

TASK 1

2p

MRI image contrast

Depending on the structures of interest, different MRI imaging sequences can be used to achieve optimal contrast. T1 and T2 weighting are the most essential ones.

The intensity of the spin echo image follows approximately

$$I(x, y) \propto \rho(x, y) (1 - e^{-T_R/T_1}) e^{-T_E/T_2}, \quad (1)$$

where $\rho(x, y)$ is the proton density at a given point in the imaged tissue slice, T_R the repetition time between the 90° pulses, and T_E the time between the excitation pulse and the center of the echo (maximum amplitude).

A) Write a short answer

Give reasoning to the Eq. 1 in a general level: What are the phenomena contributing to the intensity? How do they affect the signal and why?

B) Write a short answer

A hypothetical brain tumor has a lower concentration of water than the surrounding healthy tissue. The T_1 value of protons in the tumor is shorter than that of the protons in healthy tissue, but the T_2 value of the tumor protons is longer. Which kind of weighting (values for TE and TR) should be introduced into the spin echo imaging sequence in order to ensure that there is contrast between the tumor and healthy tissue? Why?

C) Write a short answer

A large concentration of superparamagnetic contrast agent is injected and accumulates in the tumor only. Which kind of weighting would now be optimal?

TASK 2

2p

k-space in magnetic resonance imaging

The MRI scanner acquires essentially a 2D Fourier transformation of the image slice (or a 3D FT of a volume). The location information for the image voxels is encoded in phases and frequencies, and these sampled points are said to occupy a "k-space".

In this exercise we are building intuition on this mysterious "k-space" through simple calculations and a MATLAB demo.

1. The strength of the frequency-encoding gradient in a 3-T MRI scanner is 40 mT/m. The sampling interval (dwell time) is 3 μ s and the total readout time is 0.768 ms. Calculate the sampling step Δk in k-space (unit 1/m), the field of view (FOV; m), resolution (number of voxels) and the voxel size (m) in the frequency-encoding direction.
2. Open the given MATLAB file E2_kspace.m and run the cell "2. Generate phantom". How would you describe the k-space image? How is the magnitude distributed (visually)?
3. Run the cell "3. Plot a couple of k-space points". What do the individual points in k-space represent? Are point 1 and point 2 the same?

4. Run the cell "4. Remove the center of k-space". Play around with the value of `radius_center`. What happens to the image and why?
5. Run the cell "5. Remove the edges of k-space". Play around with the value of `radius_edges`. What happens to the image and why? What is the artefact seen near the edges called?
6. Run the cell "6. Partial Fourier". Reflect on the exercise 3 above. Why does mirroring the k-space allow us to reconstruct a good-quality image? What advantages and disadvantages do the partial Fourier methods have?

TASK 3

2p

Instrumentation and limitations of NIRS

Determine usage parameters and safety limits for a measurement array.

Geometry, Snell's law, Photon energy, light attenuation

In your answers, consider a measurement system depicted in Fig. 1.

A) Calculate

The IEC 601-1 standard defines the maximum permitted exposure for optical devices as $9000 \frac{W}{m^2 sr}$. What is the maximum power at which we can input light into the subject's scalp from one source, when the fiber tip is at 3 mm distance from the subject? The subject's scalp is assumed to be flat. See figure 2 b and c for relevant info.

$\frac{W}{m^2 sr}$ is the unit of radiance. Radiance S is dependent on optical power P , size of illuminated area A , and solid angle Ω :

$$S = \frac{P}{A\Omega} \quad (2)$$

B) Calculate

Calculate the optical power detected by each detector in the array (figure 2 a), and the corresponding signal-to-noise ratio for the duration (appr. 10 ms) of one pulse when source **S** (inside red box) is emitting.

In Figure 2A, the distance between rows and columns is 1 cm, and the optical power in the tissue attenuates 60 dB/cm in the first 1 cm, and 20 dB/cm further away.

You may assume photon shot noise to be the only significant noise component. Photon shot noise is defined as $n = \sqrt{\eta N}$, where $\eta = 0.1$ is the detector quantum efficiency, and N the number of incident photons at the detector. Assume a light wavelength of 800 nm.

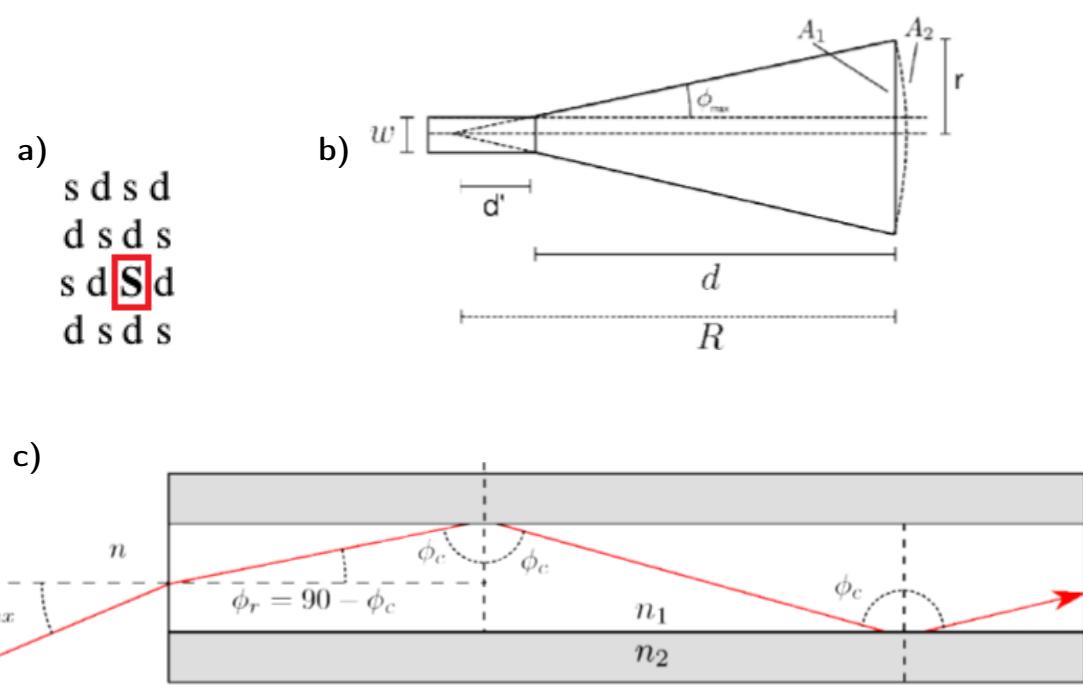


Figure 1: (a) Sketch of sensor array, (s = source, d = detector). Light propagation inside (c) and outside (b) of the optic fiber. The diameter of the fiber core is $100\text{ }\mu\text{m}$, and refractive indices n_1, n_2 are 1.48 and 1.46, respectively. n of air is 1.