Homework #3

Due: Thursday, Oct 18th, 2018;

to be submitted via course webpage

Matlab General Guidelines

Please follow the instructions below. Please provide a document that contains your images and answers / comments on the tasks described below. When you are asked to discuss or provide reasoning for how something looks, please type out your response. Also provide the Matlab code you used to generate the images and answers.

Additional Files

Matlab files and all data files for this work can be found on the course website.

Introduction

In this MATLAB exercise we will reconstruct and analyze numerically generated MRI data and data that were actually acquired on a clinical scanner.

In all processing, we assume that the readout direction for the MR acquisition was in x (left to right) and the phase encoding direction was in y (up/down).

Please label all images properly: provide colorbars and a title. Also provide labels for x and y when you see it necessary. Make sure that the images are properly displayed in terms of their aspect ratio (hint: use *truesize* with imshow or *axis image*)

Problem 1

Read the image *test_pattern.png* into Matlab. This is a digital phantom with line patterns for resolution testing. In this exercise, we will simulate various 'faster acquisitions' that only sample a subset of the data and investigate the effects on image quality.

a) Generate the corresponding k-space (aka Fourier space) data and provide images with magnitude and phase of those k-space data. Those data will function as our simulated 'acquired k-space data' from now on.
b) Simulate a 'partial Fourier' acquisition that samples 50% of the phase encodes by using only the central lines (rows) of k-space.
   - Provide images of the k-space data, and the resulting image (magnitude and phase) when reconstructed from this subset.
   - What position in the Matlab matrix represents the DC component of this frequency space representation?
   - How long would this acquisition have taken in comparison to the fully sampled data in a)?
   - Comment on differences of the phantom appearance in a) and b) in the image domain.
c) You will notice that the aspect ratio in the image in b) is different from a).
   - Explain why this occurs and demonstrate how that improper display can be fixed. Provide an image with proper aspect ratio (magnitude image is sufficient).

d) Your clinical collaborator tells you that he has observed artefacts in your image in b) that are unacceptable for him: high contrast edges are replicated with offsets to the true spatial location of those edges.
   - Explain the origin of this artefact.
   - Implement a remedy to reduce this artefact. You can only use the data you have from 1b for this problem. In other words, you do not have the fully sampled data set. Provide an image of your result and comment on possible drawbacks of your artefact reduction approach.

e) Now simulate an alternative approach for sampling fewer k-space lines: only use every other line (row).
   - Provide the image reconstructed from this k-space subset (magnitude image is sufficient)
   - Comment on the appearance of the resulting image and the origin of any artefacts.

Problem 2

Now we will work with data acquired on a clinical 1.5T system, in this case a scanner from GE Healthcare. A phantom was placed in the scanner and a single slice was imaged with a T1-weighted sequence (acquired to emphasize differences between tissues in T1 relaxation). The imaging parameters were as follows: # of samples per readout = 512, # of phase encodes = 512, FOV: 18 cm x 18 cm, receiver bandwidth = 20.83 kHz, slice thickness = 2 mm, repetition time TR = 425 ms, echo time TE = 17 ms. The data were acquired with a single channel head coil (birdcage design).
The data are stored as recorded by the scanner in a binary file that I renamed to RAW_512_512.mri. That files has a vendor specific format including a header with lots of detailed information on the scan parameters and some space reserved for calibration data which are no longer used. I also provided a Matlab routine called *read_raw.m*. This routine can be used to read the acquired data into a complex matrix, where each row represents an acquired echo. Type **>>help read_raw** to see how the routine is called properly.

a) Use read_raw to read the raw data file RAW_512_512.mri into a Matlab matrix.
   - Provide images that show the magnitude, phase, the real, and the imaginary components of the data acquired in Fourier space. Use a logarithmic scale for all of these images except of for the phase distribution.
   - Comment on similarities or differences of these k-space data to the ones numerically generated in problem 1.

b) Reconstruct the image.
   - Provide the magnitude, phase, real, and imaginary channel of the data in object space.
   - Comment on similarities or differences of these image space data to the ones numerically generated in problem 1.

c) Calculate the time required to scan this image.

d) Calculate the peak gradient amplitudes for the readout gradient Gx, the phase encoding gradient Gy, and the slice encoding gradient Gz with the following parameters: rectangular phase encoding gradient with duration of Ty = 1ms and a slice selection gradient with a bandwidth of 1250 Hz.

e) Simulate a ‘partial Fourier’ acquisition that samples 50% of the phase encodes by using only the central lines (rows) of k-space – just like you did in problem 1b).
   - Provide the resulting magnitude and phase image
   - Compare the image you generated with all k-space data to this one.

f) Estimate the signal-to-noise in the fully and the undersampled image
   - Provide SNR estimates for both acquisition and discuss your findings.

Problem 3

The data in this series were acquired during an MRI scan of a volunteer. Each data set consists of 9 sagittal slices covering one half of the head of the volunteer.

a) Read in slice 3 from the raw data file T1_350.mri, a T1-weighted gradient echo sequence with the following parameters: TR = 350 ms, TE = 6.8 ms, flip angle = 60 deg., receiver bandwidth = 15.63 kHz, field of view: 24 cm x 24 cm, # of samples in readout = 256, # of phase encodes = 160, slice thicknes = 5mm. Provide an image of the k-space magnitude in a logarithmic scale.
   - Compare these raw data with the raw data from the phantom scan e.g. in 2a).

b) Reconstruct the image with a proper aspect ratio as you learned in 1c). Provide an image of the magnitude in object space.

c) Most likely you will see the image in2.5b not properly centered in the FOV. This artifact is caused because the scanner software inverts the signal of every other phase encode acquisition (multiplied every other horizontal line of k-space by –1). The reason for this was the sensitivity of early scanners to sampling errors for the DC k-space sample.
   - Now, multiply every other column in the raw data set by –1 and perform an inverse two dimensional fft without using the fftshift algorithm in your reconstruction. View the magnitude of the reconstructed image. Can you explain why multiplying by a –1, 1 –1, 1 …. across the lines and columns of k-space properly positions the data? Hint: -1, 1, -1, 1 ….is equal to $\exp(-i\pi n)$

Appendix

For your entertainment, I included two more datasets from the volunteer scan. Check them out if you are curious.

- T1_500.mri. These data were acquired with a T1-weighted sequence with a TR of 500 ms and a TE of 6.8 ms. All other imaging parameters stayed constant except that the flip angle was reduced to 40 degrees.
- T2-weighted spin echo sequence: T2_2000.mri. The imaging parameters were: TR = 2000 ms, TE = 80 ms, # of samples per readout: 256, # of phase encodes: 120, receiver bandwidth = 16 kHz, slice thickness = 5 mm.