Optimization of Flip angle and TR schedules for MR Fingerprinting

Maxwell L Wong[1], Eric Z.C. Wu[2], and Eric C Wong[3]

[1]UC San Diego, La Jolla, California, United States, [2]University of Southern California, California, United States, [3]Department of Radiology and Psychiatry, UCSD, La Jolla, California, United States

Purpose

MR Fingerprinting was recently introduced in (1) with the following key properties: the ability to estimate T1, T2 and frequency maps simultaneously, the potential to be faster than traditional methods of imaging while maintaining similar SNR, and the ability to provide remarkable robustness to motion. The goal of this simulation study is to optimize TR and flip angle schedules in MRF to most accurately estimate T1, T2 and frequency maps.

Methods

The Fingerprinting process was simulated as described in (1). Balanced SSFP was used with matrix size 128x128. Data was generated using a highly undersampled variable density spiral (2), fully sampled in the center of k-space and undersampled by a factor of fifty toward the edge. MR Fingerprinting matches the measured signal over time of a pixel to entries in a dictionary containing possible signal timecourses corresponding to a list of T1, T2 and off resonance values. After finding the timecourse with the highest correlation to the data, the pixel is assigned the associated T1, T2 and off resonance values, and all three maps can be created after the process is completed for all of the pixels. The dictionary is composed of every combination of T1, T2 and off resonance values run through a Bloch simulator. A new dictionary must be generated for each distinct pairing of TR and flip angle schedules. Potential T1 and T2 values were chosen based on a geometric series with range 350-3000ms for T1s, and 40-550ms for T2s. Off resonance values were sampled linearly from -50-50Hz. For comparison, DESPOT1 and DESPOT2 were simulated with equivalent amounts of noise and identical overall scan time. This is a slight departure from (1), in which the DESPOT scan time was not matched to MRF. In order to optimize the flip angle and TR schedules, a random schedule was scaled and frequency filtered. Gaussian noise was generated using Matlab, scaled to a maximum flip angle and filtered with a Gaussian frequency filter centered on a frequency f with a sigma 2*f. The schedules of flip angles were scaled from 0-60° or from -30-60° and truncated at zero to generate segments with zero flip angle. TR schedules were generated using the same method, with scaling between 10ms and 14ms.

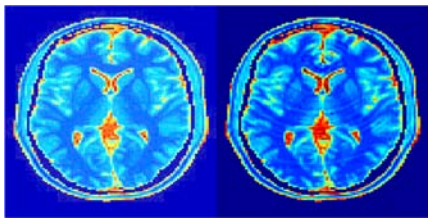

Figure 1: a) reference T1 map; b) simulated T1 map

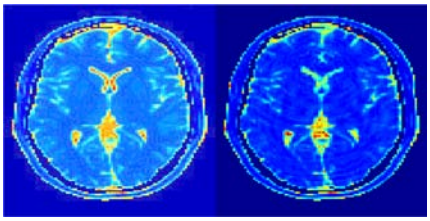

Figure 2: a) reference T2 map; b) simulated T2 map

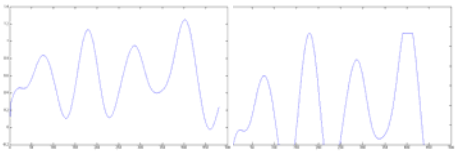

Figure 3: a) flip angle schedule generated from a filtered random function; b) the same schedule with values truncated to stay between 0° and 60°.

Results

T1 maps are shown in Figure 1, and T2 maps in Figure 2. Figure 3 shows sample flip angle schedules, both truncated and not, with Figure 4 showing the difference between the resulting estimated T1 maps. Figure 5 shows a sample TR schedule. The RMSE's were calculated for eight data sets and plotted in Figure 6.

Discussion

While no one optimal schedule for either TR or flip angles was found, certain characteristics of TR and flip angle schedules that yielded the best results were noted. T2 expectedly falls off as the filter frequency gets larger, and T1 sensitivity is best with the lower frequency filters. The accuracy of the estimated maps is critically dependent on the flip angle schedule, and the introduction of zeros into the schedule improved accuracy slightly. The TR schedule had very little frequency dependence in the range that we tested. With matched scan time, T1 and T2 estimates were 2% and 40% better with MRF than with DESPOT1 and DESPOT2, respectively.

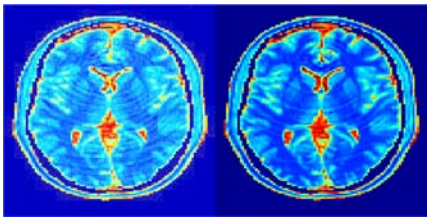

Figure 4: estimated T1 maps using a not truncated and truncated flip angle schedule as shown below.

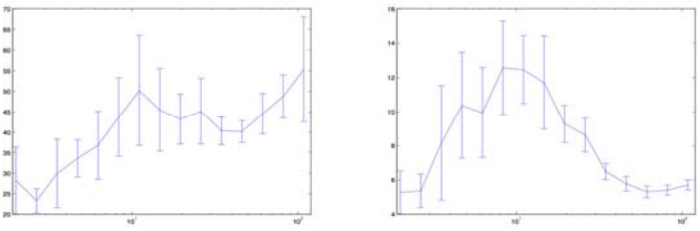

Figure 6: a) T1 RMSE; b) T2 RMSE
Plots of the RMSE by filter frequency, with error bars representing mean ± sd across eight data sets.

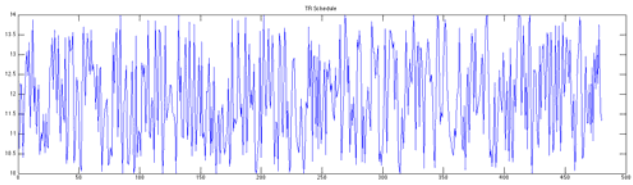

Figure 5: Sample TR schedule with a high frequency filter

References
1. Ma et al, Nature:187:192, 2013
2. Hargreaves B., http://www-mrsrl.stanford.edu/~brian/vdspiral/