Efficient Continuously Moving Table 3D MRI with Lateral Frequency Encoding

B. Aldefeld[1], P. Börnert[1], J. Keupp[1]
[1]Philips Research Laboratories, Hamburg, Germany

Introduction

In MR imaging under continuous table motion, a large sampling FOV is desired for SNR reasons, but, on the other hand, the FOV must be kept small enough to avoid image degradation from non-uniformities of the RF, static and gradient fields. For whole-body imaging, a large FOV along the left-right (LR) direction is mandatory to cover all of the anatomy, whereas the FOV length along the motion (head-feet) direction can be restricted since this direction is accommodated by the table motion. It is thus desirable for efficiency reasons to choose the frequency-encoding direction of a Cartesian 3D scan along LR, which allows the fastest *k*-space coverage. Such a choice is different from most applications described so far, see e.g. [1-3], and requires different data-acquisition and reconstruction methods. The method described in this work extends the ideas proposed in [4] and achieves complete table-motion correction in 3D scans with lateral frequency-encoding direction, which can be an interesting alternative to other methods depending on the special application.

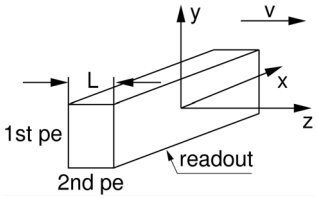

Fig. 1. Geometry.

Method

A 3D gradient-echo pulse sequence is applied while the patient is moved continuously along the *z* direction with velocity *v*. A selective RF pulse is applied to excite a slab of thickness *L* , see Fig. 1. The frequency-encoding direction is chosen along *x*, the 1st and 2nd phase encoding directions (1st pe, 2nd pe in Fig. 1) along *y* and *z*, respectively. For each of the N_y primary phase encodings, the full set N_z of secondary phase encodings is applied. During the time when a subset ΔN_y of the primary phase encodings is applied, the slab excitation is changed so that the slab moves with the same velocity as the patient, starting at position $-\Delta z$ from the isocenter and ending at $+\Delta z$. Each *k*-space line collected during such a *sweep* of the slab position is corrected for motion using the phase term $\exp(-ik_z dz)$, where d*z* is the current slab displacement from the isocenter (receiver frequency adjustment [2] is an alternative). Data of one sweep is then Fourier transformed in the *z* direction and stored in hybrid space (k_x,k_y,z) at a location matching the patient's position. The cycle is repeated for the next subset of phase encodings and continued until *k*-space scanning has been completed. Finally, the hybrid data is Fourier transformed in the remaining directions. The table velocity and the slab thickness are related via $L = v \cdot \mathrm{TR} \cdot N_y \cdot N_z$, and the sweep length is $2\Delta z = v \cdot TR \cdot \Delta N_y \cdot N_z$. The parameter ΔN_y can be chosen between 1 and N_y, allowing to experiment with different sweep lengths. This basic method is further improved by the application of some oversampling in *z* direction to suppress effects of non-ideal slab selection and to allow sufficient time for the spin system to establish a steady state.

Experiments and Results

Volunteer experiments were performed on a 1.5-T whole-body MR scanner (Achieva, Philips Medical Systems), using a spoiled 3D gradient-echo sequence with linear *k*-space scanning order. The patient table was moved at constant velocity through the FOV. The body coil was used for both excitation and reception. Reconstruction was performed offline and without any corrections with respect to gradient nonlinearity or field inhomogeneity. RF excitation pulses with two sinc periods in combination with symmetric oversampling in *z* direction (2×7 samples) were found to provide adequate slab definition and only minimal aliasing from the object outside the desired slab. A sweep length as small as possible (obtained for $\Delta N_y = 1$) provided the best image quality so far, presumably because the effective FOV length in *z* direction from which signal is collected is as small as possible in this case, i.e. $\mathrm{FOV}_z = L + 2\Delta z = L + v \cdot TR \cdot N_z$. Figure 2 shows two of 84 coronal slices from a 3D head-to-toe free-breathing scan of a healthy volunteer that covered a virtual FOV of $540 \times 256 \times 2000$ mm^3, with voxel dimensions 2×2 mm^2 in the coronal plane and 3.05 mm AP. Other imaging parameters were $v = 4$ mm/s, TR/TE = 4.6/2.2 ms, $L = 100$ mm, flip angle 15 degrees and $\Delta N_y = 1$ (resulting in slab sweeping over 1.2 mm distance). The total scan time was 8 minutes. Good image quality is obtained over the anatomy except at the lateral FOV borders (arms), where the limits of the homogeneity volume of the magnet are somewhat exceeded.

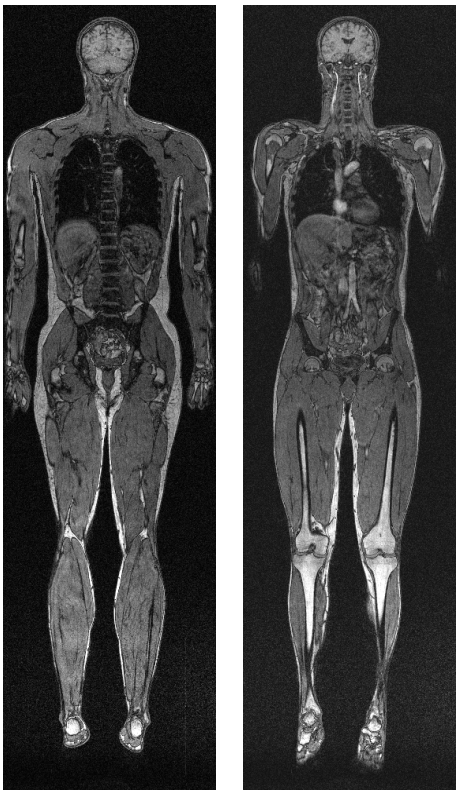

Fig. 2. Two planes of a continuous 3D volunteer scan using readout along LR.

Discussion and Conclusion

The method allows most efficient *k*-space coverage because the frequency-encoding direction can be chosen along the LR direction, i.e. along the largest FOV length required in a whole-body scan (shoulders). The data acquisition time is almost independent of the FOV length in *z* direction, prolonged only due to the oversampling. Thus, the FOV length in motion direction can be chosen so small that artefacts resulting from gradient nonlinearity and B_0 and RF-field inhomogeneities are negligible, without loss of scan efficiency. The quality of the slab profile with respect to aliasing and the steady state transient behavior of spins entering the FOV need further consideration. Correction methods, e.g. concerning the nonlinearity of the gradients, could be included in the method. The continuously moving table method described here seems especially suited for applications where fast coverage of a long virtual FOV is desired. Scout scans, cancer screening and angiography may be potential applications.

References

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