ACBI: Attenuation Coefficients Based Imaging

I. Introduction

In the human body, each & tissue has its own absorption coefficient μ_a, which describes how much this tissue absorbs a light of a particular frequency, and its own scattering coefficient μ_s, which describes how much this tissue scatters light of a particular frequency. This report discusses how the absorption and scattering coefficients can be used after breaking a common physics law to obtain a new imaging technique.

II. The law being broken

The law being broken is the attenuation law, given by the following formula: $I = I_0 e^{-z(\mu_a+\mu_s)}$ [1], where I_0 is the incoming beam intensity and I is the resultant beam intensity after a distance z. We change this law to be in the following form instead:

$$I = I_0 e^{-z(\cos^2(\theta)\mu_a + \frac{L}{L_0}\mu_s)}$$

where θ is the angle of the light source with respect to its direction of propagation. This can be visualized as holding a laser beam in your hand, then rotating your hand right or left (around the wrist). θ is the degree by which your hand was rotated right (positive) or left (negative). L is the distance between the light source and the target, and L_0 is a standard distance of 1 meter. Thus, $\frac{L}{L_0}$ is the ratio between the distance between the light source and the target and the standard distance between the source and the target.

The reason behind these modifications is to control what contributes to attenuation of the light beam during imaging. By rotating the light source around itself and moving it away or to the target patient, we are able to model a variety of equations for describing the same μ_a and μ_s. Since the dimentional analysis of the demonitaor must remain the same, the used constants had to be dimensionless, like trigometric functions and ratios.

III. How the imaging will work

As demonstrated by figure 1, the proposed device consists of a bed (with light intensity detectors) that the patient lies on and an emitter above the patient that contains a line of near-infrared (NIR) light sources. The emitter sends multiple beams of light through the target slice of the patient, and the beam attenuates through the tissues until it reaches the detectors in the bed. The emitter is then raised upward, the sources inside are rotated around themselves by a certain degree, and the procedure is repeated again. This obtains a number of equations involving the various tissues the rays have passed through in those slices. By solving those multiple equations using computers, the device obtains μ_a and μ_s for each tissue in the slice. This can then be used to obtain a high-contrast image, similar to MRI, of the imaged slice.

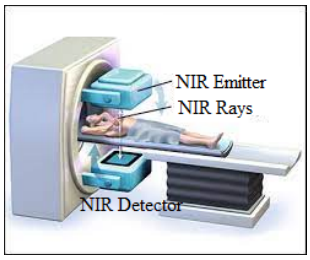

Fig. 1. An imagination of the proposed device

Consider the stack of tissues in Figure 2, A beam of light with intensity I_0 enters the first tissue. The new intensity I_1 after the attenuation of the first tissue is $I_0 e^{-0.5(\cos^2(\theta)\mu_{a1}+\frac{L}{L_0}\mu_{s1})}$. Similarly, $I_2 = I_1 e^{-0.7(\cos^2(\theta)\mu_{a2}+\frac{L}{L_0}\mu_{s2})}$. Substituting I_1 with its formula results in:

$$I_2 = I_0 e^{-0.5(\cos^2(\theta)\mu_{a1}+\frac{L}{L_0}\mu_{s1})} e^{-0.7(\cos^2(\theta)\mu_{a2}+\frac{L}{L_0}\mu_{s2})}$$

by adding exponents and simplification, the following is obtained:

$$I_2 = I_0 e^{-(0.5\cos^2(\theta)\mu_{a1}+0.7\cos^2(\theta)\mu_{a2}+0.5\frac{L}{L_0}\mu_{s1}+0.7\frac{L}{L_0}\mu_{s2})}$$

By repeating the same steps, similar expressions can be obtained for I_3 and I_4

$$I_3 = I_0 e^{-\left(0.5\cos^2(\theta)\mu_{a1}+0.7\cos^2(\theta)\mu_{a2}+2\cos^2(\theta)\mu_{a3}+0.5\frac{L}{L_0}\mu_{s1}+0.7\frac{L}{L_0}\mu_{s2}+2\frac{L}{L_0}\mu_{s3}\right)}$$

$$I_4 = I_0 e^{-\left(0.5\cos^2(\theta)\mu_{a1}+0.7\cos^2(\theta)\mu_{a2}+2\cos^2(\theta)\mu_{a3}+\cos^2(\theta)\mu_{a4}+0.5\frac{L}{L_0}\mu_{s1}+0.7\frac{L}{L_0}\mu_{s2}+2\frac{L}{L_0}\mu_{s3}+\frac{L}{L_0}\mu_{s4}\right)}$$

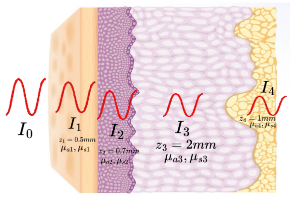

Fig. 2. A block of different tissues demonstrating how the imaging mechanism would work. Each tissue attenuates the incident beam, and that attenuated beam is the initial beam for the next tissue. Air attenuation is neglected.

Since I_4 is the ray that exits the tissue, this is the light beam that the detector will measure. Thus, by obtaining I_4 in terms of I_0, we can use those 2 known values to model an equation expressing the unknown absorption and scattering coefficients. To demonstrate this, we can simplify the above equation into:

$$\ln(\frac{I_0}{I_4}) = 0.5\cos^2(\theta)\mu_{a1} + 0.7\cos^2(\theta)\mu_{a2} + 2\cos^2(\theta)\mu_{a3} + \cos^2(\theta)\mu_{a4} + 0.5\frac{L}{L_0}\mu_{s1} + 0.7\frac{L}{L_0}\mu_{s2} + 2\frac{L}{L_0}\mu_{s3} + \frac{L}{L_0}\mu_{s4}$$

During imaging, the value of I_0, I_4, θ and $\frac{L}{L_0}$ is known. By substituting these values, we obtain a single equation with 8 unknowns. However, because θ and $\frac{L}{L_0}$ are parameters that can be changed at will during imaging, several values of θ and $\frac{L}{L_0}$ can be used within the same slice to obtain more independent equations describing the unknown absorption and scattering coefficients. In this example, a total of 8 independent equations are needed. After obtaining all scattering and absorption coefficients within the slice, the device can continue onto the next tissue and so on. This results in a map of each absorption and scattering coefficient per (x,y,z) within the body, which can be used to generate a high-resolution, high-contrast image for any slice within the body by differentiating between high-scattering regions (bones) and high-absorption regions (soft tissues).

Due to the fact that the scattering effect can be manipulated, low-energy lights, like NIR, can be easily used instead of high-energy lights like X-rays. NIR is known to be scattered throughout the body, which makes using it for imaging difficult. However, by manipulating the attenuation due to scattering through $\frac{L}{L_0}$, the minimum required intensity I_{ph} can be obtained. Thus, the NIR can exit the body without losing the critical information needed to calculate the required abosorption and scattering coefficients. A benefit of using NIR is that, unlike CT-Scans and X-rays, NIR can penetrate tissues without radiation risk [2][3]. Furthermore, because superconductors and rapid rotation are not required, the proposed imaging device will be cheap to operate[3], allowing for cheaper and safer high-contrast imaging.

References

[1] V. De, Light scattering by small particles. New York, Ny Dover Ca, 2009.

[2] C. Mi et al., “Bone disease imaging through the near-infrared-II window,” Nature Communications, vol. 14, no. 1, p. 6287, Oct. 2023, doi: https://doi.org/10.1038/s41467-023-42001-2.

[3] . Mudeng, G. Ayana, S.-U. Zhang, and S. Choe, “Progress of Near-Infrared-Based Medical Imaging and Cancer Cell Suppressors,” Chemosensors, vol. 10, no. 11, p. 471, Nov. 2022, doi: https://doi.org/10.3390/chemosensors10110471.