TArgeted Motion Estimation and Reduction (TAMER): Data Consistency Based Motion Mitigation Using a Reduced Model Joint Optimization



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Introduction & Motivation

Numerous methods have been introduced that attempt to correct motion corrupted MRI data using markers and navigators^{[1]–[5]}. Data driven approaches have also been explored to correct for motion using image entropy minimization^{[6],[7]} and alternating minimizations^[8]. The goal of this work is to create an efficient and accurate retrospective technique without navigators or markers, that jointly estimates motion trajectories and a small number of targeted voxels using a data consistency based parallel imaging forward model. Here we illustrate our method's ability to correct for translational and rotational head motion in 2D RARE (TSE, FSE) imaging, one of the most common clinical brain scans.

Methods & Results

TAMER Corrected Images of Translated Head Phantom: TAMER was tested on an anthropomorphic head phantom using ETL=11, 220x220mm² FOV, 12 slices, and resolution 0.9x0.9x3mm³. To create motion corrupted data, the phantom was placed on a translational stage and moved intermittently throughout the scan in the A-P direction. Each slice was TAMER corrected **Translation Corrupted TAMER Corrected** independently and returned consistent motion estimates, leading to a large reduction in ringing artifacts and percent RMSE (shown in white) for all slices, as illustrated in a representative slice shown above.



SENSE + Motion Forward Model

A SENSE^[9] & motion forward model E_{θ} encodes the volume image x to the multichannel signal s for a given motion time course θ . Defining the undersampling operator, U, Fourier encoding F, coil sensitivity C, in-plane & through-plane translation T_{xy} , T_z , and rotations R:

> $s = UFCT_{xy}T_zRx = E_{\theta}x$ (1)



Model Reduction Using Target Pixels

For a 3D volume, x contains millions of unknown voxels, making fixed pixels: x_f

TAMER Corrected Images of Simulated **Motion Data:** Motion corrupted k-space data was simulated by adding translation appropriate phase (for both the in-plane and through-plane directions) to k-space shots of a T2-weighted 2D TSE acquisition from a healthy volunteer on a 3T Siemens Trio with ETL=8, 224x224mm² FOV, 1.75x1.75x3mm³ resolution, 32-channel, 5 slices, TR=6.1s, TE=98ms, refocus angle=150° and R=1. The motion-free image was corrupted using the measured translation parameters taken from an Alzheimer's disease patient's fMRI study, and TAMER corrected images were reconstructed for Estimated vs. Actual Motion R = 2. Percent RMSE compared to ground $\widehat{\epsilon}$ truth was calculated for



repeated calculation of x for a given E_{θ} computationally prohibitive. To reduce computation while ensuring accuracy, xis separated into targeted pixels, x_t (shown in blue), and fixed pixels, x_f (shown in green), and is reconstructed only in x_t during the search for the motion parameters.

$$E_{\theta}x = (E_{\theta,t} \quad E_{\theta,f}) \begin{pmatrix} x_t \\ x_f \end{pmatrix} = E_{\theta,t}x_t + E_{\theta,f}x_f \qquad (2$$
$$s_t = s - E_{\theta,f}x_f \qquad (3)$$



For TSE imaging, pixels aliased in the same highly undersampled shot are coupled.

The motion and targeted pixel set are the jointly optimized to avoid degeneracy in the solution space and stabilize the reconstruction. W is a k-space weighting filter.

$$[\widehat{\boldsymbol{\theta}}, \widehat{\boldsymbol{x}_t}] = \operatorname{argmin}_{\boldsymbol{\theta}, \boldsymbol{x}_t} \left\| W(\boldsymbol{s}_t - \boldsymbol{E}_{\boldsymbol{\theta}, t} \, \boldsymbol{x}_t) \right\|_2 \tag{4}$$

TAMER Overview

(1) K-space data is SENSE reconstructed (sensitivity profiles calculated using BART^[10]) for all pixels, and an initial target set is selected. (2) TAMER searches for motion parameters with high data consistency by reconstructing the image in x_t and evaluating the forward model fit. The target pixels are shifted until all pixels have been corrected and the motion is determined.

each image (shown in $\frac{1}{2}$ white). Output motion shown in solid lines, ground truth dashed.



Translation Corrupted TAMER Corrected

TAMER Corrected Images of Rotation

Phantom: TAMER was tested on a pineapple phantom using ETL=11, 230x208 mm² FOV, 0.6x0.6 mm² resolution, 5 mm slice thickness, TR=3.8s, TE=93 ms, refocus angle=150°, and R=1. The pineapple was rotated in plane using a motion actuator throughout the scan, with estimated magnitudes of rotation up to $\pm 3^{\circ}$. Many of the high frequency components of the rotation corrupted image were visible after it was TAMER corrected. Percent RMSE compared to ground truth was calculated for each image (shown in white).



Rotation Corrupted

TAMER Corrected



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Discussion & Conclusions

We have demonstrated the effectiveness of TAMER for correcting translational motion in (1) simulated accelerated data and (2) brain phantom data corrupted by an externally controlled actuator. In addition, we have shown TAMER's ability to correct for motion artifacts when a pineapple is rotated using an actuator. The method is able to efficiently and accurately estimate motion using only parallel imaging across a targeted subset of voxels. With the inclusion of modeling terms for through plane rotation and other MR effects, TAMER should facilitate retrospective motion correction in clinical settings.

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