BE280A, Principles of Biomedical Imaging 11/27/07
Fall Quarter 2007

BE280A Final Project Assignment

Due Date: Completed project (hard copy) is due during the final exam period on Thursday, December 13, 2007 (see part 9 below for more details). In addition to the hard copy, please submit a PDF version of the report and MATLAB code via e-mail by 6 am on that day. For full credit, the subject line of your e-mail should read **BE280A07 Final Project**. The report filename should follow the following format mri_{initials of partner 1}_{initials of partner 2}.pdf – e.g. mri_lk_pb.pdf.

Guidelines:

1) Select a partner to work with (there are 30 registered students, so that there will be 15 groups). Your partner for the final project should **not** be the same as your partner for the midterm project.
2) Discussion of **general ideas** is encouraged between groups, however, each report submitted should reflect each group's own understanding of the material. Figures and MATLAB code should be **unique** to each group. Significant discussions with other groups should be given appropriate credit (e.g. we discussed part (a) with so and so).
3) An electronic copy of the MATLAB code should be submitted with the PDF of the report. The code file should be named in a similar fashion to the *.pdf file, except with a *.m extension.
4) The MATLAB code should follow the following criteria: (a) All figures in the report can be generated just by typing the name of the *.m file (e.g. no further manipulation of the files by the instructor should be required); (b) The numbering and labeling of the Figures generated by MATLAB should **exactly match** what is in the report. (c) If you use functions, they should be named such that the main file can recognize them; or else, just include functions within the main file (the main program will then need to be a function).
5) Use a word-processing program to write the report, including all equations (no handwritten reports! Use an equation editor.). Neatness and clarity of exposition will play a **significant** role in the grading of the report. Other grading criteria include technical correctness and originality.
6) You may use external references (print or electronic). If you do so, please cite them at the end of your report.
7) Title and label the axes on all plots and images.
8) For all problems, use $\gamma/(2\pi) = 4257 \ Hz/G$
9) In addition to answering the questions below, please provide additional details and original insights as appropriate. If you noticed something interesting or learned something new in doing this project, please comment on that.

Description of Problem

Part 1 (10 pts)
Design an echoplanar imaging (EPI) pulse sequence to meet the following requirements: FOV_x= 192, FOV_y = 192 mm, matrix size = 64x64 (i.e., resolution in x = 3 mm; y = 3mm); maximum available gradient = 4 G/cm. For this project you may ignore the risetime required for the gradient to reach its maximum value. Assume that each gradient waveform duration must be an integer multiple of 4 μsec. Also assume that the ADC is only on during the readout gradient, and that the sample rate of the ADC is 250 KHz (i.e., Δt = 4 μsec). Have the dephasers move to an initial position of $k_x = -W_{k_x}/2$ and $k_y = -W_{k_y}/2$. Minimize the overall duration of these dephasers. Assume that the readout gradient corresponds to the x-axis and the phase encode gradient corresponds to the y-axis.

In your design, the 33rd k_y line (phase-encode direction) should go through the $k_y = 0$ origin, so that you end up with a slightly asymmetric coverage of k-space, with 32 k_y lines below the origin and 31 k_y lines above the origin. Similarly, the coverage in the readout direction is asymmetric, so that either the 33rd or 32nd ADC sample of each line (depending on odd or even line) coincides with $k_x = 0$.

Part 2 (10 pts)
Use MATLAB to plot out your gradient trajectories (e.g. G_x and G_y versus time) and the corresponding k-space trajectories (e.g. k_x and k_y versus time). Also make a parametric plot showing the 2D k-space trajectory (e.g. Make sure to label all axes of your plots correctly). As necessary, show zoomed-in views of the critical parts of the trajectories.

Part 3 (20 pts)
Use MATLAB to generate the following 64x64 image: a uniform square of water that is 32 by 32 pixels and centered within the field of view. For the purposes of simulation, you may assume that there is a spin located at each point within the square. Also assume that at t=0, all the spins within the object are in phase.

Assuming that you are using the gradients from Part 2, plot out the MR signal as a function of time. Remember that the signal is complex so you will want to plot the real and imaginary parts or the magnitude and phase of the signal. Comment on the features of the MR signal. When does the signal reach a peak? Is the functional form of the signal what you would expect from the object? You may want to show zoomed-in views of the MR signal to help make your point.

Use the quiver command in MATLAB to show the relative phases of the spins at different points in the trajectory. In particular, show and comment on the spin phases at the following points: (a) $\left(k_x = -W_{k_x}/2, k_y = -W_{k_x}/2\right)$; (b) $\left(k_x = -W_{k_x}/4, k_y = -W_{k_x}/4\right)$; and (c) $\left(k_x = W_{k_x}/4, k_y = W_{k_x}/4\right)$. You may also choose other points that demonstrate your understanding of how the phases of the spins correspond to the Fourier transform of the object.

Part 4 (20 pts)
Reconstruct the object from the MR signal. Take into account the fact that the EPI sequence zig-zags through k-space. Also note the MATLAB ifft function assumes that the center of k-space is acquired as the first indexed point, so you will want to make judicious use of the fftshift function.

Part 5 (**10 pts)**
Investigate what happens when the reconstruction algorithm does not take into account the zig-zagging through k-space. Explain what you see. Be as quantitative as possible.

Part 6 (20 pts)
Now assume that the square object is completely composed of fat, which has a resonant frequency (at 1.5T) that is 220 Hz lower than that of water. This can be modeled by introducing an off-resonance term of the form $\exp(-j\Delta\omega t)$ into the MR signal equation (remember that Hz does **not** equal radians/sec!)

(a) Plot the MR signal from this object. How does this differ from the signal observed from the water object in Part 3?
(b) Reconstruct the object. Explain what you see with mathematical expressions. Be explicit and rigorously justify each step of your derivation. Show that your theoretical expression matches the images. Make good use of the modulation/shift theorem.
(c) Now reverse the sign of the phase-encode gradients (e.g. from negative to positive or vice versa). Repeat parts (a) and (b) and explain what you find. Be as quantitative as possible.

For parts 7 and 8, assume that the object now consists of a grid that is 33x33 pixels where each line in the grid is 1 pixel wide and the spacing between lines is 7 pixels (e.g. horizontal and vertical lines at indices, 1, 9, 17, 25, and 33).

Part 7 (15 pts)
Assume that the object has a T2* of 10ms. Plot the MR signal and reconstruct the object (assume that the object is water). Compare your results to what happens when T2* is infinite. Explain what you see – be as quantitative as possible.

Part 8 (25 pts)
Now consider the effect of a quadratic background gradient of the form $B(x,y) = ax^2$. Plot out the received MR signal and the reconstructed image in the presence of this background gradient. Make sure to pick a gradient amplitude that clearly shows the effect. Explain the observed distortion – be as quantitative as possible.

Part 9 (20 pts)
Be prepared to discuss your results during the final exam period for the course. The 3 hour exam period will be broken into three 50-minute sessions (sessions starting at 8 am, 9 am and 10am), with 5 groups assigned to each session. The hard copy of the project should be turned in at the beginning of the session for your group. In addition to sending pdf and MATLAB files via e-mail, please bring an electronic copy of your report on a flash drive (in case we encounter e-mail problems). We will use the computer to display reports to aid in discussion. Also, if you would like to bring an additional powerpoint file to help with the discussion that’s okay too, but not required.