

PASTeUR: Package of Anatomical Sequences using parallel Transmission UniveRsal kT-point pulses

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Synopsis

Despite its power to counteract the inevitable radiofrequency field inhomogeneity problem at ultra-high field, parallel transmission has failed to be embraced by the community in routine due to a cumbersome workflow. Universal pulses have shown great potential to circumvent this problem by providing plug and play solutions. Here we validate a package of 3D anatomical sequences for a given commercial coil covering multiple contrasts for use in clinical routine and including, thanks to their versatility, very few pulse solutions. The utilization of universal k_T-points enables direct embedding of these pulses in the sequences and easy handling of the power/SAR limits.

Introduction

Parallel transmission (pTx) is the most promising technology to mitigate the radiofrequency (RF) field inhomogeneity problem at ultra-high field because of its versatility and its ability to tame the SAR. One major obstacle however has been the inherent cumbersome workflow involving subject-based calibration (field map measurements), data processing and online pulse design, incurring to the user a significant time penalty. Universal pulses (UPs) were proposed to bypass entirely the calibration procedure by providing plug and play pTx solutions at no cost for the user¹. They are based on an offline pulse design performed on a database of different subject field maps to be robust with respect to intersubject variability. Non-selective and selective pulses this way were shown to counteract RF field inhomogeneity in the human brain at 7T for several applications and at a mild cost in performance compared to the tailored-based approach²⁻⁴. Here we report the integration of non-selective universal k_T-points pulses⁵ in a package named PASTeUR, covering the 3D GRE, MPRAGE, SPACE, FLAIR with T₂-preparation and DIR sequences, and handling SAR and RF coil power limits. As a first step, the package was developed for compatibility with the Siemens step 2.3 protected mode.

Methods

All sequences incorporated non-selective k_T-point pulses⁵ designed on a database of 20 subject field maps² acquired on a 7T Siemens (Siemens Healthcare, Erlangen, Germany) Magnetom scanner equipped with the Nova (Nova Medical, Wilmington, MA, USA) 8Tx-32Rx pTx coil. A second order optimization scheme with explicit constraints and with simultaneous optimization of the k-space trajectory was employed for pulse design⁶. The 3D GRE embeds 3 scalable pulses (maximum flip angles of 10, 20 and 60°) of different durations (570, 800 and 1160 μs respectively) to handle different energy demands. The MPRAGE integrates a 3.68 ms-inversion pulse, designed with a GPU-based Bloch simulator, and a small tip angle pulse (570 μs) reaching up to 8°. The readout of the SPACE, FLAIR and DIR sequences was built upon a single 1.04 ms-long refocusing k_T-point pulse that can likewise be scaled to match a given flip angle train³.

The inversions for the DIR are the same as for the MPRAGE. The T_2 -preparation for the FLAIR is constituted of a 90° , delay, 180° , delay and 90° pulse. These pulses were designed independently due to the phase coherence constraint imposed among them. All designs were performed to be compatible with Siemens protected mode step 2.3, i.e. with peak amplitude limits of 165 V and average power limits of 1.5 W per channel and 8 W total for the coil of interest. Given the low number of pulse solutions (1, for the GRE and SPACE sequences and 2 for the MPRAGE, 3D FLAIR and 3D DIR sequences), power assessment could simply be made by calculating their respective energies and weighting them with their corresponding duty cycles. The sequence thereby easily forbids parameters that would exceed the 6-min time average power limits to prevent scan abortion during runtime. The package was tested in vivo on 3 healthy volunteers at 7T.

Results

Table 1 summarizes the durations and flip angle normalized root mean square errors (FA-NRMSE) calculated over the 20 subjects of the database and for all pulses employed in the package. Figures 1 and 2 report 3 orthogonal view brain images on 1 volunteer acquired with the MPRAGE, SPACE, FLAIR with T_2 -preparation, and DIR sequences, for the CP mode and universal pulse solutions respectively. The CP mode is clearly outperformed by the universal pulse solutions with no pTx-specific procedure for the user, yielding images virtually-free of B_1^+ artefacts.

Conclusion

We have reported in this work the development and validation of a package of anatomical sequences directly embedding calibration-free pTx solutions to mitigate the RF field inhomogeneity problem in brain imaging at 7T. For easier handling of SAR/power constraints, the package for the moment conforms to the Siemens protected mode of operation where only peak and average power limits need to be fulfilled. Future work includes the use of validated Virtual Observation Points for less conservative SAR assessments and higher power limits. Yet, for the package of sequences presented here, these limits did not constitute a serious constraint, thanks mostly to the coil transmit efficiency. Finally, although this package was tested here on a small number of volunteers to propose useful default protocols, individual sequences with the same universal pulses cumulate close to a 50 volunteers experience across 4 different sites^{2-4,7}. They have never failed to suppress the ubiquitous B_1^+ artefacts observed with the CP excitation mode.

Acknowledgements

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Figures

Pulses	Duration (μ s)	FA-NRMSE (%)
Small tip (GRE) – up to 10°	570	5.4 \pm 1.3
Small tip (GRE) – up to 20°	800	5.3 \pm 1.3
Small tip (GRE) – up to 60°	1160	5.6 \pm 1.6
Small tip (MPRAGE) – up to 8°	570	5.2 \pm 1.2
Refocusing (SPACE, FLAIR, DIR) – up to 105°	1040	10.1 \pm 1.7
Inversion (MPRAGE, DIR)	3680	1.9 \pm 0.5
90° T2 preparation (FLAIR)	1020	7.5 \pm 1.5
180° T2 preparation (FLAIR)	2040	9.9 \pm 1.2

Table 1. Flip Angle Normalized Root Mean Square Errors and durations for the various k_T -points employed in the PASTeUR package. For the FA-NRMSEs, the mean \pm standard deviation is calculated over the 20 subjects database. Homogeneity on average is better than for the CP mode at 3T8 (~13%), and comparable in the worst case.

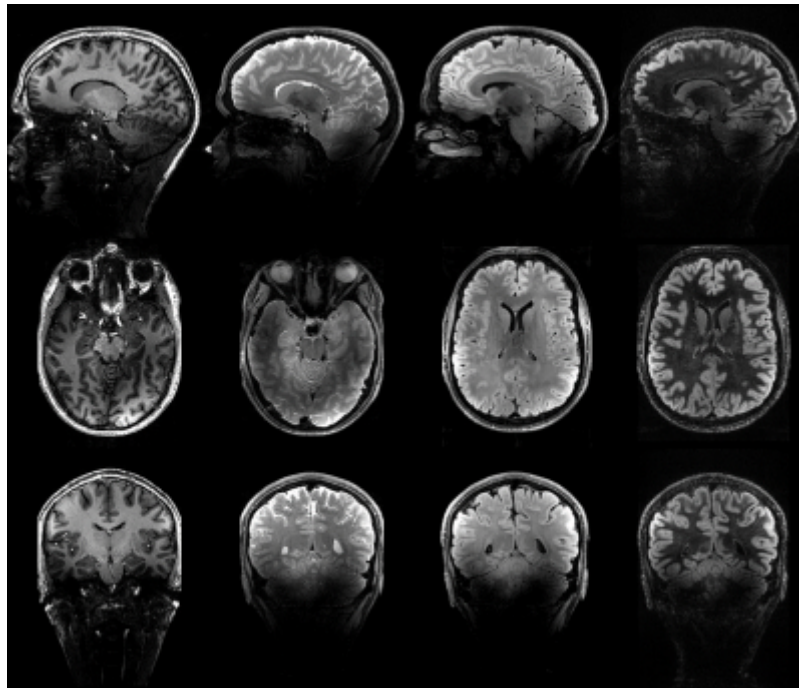


Figure 1. Orthogonal views of a human brain obtained at 7T and in CP mode for different contrasts. Great RF field inhomogeneity results in severe signal dropout or overshoot and loss of contrast throughout the different acquisitions. From left to right: MPRAGE, SPACE, FLAIR with T₂ preparation and DIR. Reception profile was not removed. The sequence parameters were: MPRAGE (resolution: 0.8×0.8×0.8 mm³, TA = 6 min 35 s), SPACE (resolution: 0.8×0.8×0.8 mm³, TA = 8 min 53 s), FLAIR (resolution: 1×1×1 mm³, TA = 9 min 48 s), DIR (1×1×1 mm³, TA = 11 min 54 s).

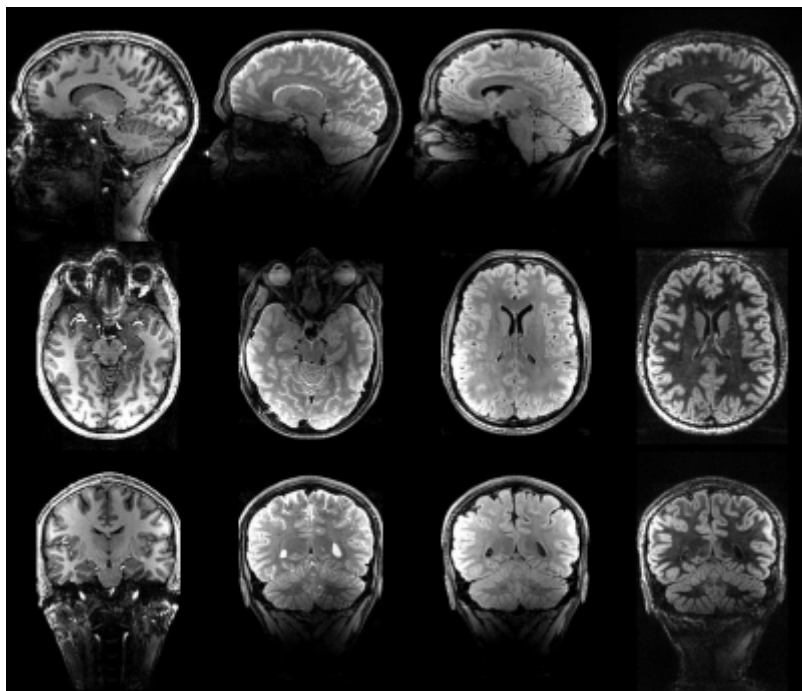


Figure 2. Same orthogonal views as in Figure 2 obtained with PASTeUR. Great RF field inhomogeneity mitigation is achieved at no cost for the user, yielding images virtually free of B_1^+ artefacts. Reception profile was not removed.