Continuous Moving Table SENSE Imaging

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Introduction :

Continuous moving table MRI techniques are of increasing interest for improving patient comfort and supporting new applications in whole body MR imaging, e.g. for cancer screening or peripheral angiography. These applications require a high spatial resolution and total imaging times on the order of one minute. Consequently, acceleration techniques are necessary for 3D imaging. To fulfill these demands, the present work introduces a combination of continuous moving table techniques with sensitivity encoding (SENSE) [1]. There are two basic options for the placement of the receive coils. First, moving coils can be fixed to the patient and switched to receive on entering the imaging region. In this case, a large number of coils are needed over the vFOV because $K \geq R$ coils (for an acceleration factor R) have to cover the stationary imaging region (FOV) of the MR system at any time. Second, a single stationary receive coil array can be used to cover an arbitrarily extended vFOV, as was implemented here. The SENSE reconstruction requires a coil sensitivity map in the vFOV, which depends on the motion and on the acquisition order in k-space in a complex way. A convenient approximation is introduced to infer this sensitivity from one or a few static reference acquisitions in the FOV. Simulations show the approximation to be valid under realistic assumptions, which is confirmed by experimental results.

Methods:

In moving table SENSE, the MR signal is received in parallel by stationary coils mounted close to the patient and fixed to the magnet bore. The number of coils can be arbitrary. The coil sensitivity in the FOV is acquired with a static reference scan at one or a few positions (e.g. shoulder and abdomen) before the continuous run. These scans can be combined to eliminate uncertainties in low signal regions (e.g. lungs) and to obtain additional information on loading effects, which may change the sensitivity with the table position. During the continuous run, the k-space is scanned repeatedly in the FOV until the vFOV is covered. Undersampling in the phase encoding direction accelerates the scan. The phase encoding directions (x, y) are typically chosen perpendicular to the motion (z). The data is corrected for continuous table motion by a hybrid space alignment (k_x, k_y, z) [2,3] to obtain individual coil images. A central part of the presented method is the generation of effective vFOV sensitivity maps to perform SENSE unfolding for the vFOV image. As an approximation, the measured sensitivity is mapped to the areas inside the vFOV where the FOV is located at the point in time of k=0 acquisitions in the continuous run. The approximation is appropriate because the smooth sensitivity patterns consist of low spatial frequencies. The sensitivity displacement for high spatial frequencies could in principle lead to ghosting in the SENSE reconstruction. However, simulations do not show discernible effects under practical conditions. Ghosting would only appear for maximum $k_{x,y}$ values if the sensitivity varies exceedingly in z direction. For advanced profile orders, a simulation of the acquisition can derive the effective vFOV sensitivity.

Measurements on phantoms and healthy volunteers were performed on a Philips Intera 1.5 T MR system using 3D FFE sequences. The computer-controlled patient support is driven at constant speed ranging from v=10 to 40 mm/s. Three elliptical coils (30 cm x 20cm) are mounted right (1), at the top (2) and left (3) of the patient space with the long axis parallel to the motion direction. In an exemplary volunteer experiment, the total imaging time was 1:17 minutes at v=24 mm/s with a vFOV of 1760mm x 460mm x 96mm (matrix 980 x 256 x 16) and a reduction factor of R=2 (TR/TE: 4.7/2.3 ms, α=12°).

Results and Discussion:

Figure 1 shows a complete SENSE reconstruction (a), the vFOV sensitivity map of coil 2 (b) and individual coil images (c 1,2,3) for one slice of the 3D measurement described above. Note the periodical intensity variation and the foldover in the individual images (c), which are corrected by the sensitivity (b). Due to the linear k-space acquisition scheme, the sensitivity map is obtained by repetition of the FOV-sensitivity indicated by the frame in (b). Although the sensitivity was recorded in one FOV reference scan, it is a good approximation throughout the vFOV (no loading effects visible). Small discernible periodic artifacts are specific to any continuous moving table method with some inhomogeneity in the FOV or small velocity variations. Since these artifacts tend to appear at the borders of a large lateral FOV and may remain at the image center after SENSE unfolding, further correction methods are required.

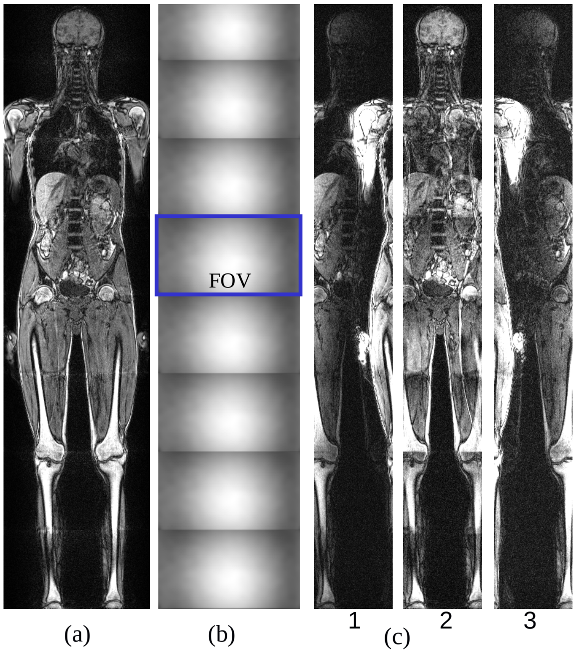

Figure 1: One slice (a) of 3D continuous moving table SENSE data of a healthy volunteer (3 coils, R=2) with coil sensitivity calibration in the virtual field of view (b) and individual coil images (c). Total imaging time is 1:17 minutes (v=24mm/s).

Conclusion:

We have demonstrated a method for large field of view continuous moving table SENSE without the need for time consuming effort for coil calibration. The introduction of stationary coil arrays and modified virtual field of view sensitivity maps paves the way to fast high resolution whole body examinations.

References:

1. Pruessmann et al., MRM 42, 952 (1999)
2. Hajnal et al., Proc. Intl. Soc. MRM 7, 1653 (1999)
3. Kruger et al., MRM 47, 224 (2002)