

Application of SENSE to Continuously Moving Table MRI: Demonstration of Feasibility

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Introduction: SENSE is a parallel imaging method [1] that has been used to provide reduction in acquisition time or improvement in spatial resolution in a variety of clinical applications. The basis for SENSE is to acquire data using a phase encode FOV which would generally cause aliasing, but to use previously measured coil sensitivity maps to account for this in reconstructing an unaliased image. In virtually all applications of SENSE done to date, the imaging field-of-view and coil assembly have been static during data acquisition.

In another recent development various techniques for MR image acquisition during continuous motion of the table (CMT) have been studied [2-4]. With these methods the patient table is moved through the bore of the scanner *during* MR data collection. These methods offer the potential of providing a seamless image of an extended longitudinal FOV. Furthermore, for contrast-enhanced (CE) MRA of the peripheral vasculature CMT can provide an advantage over multiple fixed stations by eliminating the time overhead in moving the table from one station to the next. For peripheral CE-MRA the spatial resolution in the phase encode (R/L, A/P) directions can be critical, as this is generally across the diameter of the S/I directed vessel. This applies to CMT, where the number of views is inherently dependent on the table velocity V_{TABLE} and the actively sampled, longitudinally-oriented imaging FOV, FOV_S [Eqn.1]. Thus means for improving spatial resolution, such as SENSE, can be valuable for CMT peripheral MRA.

The purpose of this work was to study the feasibility of implementing SENSE in continuous table motion MRI. The principal technical challenges were to account for the specific algorithmic steps intrinsic to the reconstruction of continuous table motion data, including correction for table displacement and gradient nonlinearity. These considerations apply not only to reconstruction of the reduced-FOV SENSE-acquired data but also to the formation of accurate coil sensitivity maps.

Methods: One of the main challenges in integrating SENSE to CMT MRI is coil coverage. Since an extended FOV is imaged, large coils or a large number of coils are needed to provide adequate coverage of the imaging volume. In our experimental setup, four coils (C1-C4) were placed about the volunteer's legs (L/R) with minimal S/I gap. This allowed a longitudinal coverage of approximately 80cm. Nevertheless, a signal drop-off region was observed between the coils in the sum-of-squares image, where SENSE reconstruction is poor due to the lack of coil sensitivity data (dashed boxes in Figure 1a and 1b). This can be compensated by using multiple overlapping phased array elements to provide continuous coverage of the extended FOV. Another issue is that SENSE requires *a priori* knowledge of coil profiles within the imaging volume. For CMT MRI, the acquisition of sensitivity maps across an extended FOV is not straightforward. Reconstruction becomes problematic because gradient nonlinearity and consequent image warping effects [5] cause spatial misregistration between the coil profiles and the SENSE-acquired data. As FOV_S is increased, gradient warp artifacts become more prominent. To address gradient nonlinearity complications in the acquisition of sensitivity maps, several approaches were considered.

Option 1: Sensitivity maps can be acquired with stationary scans at successive stations using a large FOV_S . With respect to our experimental setup, two sets of sensitivity maps can be collected centered about element pairs C1-C2 and C3-C4 (red boxes in Figure 1a). Smaller FOV_S sensitivity maps can also be acquired at the expense of additional stations and time. While this may be the most straightforward approach, SENSE reconstruction is impractical principally because the sensitivity map and aliased images experience different levels of gradient warp, and corrections prior to SENSE unfolding leads to additional spatial misregistration errors.

Option 2: Sensitivity maps can be obtained using a CMT acquisition with parameters identical to the actual SENSE scan. With the exception of the SENSE factor R , this approach forces the variables V_{TABLE} , FOV_S , N_Y , N_Z , and TR to remain constant between the coil profile and the reduced-FOV acquisitions. Gradient warping artifacts still exist for large FOV_S , while they can be minimized with modest (<25cm) values. However, because scan parameters remain fixed, gradient nonlinearity distortions equally affect all images. SENSE reconstruction can subsequently be applied in a straightforward manner.

Option 3: A third and more flexible approach extends Option 2, allowing non-identical parameters to be used by the CMT method to acquire sensitivity maps and reduced-FOV images. While the FOV_S must be the same for both to ensure consistency in gradient nonlinearity effects across all images, an increase in V_{TABLE} can be achieved by acquiring lower resolution coil maps or reducing the TR during the SENSE scan. This can potentially reduce the overall time of the clinical study.

A volunteer was scanned using the CMT method (Option 2) on a 1.5T scanner. A 3D gradient echo sequence acquired coronal slices (X-S/I, Y-L/R, Z-A/P) with $N_Y=128$, $N_Z=16$, $R_Y=2$, $R_Z=1$, $TR/TE=6.8/1.6ms$, $\Delta Z=5mm$, $FOV_S=24cm$, $FOV_Y=38cm$, and $V_{TABLE}=1.7cm/s$.

Results: Figure 1 illustrates results from our volunteer scan. In Figure 1a (non-SENSE), the non-intensity corrected sum-of-squares image shows the location of the four surface coil elements (C1-C4) and their individual sensitive regions. Figure 1b shows the non-intensity corrected SENSE reconstruction. Although not obvious in the images shown, the true lateral (L/R) spatial resolution of Figure 1b is twice improved that of Figure 1a for the same acquisition time. Noise in Figure 1b is principally caused by imperfect coil placement which leads to numerical ill-conditions of the SENSE unfolding matrix.

Conclusion: We have identified technical challenges, posed solutions, and demonstrated the feasibility of applying SENSE to the continuously moving table acquisition for extended FOV MRI. In this implementation SENSE was used to provide two-fold improved lateral resolution. Other possible usages of SENSE are increased table velocity for a fixed lateral resolution or reduced FOV_S and improved S/I resolution for a fixed velocity.

References: [1] Pruessmann, et.al, MRM 1999; 45:952-962; [2] Dietrich et al, 7th Mtg. ISMRM, 1999, #1653; [3] Kruger, et.al, MRM 2002; 47:224-231; [4] Fain, et.al, 10th Mtg. ISMRM, 2002 #212; [5] Polzin, et.al, 10th ISMRM Mtg. 2002 #380.

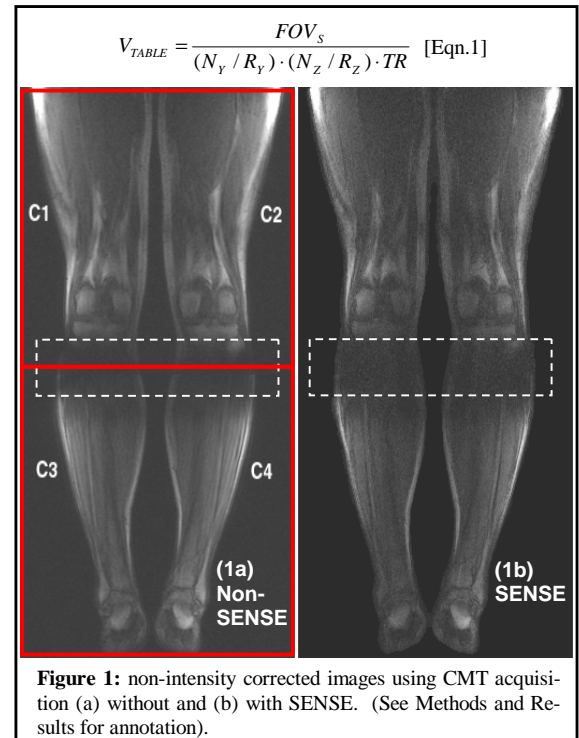


Figure 1: non-intensity corrected images using CMT acquisition (a) without and (b) with SENSE. (See Methods and Results for annotation).