ASSET – Parallel Imaging on the GE Scanner

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I. INTRODUCTION

Parallel imaging techniques use multiple receive coils to scan faster. The scan speed increase comes from omitting k-space lines or, equivalently, spacing the lines further apart. This has the effect of reducing the acquired field of view (FOV), thus producing image wrapping or aliasing if the object extends outside the reduced FOV in the phase encoding direction. Aliasing is "unwrapped" using the receive coil B1 fields ("sensitivities") with one of several methods.

In **SENSE** (SENSitivity Encoding) [1], aliased images are reconstructed from each coil and then combined using the receive coil sensitivities to cancel or unwrap the aliasing. In **SMASH** (SiMultaneous Acquisition of Spatial Harmonics) [2], the missing k-space lines are restored using the sensitivities prior to image reconstruction. In **SPACE-RIP** (Sensitivity Profiles from an Array of Coils for Encoding and Reconstruction In Parallel) [3], unwrapped images are reconstructed directly from the undersampled k-space data based on the coil sensitivity. **PILS** (Partially Parallel Imaging with Localized Sensitivities) [4] is an image-based approach that cuts away aliased signal from each image using the coil sensitivities as a template, and pastes together the remnants. In **AUTO-SMASH** [5] and **GRAPPA** (GeneRalized Autocalibrating Partially Parallel Acquisition) [6], acquired k-space data are used for direct synthesis of missing k-space data without the intermediate step of reconstructing coil sensitivity maps. **Generalized SMASH** [7] and **GEM** (Generalized Encoding Matrix) [8] are extensions of SMASH that allow greater flexibility in Cartesian k-space sampling. **Generalized SENSE** [9] allows any k-space sampling pattern including non-Cartesian trajectories such as spirals to be reconstructed. For all reconstruction methods, coil sensitivities are measured either by doing a separate scan or by collecting extra Nyquist-sampled data near the center of k-space within the parallel imaging scan (self-calibration) [10].

Parallel imaging has lower signal to noise ratio (SNR) than conventional imaging because of the reduced scan time and also because removing the aliasing magnifies noise. In SENSE, noise magnification is described by the geometry factor and is determined by the effective amount of coil separation in the phase encoding direction. Parallel imaging is a very efficient way to save scan time, but should be used with caution, since it can be costly in terms of SNR and risky in terms of artifact potential.

II. ASSET

ASSET (Array Spatial Sensitivity Encoding Technique) is based on the SENSE method, which combines multi-coil aliased images in a way that removes the aliasing. At a given pixel, each coil measures signal from each aliased replicate with a different (known) weight factor, so the set of multi-coil images can be used to separate (unwrap) the replicates. At each pixel, the equations can be written in matrix form as I=SM, where I is a column vector of measured complex image intensities for each coil at the pixel, M is a column vector of aliased complex spin densities, and S is a matrix of measured coil sensitivities. The equations can be solved by computing the pseudoinverse of S.

Optimal unwrapping requires knowing the number of overlapped aliasing replicates at each pixel. If the number of replicates is underestimated, uncorrected aliasing results, whereas if the number is overestimated, the SNR is needlessly degraded. The number of aliasing replicates can be calculated from the patient edge locations in the phase encoding direction. This information can be obtained from the sensitivity calibration images. In theory, the FOV reduction factor R (also called the acceleration factor) is limited by the number of coils. With two coils, a reduction factor of R=2 is possible (the acquired FOV is 1/2 the size of the prescribed FOV). In practice, coil geometry and SNR place stronger limitations on R.

For 3D ASSET scans, the reduction is in the primary (phase) Fourier encoding direction. With VIBRANT 3D bilateral breast imaging, the reduction is in the secondary (slice) Fourier encoding direction.

ASSET reconstruction time is longer than normal reconstruction time and is dominated by processing steps to unwrap aliasing, rather than Fourier transform operations. Matrix inversion uses LU decomposition with mild numerical conditioning to improve SNR at the cost of slight uncorrected aliasing.

ASSET sensitivity calibration is a separate scan with the phased array coil to be used for the ASSET scan. The scan is a 2D fast gradient echo with low spatial resolution and all parameters fixed except the slice thickness and locations. The operator prescribes a volume of axial slices encompassing the desired ASSET scan volume. A body coil calibration scan is not used. The calibration scan time is 6 to 12 seconds, depending on the number of slices used, fast enough to allow breath-holding for body scanning. The sensitivities at the pixel locations of the ASSET scan are obtained by linear interpolation.

Patient motion between the calibration and ASSET scans can cause uncorrected aliasing and reduced SNR. The low spatial resolution of the calibration smears out the sensitivity data, reducing effects of patient motion. Extrapolation of the sensitivity is also used to further reduce the effects of patient motion.

Applications must be able to tolerate the SNR loss of parallel imaging. ASSET can be used to reduce breath-holding times, improve temporal resolution, improve spatial resolution, or reduce artifacts. In general, contrast-enhanced applications are good candidates for ASSET. Abdominal scanning also has sufficient SNR and benefits from the resulting reduced breath-holding times. ASSET can be used with high-SNR steady-state gradient echo pulse sequences (FIESTA) in cardiac imaging to either reduce breath-holding times or improve temporal resolution. With bilateral breast imaging, ASSET allows high temporal and spatial resolution in a single acquisition.

With echo-train acquisitions such as Echo Planar Imaging (EPI) or Fast Spin Echo (FSE), ASSET allows reduced echo train length for a fixed spatial resolution and scan time. The result is reduced geometric distortion for EPI and reduced T2 blurring for FSE. This can be especially significant for diffusion weighted EPI where geometric distortion from uncompensated eddy currents is a problem.

III. FUTURE DIRECTIONS

With parallel imaging, coil performance is critical. Many phased array coils that were designed for conventional imaging work poorly with parallel imaging. The most important consideration is to orient the coil separation in the phase encode direction. For example, for left/right phase encoding, left/right coil separation gives a much better geometry factor than anterior/posterior or superior/inferior coil separation. Some additional improvement in the geometry factor comes from increasing coil separation in the phase encode direction, by reducing or even eliminating coil overlap [11].

Coil design is specific to each application because different applications can use different scan planes and different phase encoding directions. As more coils are developed that are compatible with ASSET, the range of applications will expand.

For coils with appropriate geometry, reduction can be applied in both the phase and slice directions (2D ASSET), giving an improved geometry factor for the same scan time [12]. One of the limitations of parallel imaging is uncorrected aliasing and excessive noise with small FOVs. 2D ASSET enables smaller FOVs by improving image quality for the same scan time.

Parallel imaging methods can be combined with **UNFOLD** (UNaliasing by Fourier-encoding the OverLaps using the temporal Dimenson) [13] for greater speed or improved image quality with cardiac applications, and with partial k-space updating methods such as **TRICKS** (Time Resolved Imaging of Contrast Kinetics) [14] for improved temporal resolution. Applications such as **DIXON** [15] that were seldom utilized because of long scan time are more practical when combined with parallel imaging.

More channels allow coil separation in more directions as well as more coils in a given direction. The result is more flexibility in phase and slice encoding direction placement with ASSET. New applications such as large volume scans that would have been too long with conventional imaging are now possible. Having more channels also improves image quality with existing applications by improving geometry factors. More channels may also improve the base SNR for some applications, thereby enabling higher reduction factors.

Higher field strength gives improved base SNR as well as better geometry factors [16]. Whereas R is typically limited to four or less at 1.5T due to limited SNR, considerably higher R is possible at field strengths of 3T or higher. The resulting higher reduction factors enable new applications such as the scanning of very large volumes with high spatial and temporal resolution.

IV. CONCLUSION

Parallel imaging on commercial scanners is still rapidly developing. Improvements in hardware and algorithms are being developed that will improve image quality with existing applications and enable new ones.

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