Motion-immune structural MRI based on repeated k-t-subsampling and artifact-minimization (REKAM)

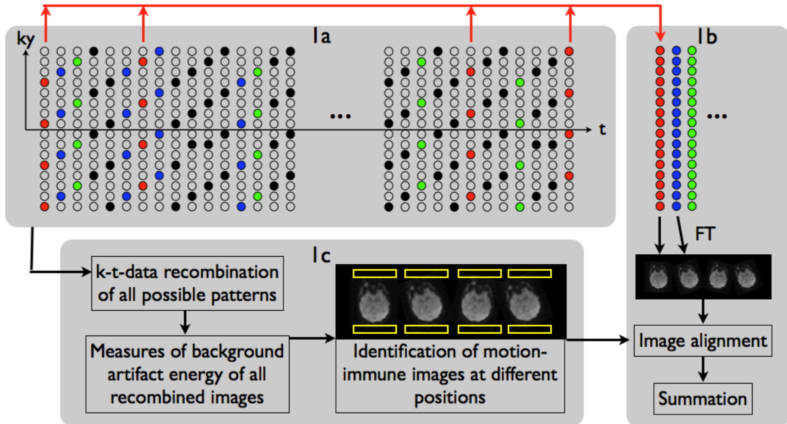
Mei-Lan Chu[1,2] and Nan-Kuei Chen[2]

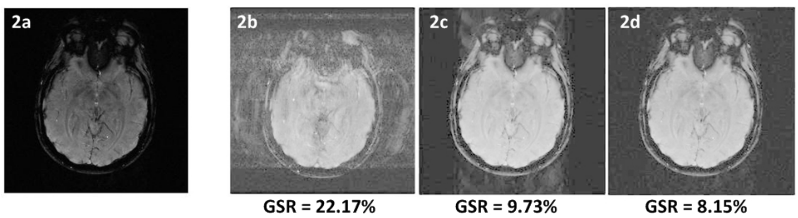
[1]*Graduate Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan,* [2]*Brain Imaging and Analysis Center, Duke University Medical Center, Durham, NC, United States*

TARGET AUDIENCE: Researchers who are interested in motion-insensitive and high-quality MRI; Investigators who are conducting MRI studies in challenging populations (e.g., children, patients with tremor-dominating Parkinson's disease).

PURPOSE: It has been highly challenging to generate high-quality structural MRI data in the presence of <u>continual</u> and <u>unpredicted</u> motion. Existing motion artifact reduction methods, such as navigator-echo based methods and PROPELLER can reduce motion-related artifacts in many cases, but may not always completely eliminate artifacts for highly challenging cases, such as neuro MRI in the presence of pronounced head tremor in Parkinson's patients. Here we report a novel technique, based on *<u>re</u>peated <u>k</u>-t-subsampling and <u>a</u>rtifact-<u>m</u>inimization (REKAM)*, to enable high-quality MRI for highly challenging populations.

METHODS: The new motion-immune structural MRI method has two modules. 1) *<u>Acquisition</u>*: a fast imaging pulse sequence is used to rapidly and repeatedly acquire subsets of k-t-space data corresponding to different subject positions, and 2) *<u>Reconstruction</u>***:** Multiple images are generated from the acquire data using all possible k-t-data grouping patterns, and motion-immune images corresponding to multiple subject positions are then identified automatically based on their low background artifact energy level. The identified motion-immune images can be subsequently combined to form a final image with high SNR.





The acquisition module of REKAM is schematically illustrated in Figure 1a, where k-t-space data are repeatedly scanned with echo-planar imaging (EPI) with a sub-sampling factor of 4. The solid and empty circles represent sampled and unsampled ky lines respectively, and the circles with the same color (e.g., red) correspond to approximately the same subject position (while the subject position changes continually during scans).

As illustrated in Figure 1b, if the position information corresponding to every time point is known, then the k-t-data corresponding to a particular position can be grouped to form an artifact-free image (e.g., red k-space data points in Figure 1b). Motion-immune images corresponding to multiple positions (e.g., red, blue and green k-data points) can then be aligned and summed to produce a final image with high-SNR. Practically, the patterns of intra-scan motion are unknown and unpredictable. Therefore, in the REKAM reconstruction module (shown in Figure 1c), a brute-force search strategy is used to identify motion-immune images corresponding to different positions with the following steps. First, the acquired k-t-space subsampled data are regrouped using all possible data grouping patterns, producing a series of images. Second, the background artifact energy is measured from pre-defined ROIs of the produced images. Third, motion-immune images (i.e., with lowest background artifact energy in ROIs) corresponding to multiple positions can then be identified. Afterward, the motion-immune images corresponding to different positions can be aligned and summed to produce a final image with high-SNR and minimal artifact.

The developed technique is evaluated with human MRI studies performed on a 3 Tesla scanner. The healthy participants were asked to have continual head tremor (at ~ 3Hz) during i) a conventional T2*-weighted SPGR scan (scan time = 10 sec) and ii) our repeated k-t-subsampling scheme (64 repetitions of T2*-weighted EPI with a sub-sampling factor of 8: total scan time = 10 sec). The SPGR data were reconstructed with 2D FFT, and the repeated k-t-subsampled data were processed with either a direct 2D FT of temporally-averaged data (as for regular segmented EPI reconstruction) or the REKAM artifact minimization module outlined in Figure 1c.

RESULTS: Figure 2a shows the artifact-free image generated by REKAM, in the presence of continual head tremor. The conventional 2D SPGR, segmented EPI reconstruction of the acquired EPI k-t-space data, and the final REKAM images are shown in Figure 2b, 2c, and 2d, respectively, with the display level elevated to better visualize the background artifacts. It can be seen that the SPGR image (2b) is severely corrupted by motion artifacts, with a ghost-to-signal ratio (GSR) > 22%. The segmented EPI reconstruction of the temporally-averaged EPI data produces an image with a lower artifact level (with GSR = 9.73%: Fig 2c). Among these images, the REKAM produced image has the lowest artifact level (with GSR = 8.15%: Fig 2d), demonstrating the robustness and effectiveness of the developed motion-immune REKAM technique.

DISCUSSION: A robust motion-immune MRI acquisition and reconstruction strategy is presented in this study. The experimental results indicate that the proposed REKAM method can effectively suppress motion-related artifacts even for highly challenging cases, such as continual head tremor during scans. As compared with the conventional SPGR that is highly susceptible to intra-scan motion, the REKAM method can produce artifact-free images of the same spatial resolution within the same scan time. Even though the REKAM method is demonstrated here with T2*-weighted imaging, the developed technique can be applied to structural MRI pulse sequences of other weightings and contrasts (e.g., proton-density, T1, among others).

CONCLUSION: The developed REKAM technology enables high-quality and motion-immune MRI for highly challenging patient populations.

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