 229–237 (2009) [4] Doran, Phys. Med. Biol. 50 1343–1361 (2005) 5] Haacke 1998 [6] Lustig, Magn Reson Med. 58(6):1182-95 (2007) [7] Balcom, J. Magn. Reson. A 123, 131 (1996).