Tutorial

Series 4

Advanced Biomedical Signal and Image Processing

Master: Plasturgy & Biomedical Engineering

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Exercise 1

1. Explain the principle of nuclear magnetic resonance (NMR) and how it applies to MRI.
2. What role do hydrogen nuclei play in MRI?
3. Define the Larmor frequency and provide the equation that describes it. How does the Larmor frequency vary with changes in the magnetic field strength?
4. Describe the significance of the flip angle in MRI. What are the typical values for flip angles used in MRI, and how do they affect image contrast?
5. What is ultrasound imaging, and how does it work? What are the three types of ultrasound, and how do they differ?
6. What are the primary applications of ultrasound imaging in medical diagnosis?
7. Explain the time-of-flight principle in ultrasound imaging.
8. What is the difference between axial resolution and lateral resolution in ultrasound imaging?
9. Describe the Doppler effect and its application in ultrasound imaging. What are the advantages and limitations of Doppler ultrasound?

Exercise 2

1. Differentiate between T1 and T2 relaxation processes. How do T1 and T2 relaxation times influence the appearance of tissues on MRI images?
2. What is Free Induction Decay (FID), and how is it related to signal detection in MRI? Describe the process of FID and its importance in acquiring MRI signals.

Exercise 3

1. Explain the concept of spatial encoding in MRI. How do gradient magnetic fields facilitate spatial encoding of signals from different locations in the body?
2. Describe the process of slice selection in MRI. How does the application of gradient fields and selective RF pulses allow for the imaging of specific tissue slices?
3. What is the role of Fourier transform in MRI image reconstruction? Explain how the inverse Fourier transform is used to convert k-space data into a spatial image.

Exercise 4

1. Compare T1-weighted and T2-weighted images in terms of their acquisition parameters and clinical applications. What types of tissues appear bright or dark in T1-weighted and T2-weighted images?
2. 2. Discuss the use of contrast agents in MRI. How do gadolinium-based agents enhance the visibility of certain tissues in MRI scans?

Exercise 5

1. An MRI scanner operates at a magnetic field strength of 3 Tesla. If the thermal noise in the system is measured to be 0.5 μV, calculate the expected signal-to-noise ratio (SNR) given that the signal from the tissue being imaged is 10 μV.
2. An MRI sequence has a repetition time (TR) of 2000 ms and an echo time (TE) of 30 ms. If the number of signals averaged (NSA) is 4, what is the total time required to complete one imaging sequence?

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Exercise 6

1. A cylindrical MRI magnet has a length of 1 meter and a diameter of 0.5 meters. If the magnetic field inside the cylinder is measured to have a variation of 0.5% across its volume, calculate the maximum deviation in Tesla if the intended magnetic field strength is 1.5 Tesla.
2. An RF coil designed for a 1.5 Tesla MRI system operates at a frequency of 63.87 MHz. If the coil has a quality factor (Q) of 100, what is the bandwidth of the coil?
3. In an MRI scan, the Specific Absorption Rate (SAR) is measured at 2 W/kg. If a patient weighs 70 kg, what is the total power absorbed by the patient during the scan?

Exercise 7

1. A sample of a radioactive substance has an initial quantity of $N_0 = 1000$ nuclei. If the decay constant λ is $0.1\ \text{day}^{-1}$, calculate the number of nuclei remaining after $t = 10$ days.
2. If a radioactive isotope has a decay constant $\lambda = 0.693\text{day}^{-1}$, calculate its half-life.
3. A radioactive sample has an initial activity of $A_0 = 500\text{Bq}$ and a decay constant $\lambda = 0.05\text{day}^{-1}$. Calculate the activity after $t = 20$ days.
4. A gamma ray source has an initial intensity $I_0 = 2000\text{CPM}$. If the linear attenuation coefficient μ for lead is $0.1\ \text{cm}^{-10}$, calculate the intensity after it passes through 10cm of lead.

Exercise 8

1. In a one-compartment model, a radiopharmaceutical has an initial concentration $C_0 = 50\ \text{mg/L}$ and an elimination rate constant $k = 0.2\text{h}^{-1}$. Calculate the concentration after $t = 5$ hours.
2. A patient receives a radiopharmaceutical with an activity of $A = 370\text{MBq}$ and an energy of emitted radiation $E = 0.511\text{MeV}$. If the mass of the tissue is $m = 0.5\text{kg}$ and $\phi = 0.6$, calculate the absorbed dose D.

Exercise 9

A patient is referred for a Positron Emission Tomography (PET) scan to evaluate a suspected malignancy. The radiopharmaceutical used for the scan is Fluorodeoxyglucose (FDG), which has the following properties:

Initial Activity: $A0 = 10\text{mCi}$ (millicuries)

Decay Constant: $\lambda = 0.693\text{h}^{-1}$

Energy of Emitted Radiation: $E = 0.511\text{MeV}$

Fraction of Emitted Energy Absorbed by Tissue: $\phi = 0.6$

Mass of Tumor Tissue: $m = 0.5\text{kg}$

1. Calculate the initial activity in Becquerels (Bq).
2. Determine the absorbed dose D received by the tumor tissue after 1 hour.

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3. Calculate the effective dose E if the tissue weighting factor for the tumor is w_T=0.12.

Exercise 10

1. If the speed of sound in human tissue is approximately 1540 m/s, how long does it take for an ultrasound pulse to travel to a tissue located 10 cm away and return to the transducer?
2. An ultrasound transducer operates at a frequency of 5 MHz. What is the expected axial resolution if the pulse duration is 0.3 ms?
3. An ultrasound wave with a frequency of 3 MHz is transmitted towards a blood vessel moving at a velocity of 0.5 m/s. If the angle between the ultrasound beam and the direction of motion is 30 degrees, calculate the Doppler shift (Δf).
4. If an ultrasound beam has a width of 1 cm and focuses on a region 5 cm away, what is the expected lateral resolution, assuming ideal conditions?
5. Explain why continuous wave Doppler cannot localize the source of the signal, despite providing accurate velocity measurements.

Exercise 11

An ultrasound examination is performed to assess blood flow in a patient. The ultrasound transducer is operated at a frequency of 5 MHz and emits pulses that travel through human tissue, where the speed of sound is approximately 1540 m/s. The transducer is aimed at a blood vessel located 10 cm away, and the blood vessel is moving at a velocity of 0.5 m/s at an angle of 30 degrees relative to the ultrasound beam.

1. Calculate the time it takes for an ultrasound pulse to travel to the tissue and return to the transducer.
2. Determine the expected axial resolution based on the pulse duration of 0.3 ms.
3. Calculate the Doppler shift (Δf) for the moving blood vessel.
4. If the ultrasound beam has a width of 1 cm and focuses on a region 5 cm away, what is the expected lateral resolution?
5. Discuss why continuous wave Doppler cannot localize the source of the signal while providing accurate velocity measurements.

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