Sharing of k-space profiles to accelerate T1 relaxometry

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Introduction: The quantitative measurement of T1 is important for, e.g., brain diagnosis [1] and contrast agent quantification [2], which is particularly valuable in the framework of molecular imaging. However, the fitting of exponentials typically requires the acquisition of $P \approx$ 5-25 images along an inversion recovery curve (e.g., using the Look-Locker technique [3]), which prolongates the measurement by a factor of P. To fasten the measurement, this study investigates the mutual sharing of k-space lines of adjacent images [4]. The method is tested on fully acquired brain data by a posteriori sharing different fractions F of k-space lines.

Theory: Figure 1 sketches the basic principle of profile sharing. Regarding for instance image 3, only every second (e.g., the even-numbered) k-space line is acquired for $k_{max} > k_y > (1\text{-}F)\ k_{max}$,, using a sharing fraction $0 < F < 50\%$. For the subsequent image 4, only the complementary (i.e. the odd-numbered) k-space lines are acquired for this k-space region. The missing lines of image 3 are taken from image 4 and vice versa. The same procedure is applied for $-k_{max} < k_y < -(1\text{-}F)\ k_{max}$ between images 3 and 2 and accordingly for the remaining images. The sharing fraction F can be varied across the P images. In this study, a sharing fraction F_1 is applied to the first P_1 images and a sharing fraction of F_2 to the remaining $P_2 = P - P_1 + 1$ images (see Fig. 1). The time reduction factor R is given by

$R = P / (P - F_1(P_1 - 1) - F_2(P_2 - 1))$.

Thus, the maximum reduction factor possible is $R \approx 2$ for $F_1 = F_2 = 50\%$. The maximum R is always slightly lower than two, since only one half of the k-space of the first and last acquired image can be shared with adjacent images. If k-space profiles are shared also with non-adjacent images, which is not tested in this study, also higher reduction factors than $R = 2$ could be obtained.

Methods: A fully sampled T1 map of a brain is acquired with an inversion recovery turbo field echo sequence using P = 25, TR = 12 ms, α=10°, and a linear profile order on a Philips Intera 3T system (Philips Medical Systems, Best, The Netherlands). Different sharing rates $0 < F_1,F_2 < 50\%$ are tested. The images are then Fourier transformed and exponentials are fitted for each pixel using a Levenberg-Marquardt fitting algorithm. Finally, a Look-Locker correction is applied [3]. The resulting T1 maps are compared by the mean quadratic difference δ to the fully sampled T1 map within a region of interest sketched in Fig. 3. Pixels with T1 > 2000 ms, i.e. pixel containing CSF, are ignored to concentrate on gray matter (T1 ≈ 1100 ms) and white matter (T1 ≈ 800 ms).

Results: For a constant sharing fraction $F_1 = F_2$, the mean error increases from $\delta = 0$ for $R = 1$ to $\delta = 2.6\%$ for $R = 1.92$, i.e. full profile sharing with $F_1 = F_2 = 50\%$ (Fig. 2). Using full sharing $F_2 = 50\%$ only for the last $P_2 = 20$ images and $F_1 < 50\%$ for the first $P_1 = 6$ images, the mean error can be reduced by roughly 0.25% (Fig. 2). The reconstructed T1 map for $R = 1.92$ (full sharing $F_1 = F_2 = 50\%$) and R = 1.74 ($F_1 = 30\%$, $F_2 = 50\%$) are shown in Figs. 4/5. For both cases, a difference to the fully sampled T1 map can hardly be recognized. The difference to the fully sampled T1 map becomes visible taking the ratio of the shared/unshared T1 maps (Figs. 6/7). In the first case of $R = 1.74$, the quotient is close to white noise, and no structured artifacts are present (Fig. 6). In the second case of $R = 1.92$, ghosts appear in the quotient in a distance FOV/2 corresponding to the sharing of every second k-space line (Fig. 7).

Discussion and Conclusion: Profile sharing seems to be able to reduce the acquisition time of inversion recovery T1 maps independent of the sequence used. Possible reduction factors might be up to $R \approx 1.8$, thus leading to a significant acceleration of T1 relaxometry, while introducing an additional error of only a few percent. Even higher reduction factors might be achieved introducing profile sharing with non-adjacent images or flexible sharing fractions adapted to the expected T1 distribution in the region investigated. Also alternating profile orders might help to stabilize the approach. Profile sharing could be combined with other acceleration techniques like half Fourier or parallel imaging to further reduce the acquisition time, approaching real-time relaxometry.

References:

[1] Henderson E et al., Magn Reson Imaging. 8 (1999) 1163-71

[2] Hofman MB et al., Magn Reson Med. 41 (1999) 360-7

[3] Deichmann R et al., Magn Reson Med. 42 (1999) 206-9

[4] Riederer SJ et al., Magn Reson Med. 8 (1988) 1-15

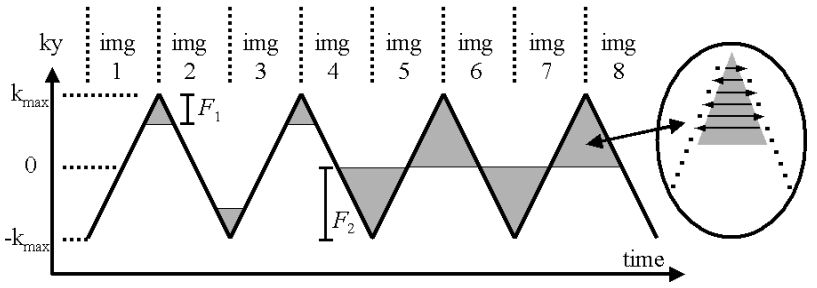

Fig. 1: Example of $P = 8$ images acquired along an inversion recovery curve for an alternating profile order. The first $P_1 = 4$ images share a fraction $F_1 = 20\%$ of k-space profiles, the last $P_2 = 5$ images share a profile fraction $F_2 = 50\%$. The principle of profile sharing is sketched in the inlay on the right.

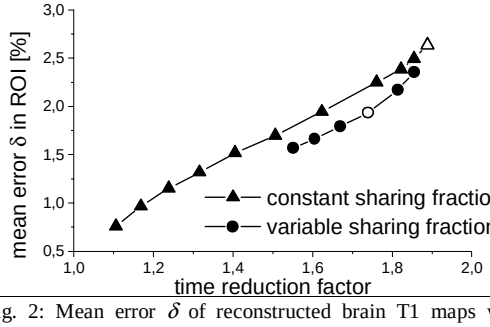

Fig. 2: Mean error δ of reconstructed brain T1 maps with $P = 25$ and $\alpha = 10°$ using different schemes of profile sharing. The open symbols indicate T1 maps shown on Figs. 4-7.

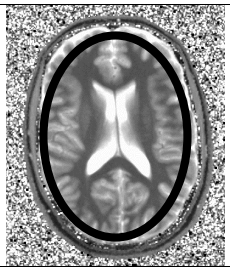

Fig. 3: Original T1 map without using profile sharing. The mean error δ is calculated within the indicated ROI.

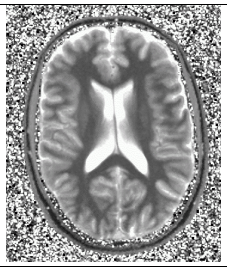

Fig. 4: T1 map for a time reduction factor $R = 1.74$. Almost no deviation to Fig. 3 is visible.

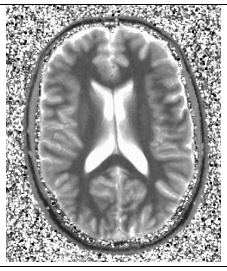

Fig. 5: T1 map for a time reduction factor $R = 1.92$. Almost no deviation to Fig. 3 is visible.

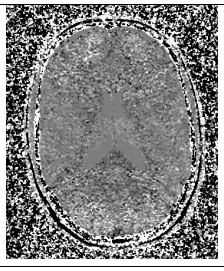

Fig. 6: Quotient of Fig. 4 ($R = 1.74$) and Fig. 3 ($R = 1$), which is close to white noise.

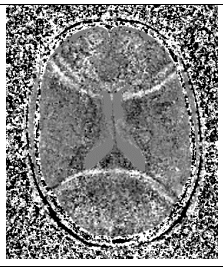

Fig. 7: Quotient of Fig. 5 ($R = 1.92$) and Fig. 3 ($R = 1$), showing ghosts in a distance of FOV/2.