Diamond-SENSE: undersampling on a crystallographic grid

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INTRODUCTION

In parallel imaging multiple receive coils are used to reduce scan time by acquiring a smaller set of phase encoded profiles. In 'basic' SENSE[1] this is done by undersampling in the first phase encoding direction. The phase encoding step is increased with the desired SENSE reduction factor. For high SENSE factors the distance between positions in the image that have to be resolved (unfolded) during the SENSE reconstruction becomes small. Due to the small difference in coil sensitivity between neighbouring pixels this results in artefacts caused by less stable matrix inversions. In 3D scans the SENSE reduction factor can be realized by dividing the undersampling in the two phase encoding directions. Now the distance between the overlapping pixels is larger than in the one-dimensional case resulting in a better image quality. If however the reduction factors per direction are non-integers then the number overlapping pixels varies a lot between different regions. In regions with high numbers of overlapping pixels (high local SENSE factor) the image quality is lower or the set of SENSE equations can become even underdetermined. To prevent these high local SENSE factors we propose a method that acquires profiles on a non-rectangular grid in k_yk_z-space, Diamond-SENSE.

THEORY

In 3D scans the SENSE reduction factor R can be divided into a reduction factor R_y in the first encoding direction (k_y) and a factor R_z in the second encoding direction (k_z, the slice direction). The phase encoding steps in a rectangular undersampled k_yk_z-space are R_y/Y and R_z/Z. Here Y is the FOV in the first encoding direction and Z is the FOV covered by the set of slices. By shifting one half of the rows or columns of a rectangular grid over half a phase encoding step, a crystallographic grid with the same sample density is created, see figure 1. By crystallographic sampling k-space the grid of backfolding positions in image domain is also crystallographic. The backfolding points that are positioned within the rectangular FOV (Y,Z) have to be resolved during the SENSE matrix inversions. Resolving crystallographic distributed backfolding pixels has two advantages. (1) It is possible to undersample in two directions without creating regions with high local SENSE factors. (2) The distance between backfolded pixels is larger and this results in a more stable matrix inversion during the SENSE reconstruction.

In figure 2 a comparison is made between rectangular and Diamond-SENSE at different reduction factors R. With Diamond-SENSE the number of backfolding positions does not exceed R, see examples R=3 and R=5. At every reduction factor R Diamond-SENSE has a larger distance between the backfolding positions.

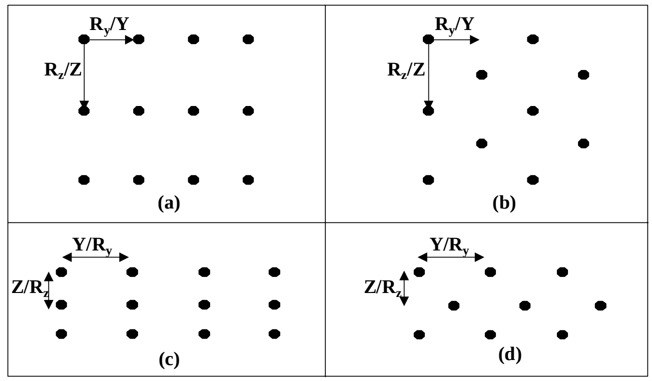

Fig.1: Rectangular (a) and crystallographic (b) undersampling k_yk_z-space with reduction factor $R = R_yR_z$ and the corresponding rectangular (c) and crystallographic (d) grids of backfolding positions in image domain.

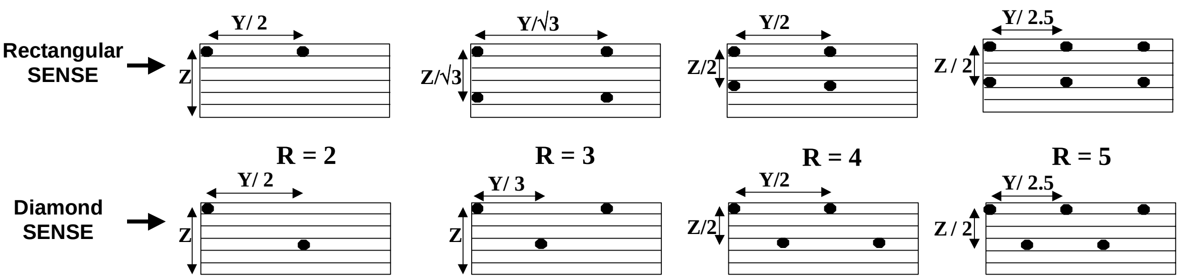

Fig.2: The figures show the backfolding positions at different SENSE factors R. These positions are drawn as black dots in a stack of 6 slices. The first row shows examples of rectangular SENSE. The second row shows the result of applying Diamond-SENSE.

RESULTS

On a Philips Intera 1.5T a full dataset (R=1) has been acquired with an 8 element head coil. By removing the appropriate profiles Diamond-SENSE with different reduction factors have been simulated, see figure 3. Comparison of Diamond-SENSE 5 (3c) with rectangular SENSE 5 in one direction (3e) demonstrates clearly that applying SENSE in two directions results in a better image quality. The SENSE factors 4 and 6 can also be performed by rectangular SENSE in two directions, but with Diamond-SENSE lower geometry factors g [1] have been measured. For example with R=6 (d) the maximal geometry factor was 20% lower compared with rectangular sampling (R_y=3,R_z=2).

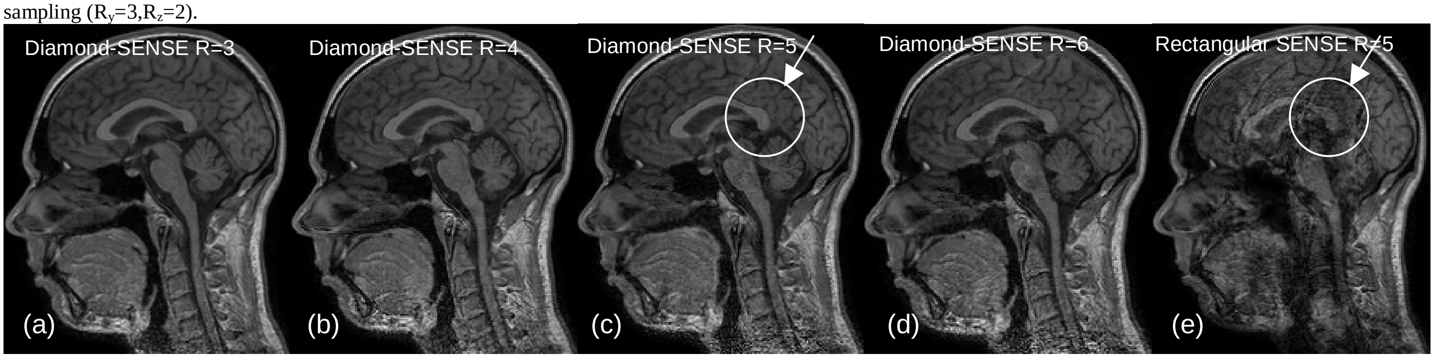

Fig.3: On the left Diamond-SENSE images at different SENSE factors R. On the right (e) the result of R=5 in one direction, the foldover direction.

CONCLUSION

We have introduced a new method for 2D undersampling k-space. It is shown that undersampling on a crystallographic grid improves the reconstruction quality, both from visual inspection as well as from g-factor analysis. Diamond-SENSE provides opportunities for very high SENSE reduction factors.

REFERENCES 1. Pruessmann K et al., MRM42: 952, 1999