Computational MRI (COMP0121) Coursework 2

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Due: December 9th, 2020 (16:00)

General Notes:

1. Please read each problem carefully; make sure that you answer each one as completely as possible.
2. The problems have been phrased in the MR terms that you are expected to be familiar with at this point of the module; if you find any of them to be unfamiliar, look them up in the book chapters, the lecture slides, and/or the worksheets.
3. The problems are deliberately non-prescriptive with some parameters. You are expected to know, or to be able to work out, the suitable choices of these, and can justify your choices.
4. For simulation/visualisation tasks, remember that the objective is to use these as a tool to better understand the underlying MR phenomena. So you are expected to describe what your simulation shows, explain if they make sense, and reflect on what you have learned from it.

Submission Guidance:

1. A written report: submit as a single pdf file; maximum three-page long; minimum font size 10; recommended to use Latex; include any figures at the end of the report, which will not be counted towards the page limit.
2. A code listing: submit as a single pdf file; no page limit
3. A collection of videos: submit as a single zip file; please label clearly which simulation visualisation each video corresponds to.

Problem 1: Frequency encoding

Objective: To develop the basic framework to simulate the imaging of a 1-D spin-bearing object, with frequency encoding.

Setting: The object that you will simulate is a 1-D segment of length L with uniform spin density. The segment is immersed in a homogeneous static magnetic field B_0, and the length of the segment is oriented perpendicular to B_0.

For the rest of this problem, we will assume a Cartesian coordinate system in which the direction of B_0 is aligned with the z axis and the length of the segment is oriented along the x axis.

We will further assume that, at the start of the experiments that you will simulate, all the spins are at thermal equilibrium, with some common longitudinal magnetisation M_0.

You will simulate three experiments with increasing complexity.

All the experiments start with a 90^o hard excitation pulse, which has a constant non-zero amplitude B_1 over 0.32 ms.

The setting of the experiments after the excitation is as follows:

1. Free precession in the presence of only B_0, with the ADC recording N data points of the continuous signal (demodulated with the Larmor frequency) for a period of T_s, immediately after the excitation pulse.
2. As in 1, but now with an additional linear gradient field along the x axis, $G_x < 0$, which is turned on after the excitation pulse for T_s; the isocentre of the gradient is assumed to coincide with the centre of the segment; the ADC records the signal when the gradient is on.
3. As in 2, but now $G_x < 0$ is on for $T_s/2$; subsequently a gradient field of the same magnitude but the opposite polarity ($-G_x$) is instead on for T_s; the ADC records the signal only when the second gradient is on.

Your simulation should visualise 1) the evolution of the magnetic moment of the spin isochromats along the segment, 2) the signals recorded over time, and 3) the trajectory through the k-space.

Task 1: To start, set L to 20 mm and approximate the uniform spin density by placing a set of spin isochromats 1 mm apart along the segment. Set the magnitude of G_x to 4.6 mT/m, N to 256, and T_s to 5.12 ms. Finally, choose reasonable values for the relaxation time constants for brain tissues, but ignore the relaxation effect during the excitation pulse.

Task 2: For Experiment 3, investigate how the measured signal depends on L, G_x, N, and T_s.

Task 3: For Experiment 3, investigate the consequence of choosing frequency encoding gradients oriented in directions other than the x axis.

Problem 2: Phase encoding

Objective: To extend the basic framework from *Problem 1* to simulate the MR imaging of a 2-D spin-bearing object with the addition of phase encoding.

Setting: The object that you will simulate consists of two identical, non-overlapping squares. They are placed flat in the xy plane, with the centres of the squares positioned along the diagonal line through the first and third quadrants of the plane, at equal distance to the origin. Choose the size of the squares and the distance between their centres based on your experience from *Problem 1*.

You will extend the gradient echo simulation from *Problem 1* with the addition of a phase encoding gradient along the y axis, G_y.

Your simulation should visualise the isochromat configurations for different phase encoding steps, the resulting measured signal, and the trajectory through k-space. For simplicity, assume that the longitudinal magnetisation is fully recovered and the transverse magnetisation fully lost, in between the excitation pulses for different phase encoding steps.

Task 1: Start with the phase encoding gradient not overlapping with the initial dephasing portion of the readout gradient. Set the maximum amplitude of G_y to be the same as the amplitude of G_x. Determine the duration of the phase encoding gradient such that the coverage of the k-space along k_y is identical to that of k_x in the *Task 1* of *Problem 1*. Determine the step change in magnitude required to acquire 256 equally spaced lines through k-space.

Task 2: Now consider the case when the phase encoding gradient and the dephasing lobe of the readout is allowed to overlap as much as possible. Investigate how this impacts the measured signal and the trajectory through k-space.