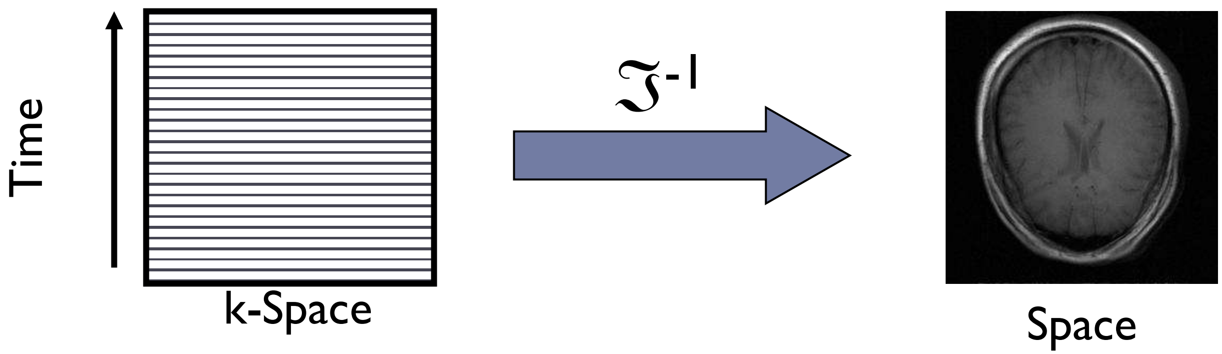
# Medical Image Reconstruction
# Term II – 2010

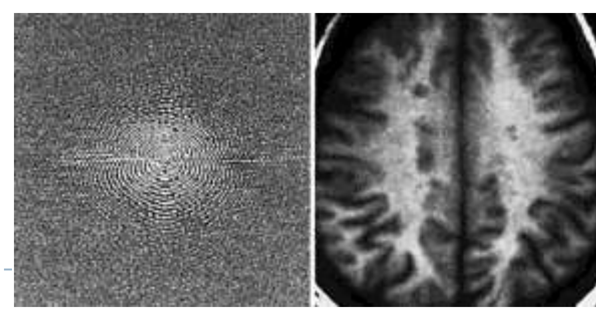
# Topic 4: MRI Reconstruction Under In-Slice Motion

Professor Yasser Mostafa Kadah

# MRI Data Acquisition

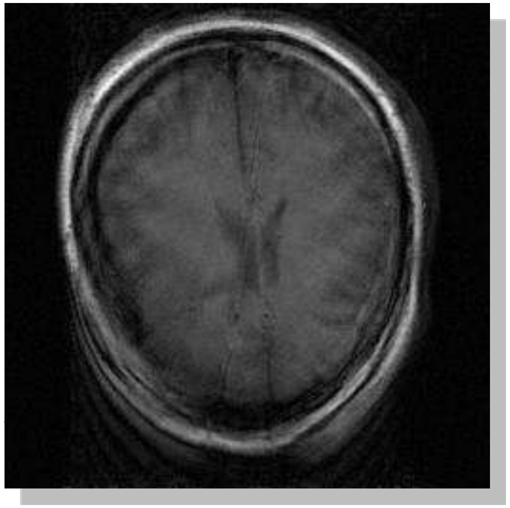
- MR image is acquired in the k-space
- Reconstruction is an inverse Fourier transformation
- Parts of k-space are acquired at different times



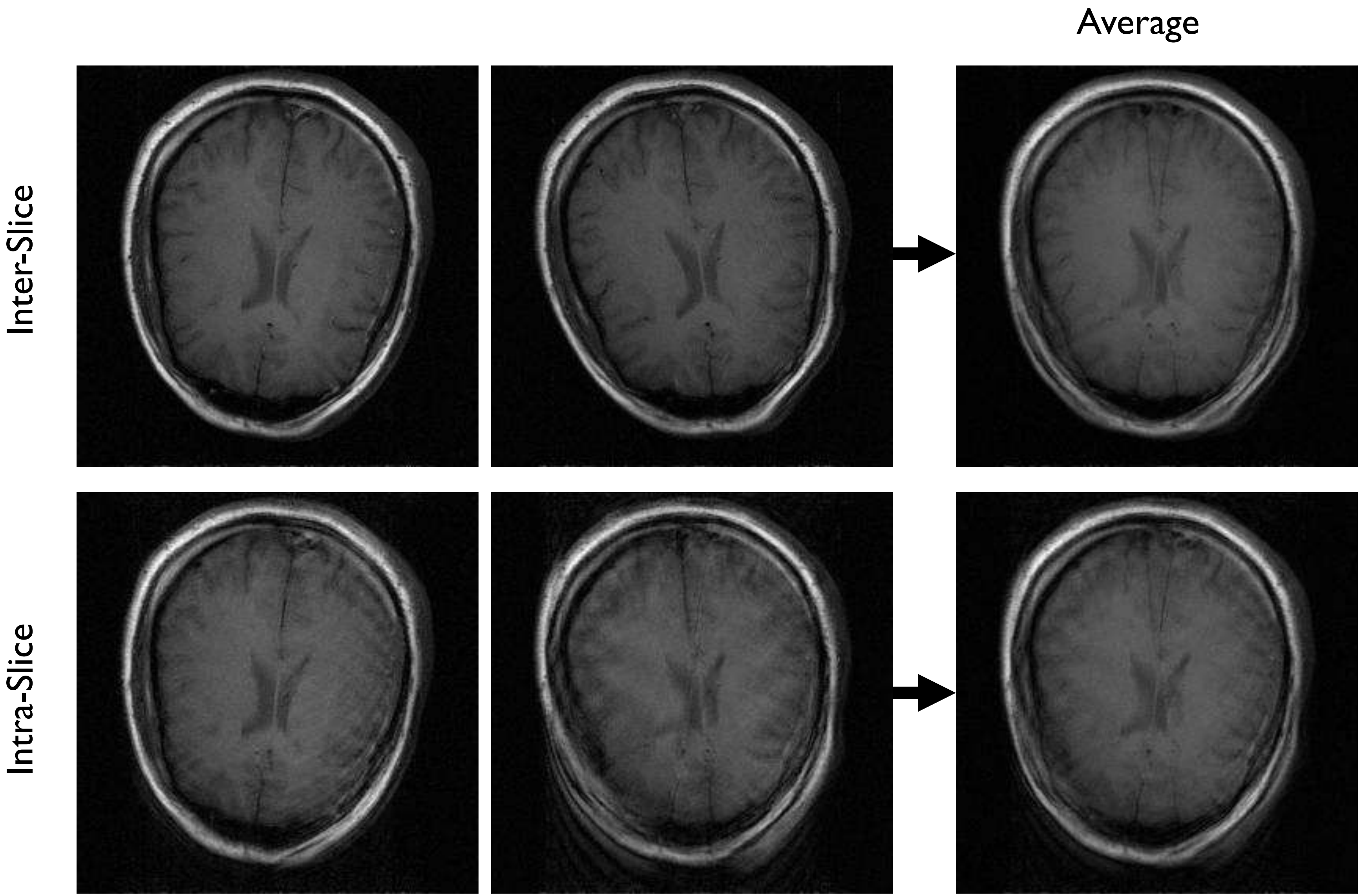
# Motion Artifact in MRI

- Motion artifacts result when the patient moves during MR acquisition
  - Physiological/voluntary motion
- Motion artifact manifests itself in the image as severe blurring that usually mandates the scan to be repeated
  - Costly in addition to added discomfort to the patient
- Postprocessing techniques can be used
  - Time consuming and inefficient in many cases
  - No considered practical for clinical use



# Types of Motion Artifacts

- Intra-slice: motion during acquisition of a slice
  - causes k-space of a given image to contain magnitude and phase errors
- Inter-slice: motion in between acquisition of whole slices
  - causes repeated acquisitions of the same slice to be different
- These two types have been treated separately in the literature
- Inter-slice motion is simpler to correct for using registration techniques (e.g., AIR)

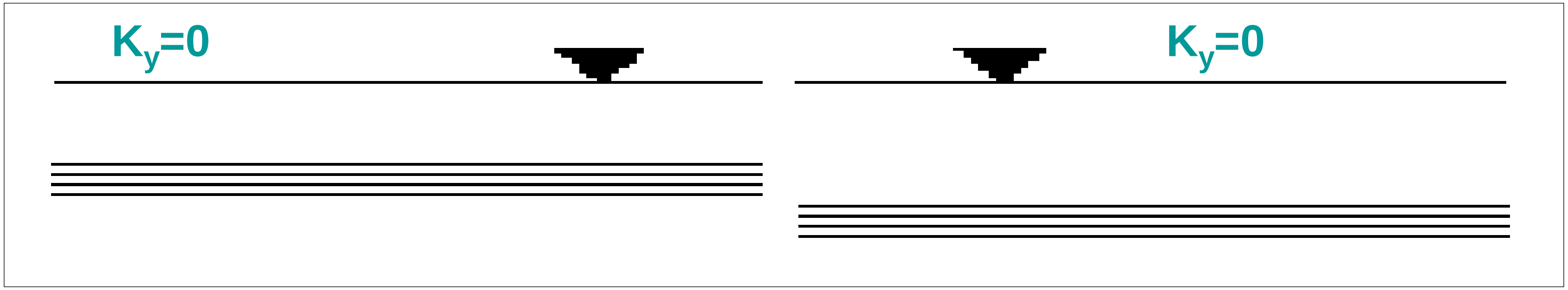

Average
Inter-Slice
Intra-Slice

# Intra-Slice Motion Suppression

- Intra-slice motion artifact suppression is a challenging problem
  - k-space "pieces" are more difficult to register!
- Among the most successful techniques used to estimate motion is the navigator echo (NAV) technique.
  - Most practical for clinical use.
- The original formulation relies on acquiring an extra line in the center of k-space along the $k_x$ or $k_y$ directions to detect motion in that direction.

# Classical Navigator Echo*

- Acquire the navigator (NAV) echo line in the center of the k-space with every k-space section.
  - Each represents the Fourier transform of a projection of the image
- Register the two NAV lines together to estimate motion along the NAV direction



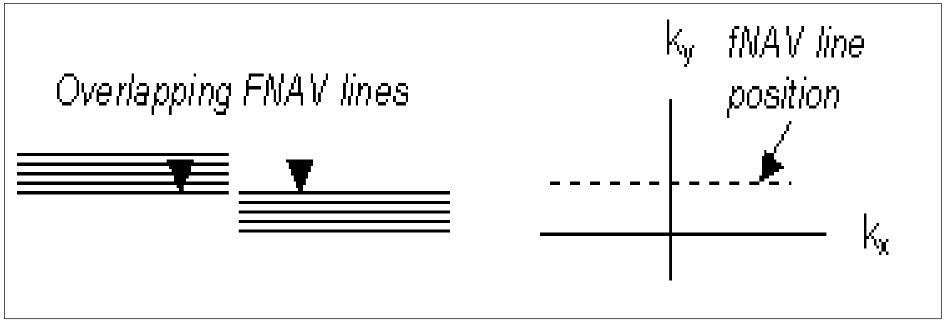

* Felmlee and Ehman, *Magn. Reson. Med.*, 1992

# Limitations of NAV

- Requires an extra amount of time to acquire this line prior to actual k-space acquisition
  - limits the minimum TE of such sequences
  - Additional complexity in sequence programming
- The estimation of motion parameters in both the read-out and phase encoding directions is not possible with a single line.
  - Two NAV lines in orthogonal directions must be used
  - Circular and spherical NAV for 2- and 3-D estimation

# Floating Navigator Echo (fNAV)*

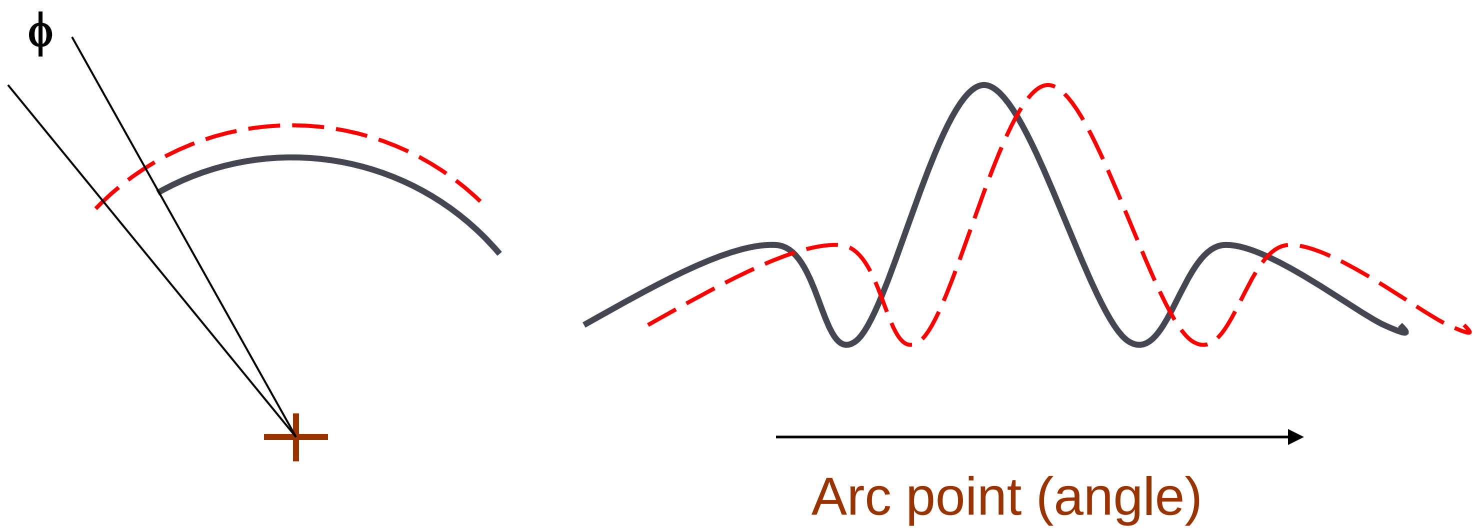
- Instead of acquiring the navigator echo line in the center of the k-space, we acquire this line by acquiring k-space sections that overlap in a single line.
- Enables the estimation of 2-D translational motion
- Rotation cannot be estimated




* Kadah et al, *Magn. Reson. Med.*, 2004

# Arc Navigator Echo (aNAV)*

- A fast way to compute the rotational motion is to match points on an arc within the area of overlap rather than the whole area.
  - Similar in theory to orbital navigator echo (ONAV)

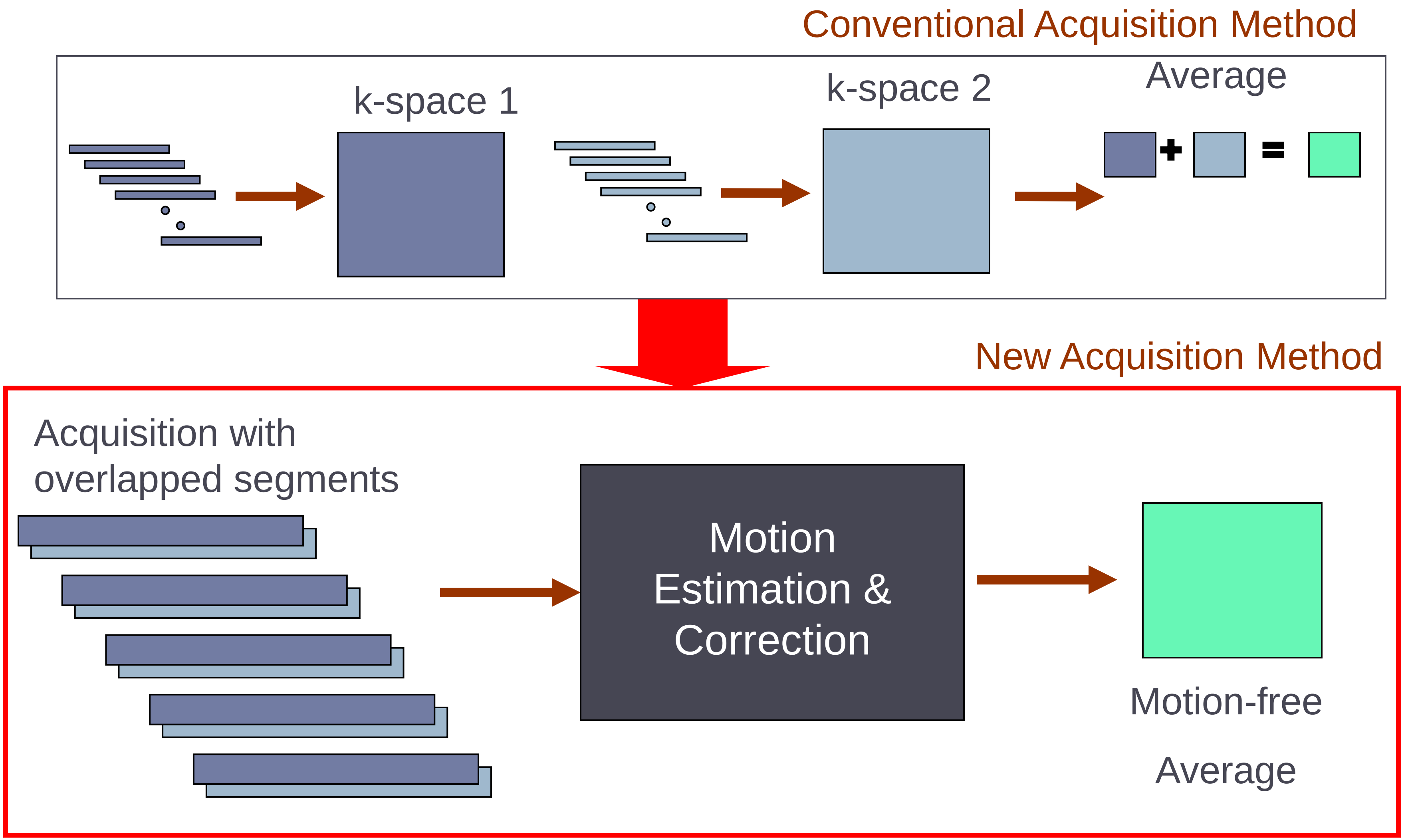



* Mohamed, Youssef and Kadah, *Proc. SPIE Med. Imag. 2003*

# Aim of this Work

- Address the problems of intra-slice and inter-slice motion together
  - For example, when segmented acquisition is used with NEX>1
- To propose an extension of the fNAV to allow rotation to be estimated
  - Acquisition of navigator "area" rather than "line" or "arc"
  - Take advantage of the extra data acquisition when NEX is required to be >1 to estimate the intra-slice motion
  - Maintain efficiency by not acquiring extra data other than those required for averaging

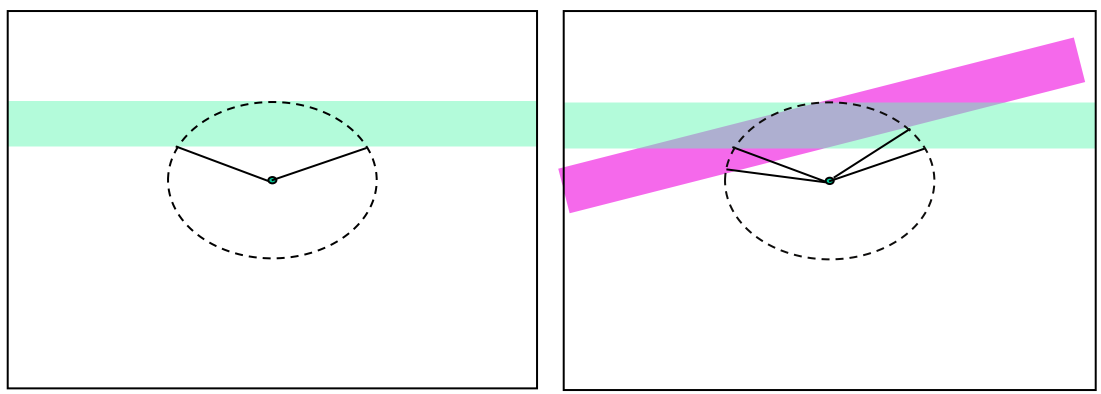
# Basic Idea



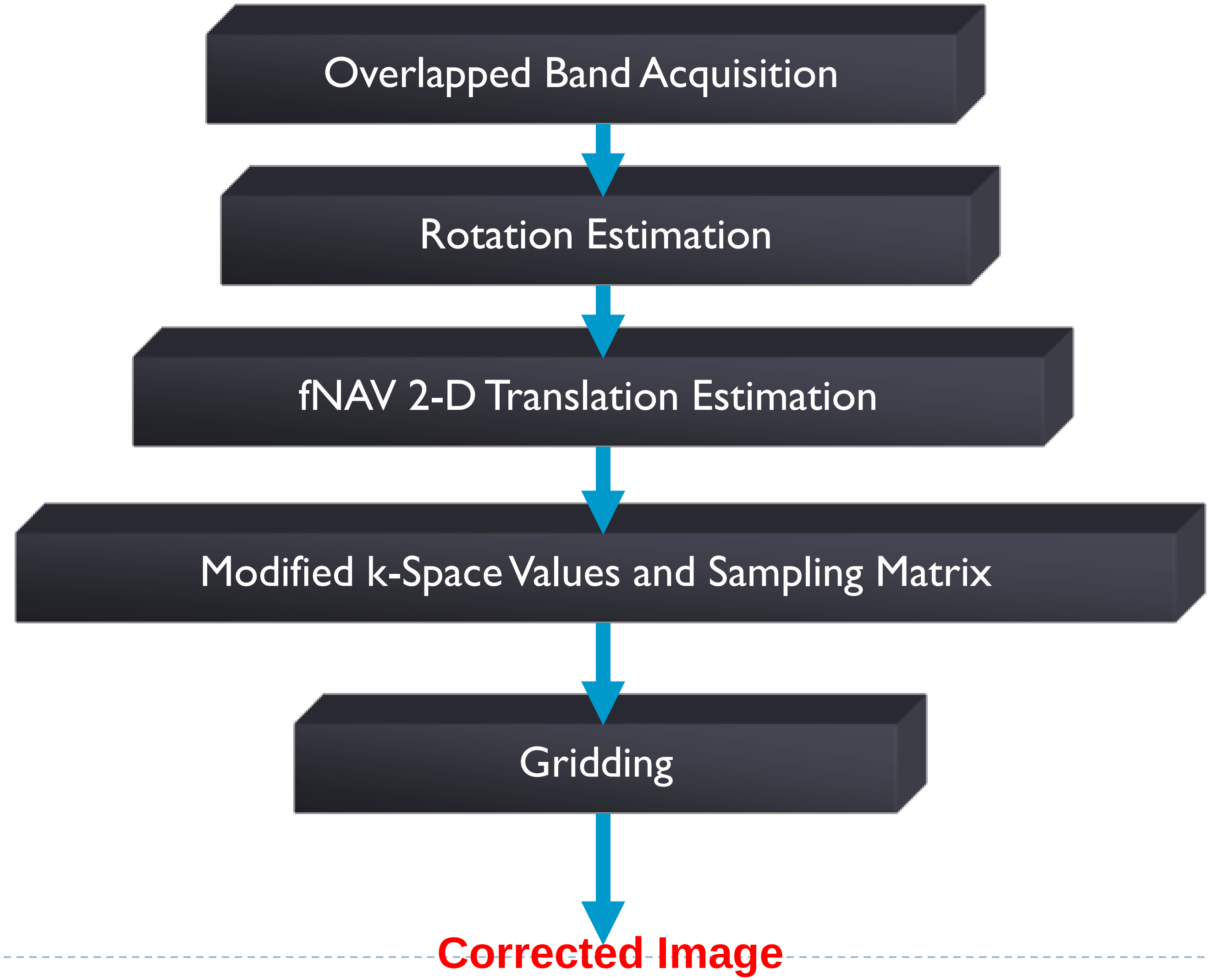
Conventional Acquisition Method
k-space 1
k-space 2
Average
New Acquisition Method
Acquisition with
overlapped segments
Motion
Estimation &
Correction
Motion-free
Average

# Motion Estimation

- Identify the area of overlap under the assumption of a general in-plane rigid body transformation
- Estimate rotation from magnitude of overlap area
  - Correlation based methodology
- Estimate translation from phase of overlap area
  - fNAV estimation method



# Proposed Method



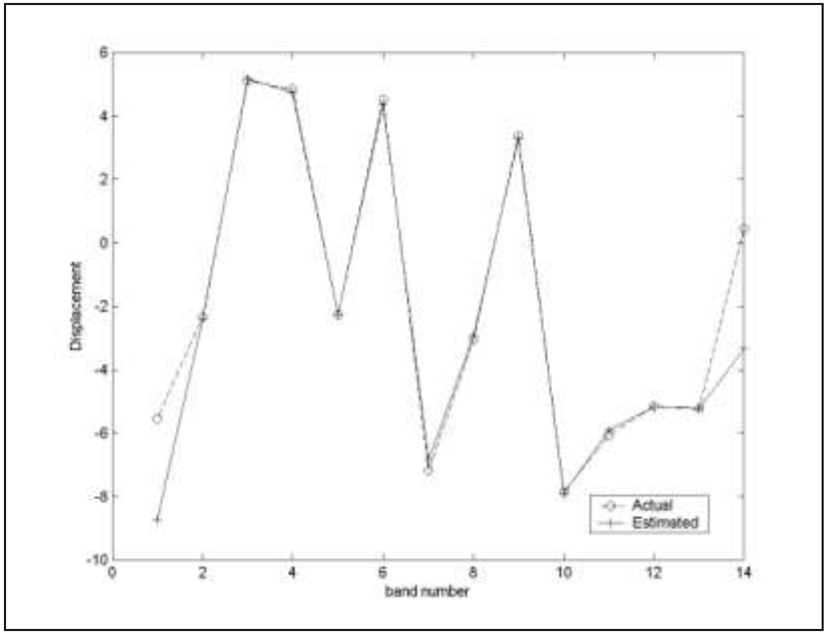
# Experimental Verification Using Numerical Simulations

- Simulated motion data were obtained from evaluating the analytical form of the Shepp-Logan phantom with different motion as well as simulating motion on real MRI head images.
  - Matrix: 128, Band size=16 with 50% overlap.
  - Random translational and rotational motion parameters were simulated for each band
- Reconstruction is performed using conventional gridding method to account for nonuniformity of sampling after motion

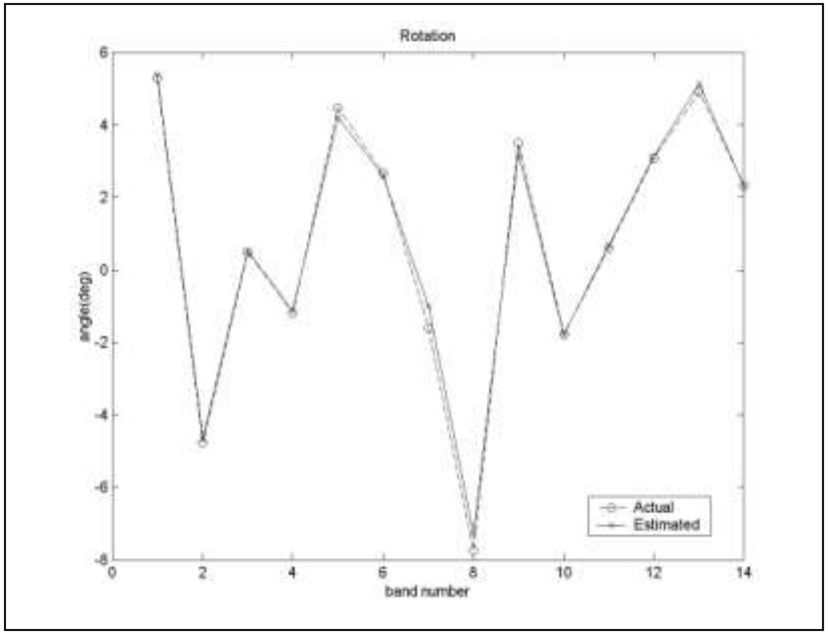
# Simulated Data

- Estimated vs. real motion

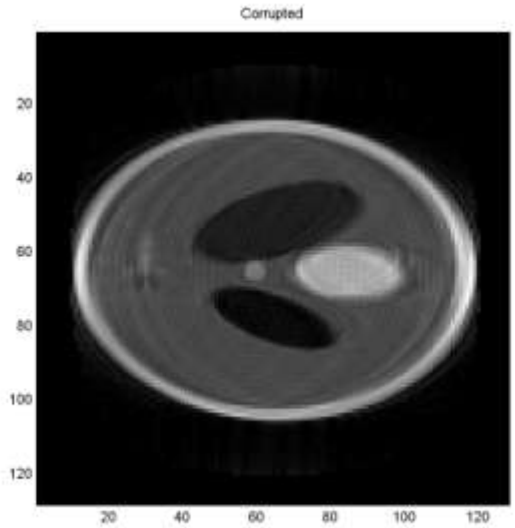
Translation

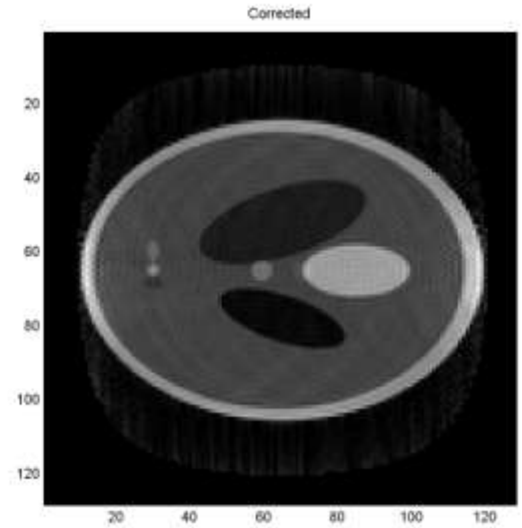



Rotation



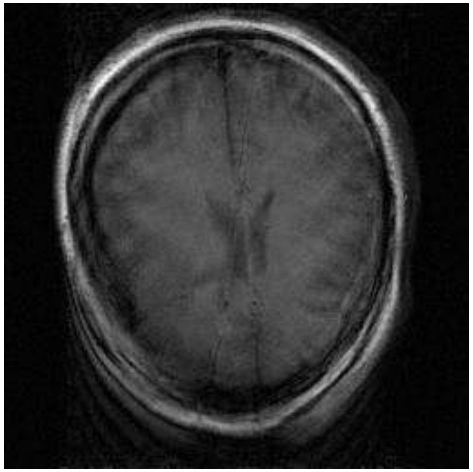
Distorted



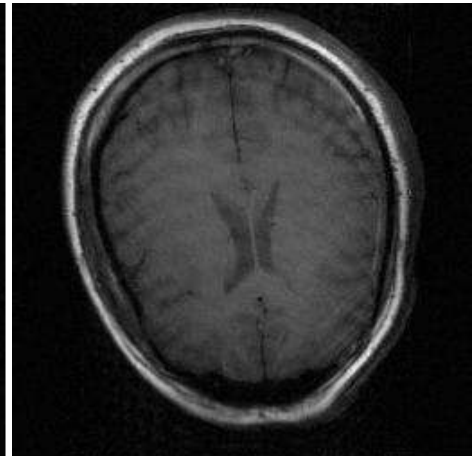




Corrected

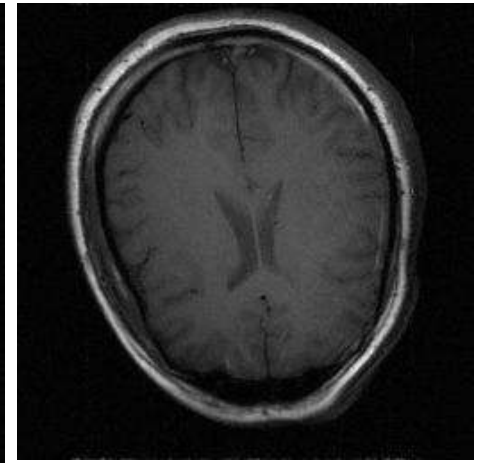
Distorted



Corrected



Motion-free



# Experimental Verification Using Real MRI Data

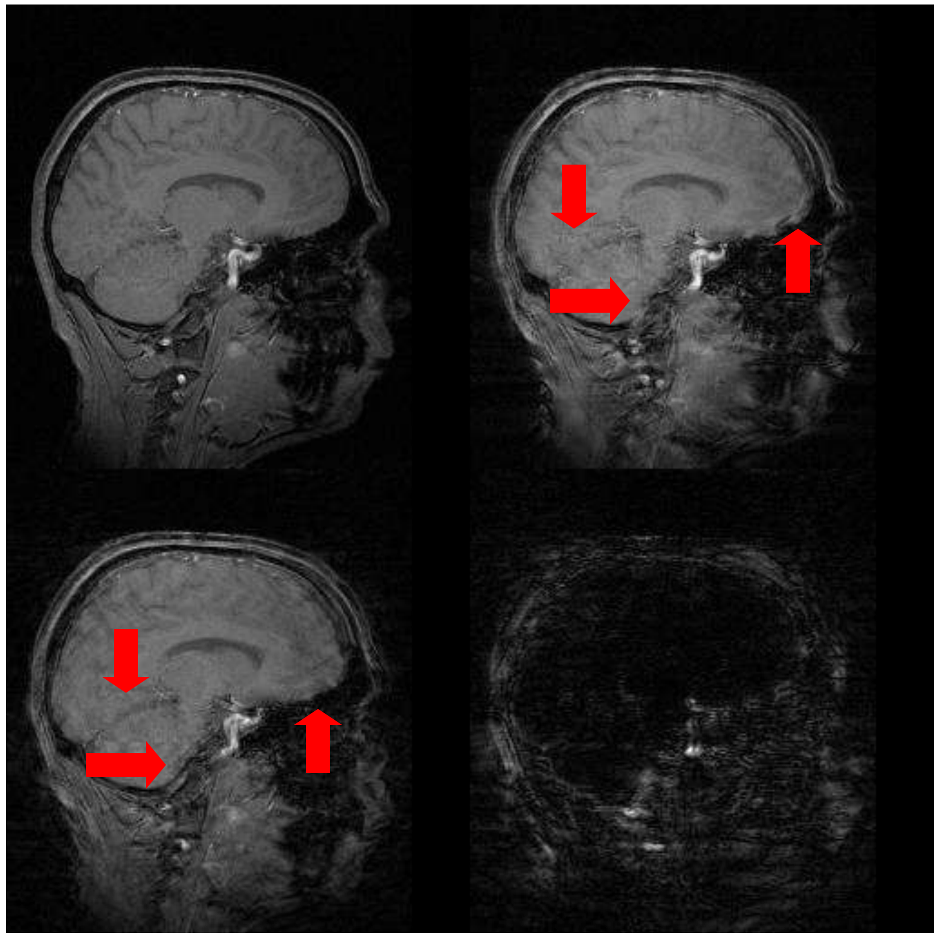
- Real data were obtained from a Siemens Magnetom Trio 3.0T MR system*
  - Matrix 256×224
  - ETL=16, NEX=2
  - Overlap of 50% was used
  - Normal human volunteer instructed to move once in the middle of acquisition
- Reconstruction is performed using conventional gridding method to account for nonuniformity of sampling after motion

* Acquired by author at BITC - Emory/Georgia Tech Biomedical Engineering, Atlanta, GA, U.S.A.

# Real Data

No Motion

Motion Distorted

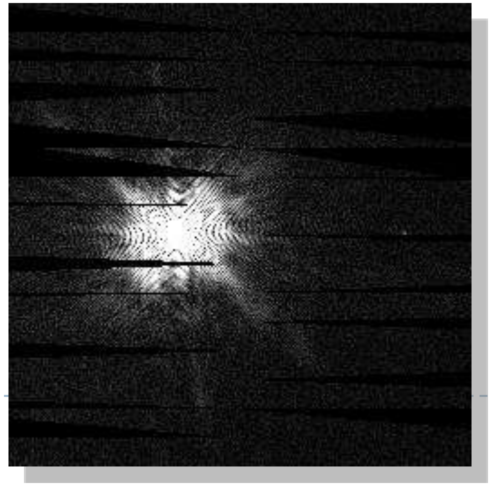


Corrected

Difference between Corrected and Distorted

# Discussion

- Two problems were observed in the reconstruction phase of the developed method
- Problem 1: Existence of k-space voids
  - Missing k-space data
  - Undesired variations in the SNR within k-space
- Problem 2: Long reconstruction time
  - Rotation requires regridding according to estimated motion
  - A new reconstruction table has to be computed each time



# Conclusions

- A new method for motion correction was developed
- Takes care of both intra- and inter-slice motion types
- No additional data acquisition is required
- Based on a new acquisition strategy to take advantage of of extra acquisitions for averaging to detect motion
- Limited to in-plane motion correction
- New method was demonstrated using numerical simulations and real data
- Potential for clinical implementation is evident

# Exercise

- Write a short literature review section on the methods used for inter-slice motion correction in MRI with references. [1 Point]
- Use the data set on the class web site to show that 2D translational motion does not affect the magnitude of k-space and that such motion can be estimated by correlation based method. [2 Points]
- Do a literature search on the topic of motion artifacts in all medical imaging modalities and come up with a list of all references related to the subject. [1 Point]