Biomedical Imaging

Exercise XCT #1 – X-ray Projection and Digital Subtraction Angiography

The purpose of the exercise is to understand and study X-ray planar projection imaging and digital subtraction angiography. To this end, a simple test and an analytical computer model of the human thorax is implemented using circles/ellipses assigned with realistic densities and mass attenuation coefficients. Line integrals will be computed to obtain X-ray projection data.

To start, please download the Matlab code for XCT_EXERCISE1 from https://moodle-app2.let.ethz.ch and unpack the *.zip file on your computer. Upon completion, submit your *.m file along with a report of results using e.g. Word/PowerPoint.

Task 1.1

- Start Matlab and enter “XCT_EXERCISE1”; a test object along with its profile is displayed.
- Open XCT_EXERCISE1.m in the editor and read the code lines and comments carefully.
- Update density ρ and mass attenuation coefficients μ/ρ for anode voltages (U_a) of 50 and 150 keV (refer to Tables 2+4 at https://www.nist.gov/pml/x-ray-mass-attenuation-coefficients).
- Fill in code lines to compute linear attenuation coefficients.
- How do linear attenuation coefficients μ vary as a function of anode voltage and why?
- Ellipses are defined using center point $\mathbf{x_0,y_0}$, half axes **a,b** and tilt angle θ relative to the x-axis (*see Figure 1*) according to:

$$\left(\vec{x}-\left(x_0,y_0\right)^T\right)^T Q^T D^2 Q\left(\vec{x}-\left(x_0,y_0\right)^T\right)\leq 1 \text{ with} \tag{1}$$

$$D=\begin{bmatrix} 1/a & 0 \\ 0 & 1/b \end{bmatrix},\ Q=\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

- Function ***CalcDiscretePhantom*** demonstrates how to use the formalism of defining elliptic/circular areas.
- Modify the test object by changing position, size, and shape. Compute the sum along the vertical direction (per column) and compare the results. What is seen and why?

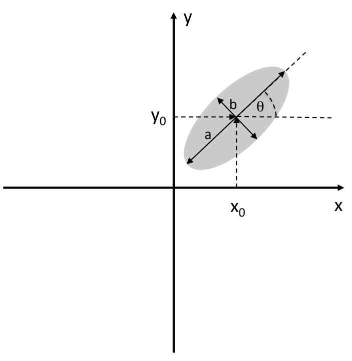

Figure 1: Definition of ellipse using center point (x_0,y_0), half axes (a,b) and tilt angle θ

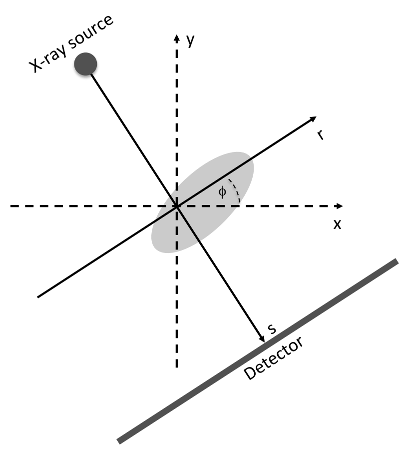

Figure 2: Definition of line integral $L(r,s,\phi)$. Location of X-ray source and detector are indicated.

Task 1.2

- Edit function ***CalcLineIntegral*** to calculate the projection at arbitrary angles ϕ. Consider that any point along **L(r,s,ϕ)** can be written as follows (*see Figure 2*):

$$\vec{x} = (x,y)^T = r\begin{pmatrix} \cos\varphi \\ \sin\varphi \end{pmatrix} + s\begin{pmatrix} \sin\varphi \\ -\cos\varphi \end{pmatrix} \qquad (2)$$

  To compute the projection, points of **L(r,s,ϕ)** that intersect an ellipse have to be found. Since ellipses are convex there can only be one entry and one exit point; these two determine the integration borders. Implement the equation to compute the line integral or projection (proj) in function ***CalcLineIntegral.***

- Modify the test object by changing position, size, shape, check the intensity profile display, and document your results. How does the result compare to the projection computed using the sum in Task 1.1?

Task 1.3

- Extend the test object to represent a simple model of the human thorax as shown below (*see Figure 3*). Consider that line integrals are additive. Accordingly, to generate the lung spaces on top of the thorax (muscle) the difference of linear attenuation coefficients of muscle and lung needs to be assigned to the lung space.

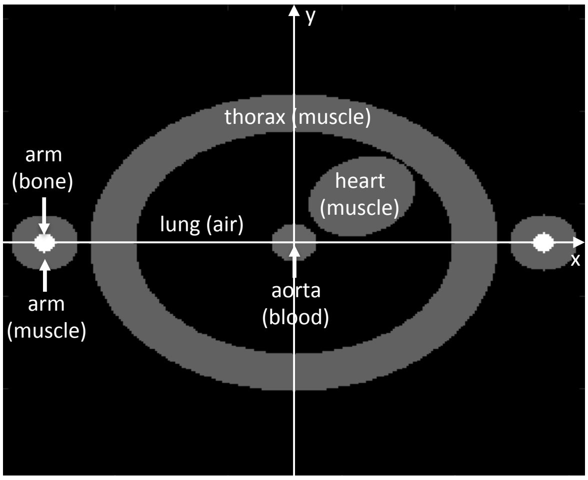

Figure 3: Example of a simple thorax phantom consisting of thorax muscle, left and right arm muscle and bone, lung air space, heart muscle and the aortic vessel filled with blood.

- Compute horizontal projections for anode voltages of 50 versus 150 keV. How does contrast between bone and muscle change and why?
- Compute horizontal, vertical and angulated projections, and document your results. Why is the aorta (blood) not seen well?
- Derive general equation of blood contrast based on Beer-Lamberts law for the DSA principle.
- Implement Digital Subtraction Angiography (DSA) using two projections – one without and one upon intravascular administration of an iodine contrast agent (mass attenuation coefficient of blood with iodine contrast agent is doubled relative to the value of blood only).
- Document the DSA result and explain why vessel contrast has improved?

Questions?

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