Monte Carlo Probability To Determine Attenuation Coefficient In Identifying The Selectivity Properties Of Near-Infrared-Based Materials

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***Abstract*–Accurate attenuation coefficient measurements are able to display the nature of selectivity in an image. The methods used to measure the attenuation coefficient are Monte Carlo probability and linear regression models. This attenuation coefficient will appear if an image is taken in transmit mode. Selectivity properties are characterized by contrast ratios between different materials. In this transmission mode, if a near-infrared beam with a different wavelength is passed, it will produce different intensity values depending on the type of wavelength. According to Beer-Lambert's law, the intensity value will experience attenuation depending on the exponential function of the attenuation coefficient and thickness. By using Monte Carlo probability, we get the thickness value of a material per point. This thickness value is then displayed in image form. This thickness function is then used to display an image. The near-infrared wavelengths used are 780 nm and 808 nm. The results show that Monte Carlo probability shows more selectivity than the linear regression method. The wavelength of 808 nm can show more selectivity properties than 780 nm.**

Keywords: Attenuation Coefficient, Imaging, Monte carlo, Tranmittance, Selectivity.

I. INTRODUCTION

The use of near-infrared rays for tomography purposes has been widely developed. One of the important parameters used for tomography purposes is the attenuation coefficient value[1-3] This is because the attenuation coefficient plays an important role in the process of forming an image. The attenuation coefficient in near-infrared can differentiate the brightness level of an image, giving rise to selectivity properties. Near infrared has a short wavelength of around 650–1450 nm [4, 5]. With this wavelength range, near-infrared light is widely used because it has non-ionization, non-invasive, and non-radiative properties [6-8]. If near-infrared light with a certain wavelength is passed through a material, the transmitted waves that come out will provide a certain level of brightness (intensity). Likewise, if the wavelength is varied, each variation in wavelength will provide a certain intensity according to the characteristics of the wavelength. The intensity value that passes through a material also depends on its thickness. The relationship between thickness and output intensity is exponential. This is in accordance with Lambert Beer's law [9]. From this equation, the value of the material attenuation coefficient can be determined based on the thickness and intensity values. From various experimental results, the relationship between thickness variations and the attenuation coefficient value shows a non-linear equation that is closer to exponential [10]. So it can be seen that the thicker the material, the attenuation coefficient tends to be stable. In this area, it was concluded that the thicker the material, the more dominant the absorption properties, so that the optical properties of the material would be identified. In this condition, it is deemed very appropriate to measure the attenuation coefficient value.

The problem is at what thickness the coefficient value is considered to start to stabilize. To determine the value of the attenuation coefficient, one way is to use Monte Carlo probability [8]. The Monte Carlo method can predict the level of stability of the object without needing to use a large number of samples. The Monte Carlo method only requires a small sample as material for further predictions. The use of Monte Carlo probability is widely used, especially for non-linear models such as exponentials [10]. This research aims to use Monte Carlo probability in measuring the attenuation coefficient to determine the level of selectivity of near-infrared-based materials. In this research, meat, skin, and bone materials based on near-infrared wavelengths of 780 and 808 nm were used.

If a transmitted wave passes through a material, it will experience attenuation, which is stated in Beer Lambert's law [11]

$$I = I_0 e^{-\mu x} \tag{1}$$

where Io is the light intensity when it enters the material, I is the light intensity after passing through the material at thickness x, and μ is the material attenuation coefficient, which is a function of wavelength. If attenuation T is the ratio between output and input intensity, then equation (1) can be written:

$$T = \frac{I}{I_0} = e^{-\mu x} \tag{2}$$

To determine the value of the attenuation coefficient (μ), equation (2) is written as

$$\mu = \frac{-ln\, T_\lambda}{x} \tag{3}$$

Equation 3 above can then be described as a non-linear equation as follows [12]:

$$\mu_\lambda = \beta_0 + \beta_1 \frac{1}{d_i} \tag{4}$$

Furthermore, if a near-infrared ray passes through material consisting of flesh, skin, and bones with their respective thicknesses, then equation 2 can be explained as follows[13]

$$T_\lambda = e^{-\mu_d x_d} . e^{-\mu_k x_k} . e^{-\mu_t x_t} \tag{5}$$

Where: μ_d is meat attenuation coefficient, μ_k is skin attenuation coefficient $and\ \mu_b$ is bone attenuation coefficient

$$\ln T_\lambda = -[\mu_d x_d + \mu_k x_k + \mu_t x_t] \tag{6}$$

Equation 6 represents a linear equation for the coordinates of an image taken at a certain wavelength. In equation 6 above, if it is placed in a preparation with the same thickness, the equation changes to:

$$x_d = x_k = x_t = x_{total} \tag{7}$$

$$\frac{-\text{LN}\, T}{\mu_d + \mu_k + \mu_t} = x_{total} \tag{8}$$

The thickness value resulting from equation 8 is then displayed in image form [14].

$$d_m(x,y) = \begin{bmatrix} x_m(0,0) & x_m(0,1) & \dots\ x_m(0,N-1) \\ x_z(1,0) & x_m(1,1) & \dots\ x_m(1,N-1) \\ & \vdots & \\ x_m(M-1,0) & x_m(M-1,1) & \dots\ x_m(M-1,N-1) \end{bmatrix} \tag{9}$$

II. MONTE CARLO

Monte Carlo is a probability-type simulation that approaches the solution of a problem by doing something from a random process. Monte Carlo involves establishing a random sampling distribution from a distribution to generate data. Monte Carlo is used to show something that tends to be uncertain. The basis of the Monte Carlo technique is to conduct a probabilistic experiment through random sampling. [15]

In general, this method is divided into 5 stages: 1. Create a probability distribution for important variables. 2. Build a cumulative probability distribution for each variable in the first stage. 3. Determine the random number interval for each variable. 4. Create random numbers. 5. Create a simulation of a series of experiments. This technique simulates variables repeatedly. Repetition or iteration can be done hundreds or even thousands of times, depending on the variable being reviewed. One way to determine the number of iterations is by formulating the error value (ε). The Monte Carlo technique can predict the error value over several iterations. The error value formula is as follows

$$\epsilon = 3\sigma/\sqrt{N} \tag{10}$$

Where: ε = error value σ = standard deviation N = number of iterations. The next step determines the total absolute error value that is still acceptable from all measurements. The absolute error value provides a very small tolerance for error for each random value generated in the simulation. The absolute value is expressed in α. So the relationship with the error value is

$$\epsilon = \mu/(1/\alpha) \tag{11}$$

So the number of iterations is

$$N = \left(\frac{3\sigma}{\mu\alpha}\right)^2 \tag{12}$$

The value of N is used to determine the value of the attenuation coefficient. This is considered a stable value[16]..

III. METHODS

Some of the instruments used include a laptop, which is used for data processing, especially for visualizing images. The laser used is a diode laser with wavelengths of 780 nm and 808 nm and a negative lens with a focus point of 5 cm. This lens is used to diverge infrared rays so that the diameter becomes wider. Thorlab CMOS CS505MU near-infrared camera. The camera lens used is the MVL5M23. This camera lens is useful for forming a field of view so that the image can be captured by the screen. Meanwhile, the diffuser paper is placed between the phantom and the camera. There are two diffuser papers. This diffuser paper is used to even out the distribution of light. The materials used for this research were meat, skin, and bones.

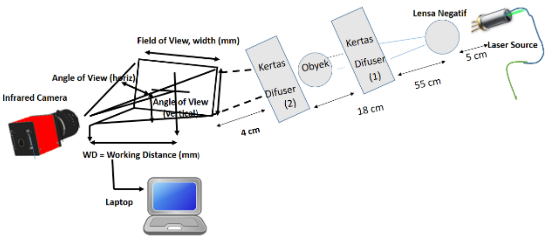


Figure 1. Experiment setup

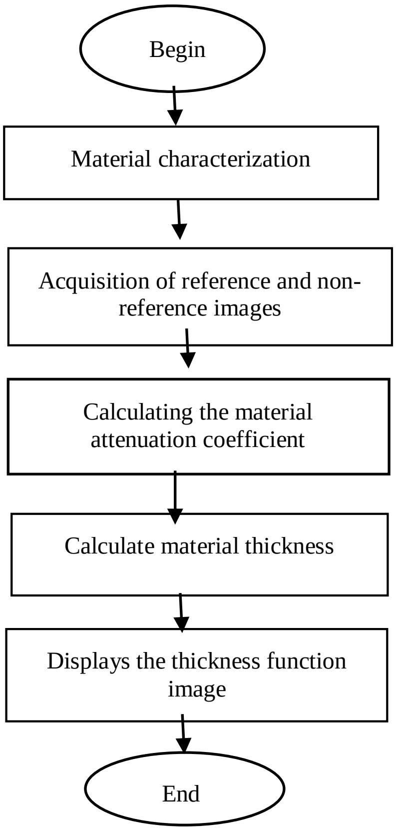


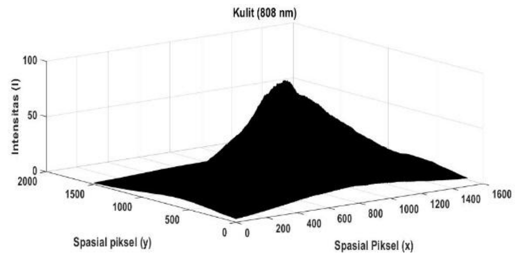
Figure 2. Research flow diagram

In the flow diagram in Figure 2, it can be explained. The materials to be used are prepared in advance. The materials prepared include meat, skin, and bones. Acquisition in the form of images is carried out to produce reference images and images resulting from variations in the thickness of each material. This image acquisition is carried out using different wavelengths. After obtaining several images, the attenuation value was calculated for each material at different thicknesses and different wavelengths. By dividing the attenuation value by the thickness, we get the attenuation coefficient value for each thickness at one wavelength. By using non-linear regression, the attenuation coefficient value for a material at a certain wavelength is produced. To display an image, the thickness value is calculated based on Equation 8. This thickness value is displayed in an image.

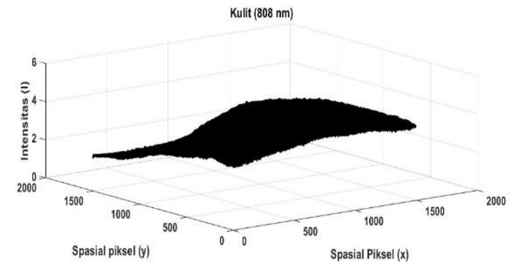
IV. RESULTS AND DISCUSSION

Before the tomography process is carried out, the materials to be measured are all finely ground and put into a glass box. The thickness varies, namely from 0.4 cm to 0.9 cm. The first is to acquire an immaterial image. The experimental design is shown in Figure 1 above. The results of image acquisition without this material are called reference images. Next, image acquisition was carried out again by varying the thickness level. These images are visualized into a curve to obtain a beam profile. The laser beam used for this process consists of two laser beams with wavelengths of 780 nm and 808 nm. This beam profile measurement varies according to the thickness level. The light intensity used to measure the beam profile that passes through the material is the same intensity used to acquire the reference image. The intensity output of the near-infrared laser used is regulated in such a way that saturation does not occur on the camera sensor. The intensity to display the beam profile is taken from the entire surface of the reference image, and the image is obtained from various thickness variations.

The results of the beam profile curve on skin material at a wavelength of 808 nm are shown in Figure 3 below:



(3a)



(3b)

Figure 3. Infrared Ray Intensity (3a) condition without substance (b) substance with a thickness of 0.4 cm

The results of attenuation measurements after passing through a 0.4-cm-thick meat substance are expressed in the following equation, as in Equation 2 above. Furthermore, equation 3 is realized in Figure 4 below. In theory, it should be a flat plane. If there are deviations on the entire surface due to noise, imperfections, or non-homogeneity of sample thickness,

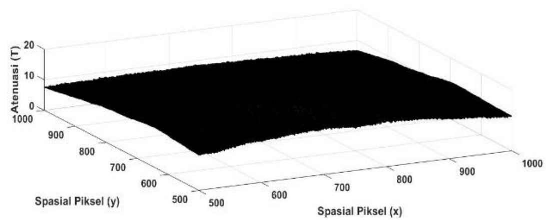


Figure 4. Cross-section of attenuation values of 0.4-cm thick skin

To get the attenuation value, do it by averaging all the surface attenuation values. In this case, the surface area.[17] If you divide the averaging result value as in Figure 4 above by thickness, you will get the attenuation coefficient value according to Equation 3. The same method is also carried out for meat, skin, and bone materials at a wavelength of 780 nm. Meanwhile, meat and bone materials are at a wavelength of 808 nm. Using equation 12 and an error value of 5%, the iteration value (N) for each material at a certain wavelength is obtained. This N value is the thickness level used, assuming a stable attenuation coefficient value. The results of calculating the attenuation coefficient value using non-linear regression and Monte Carlo models can be seen in Table 1.

Table 1: Results of measuring the attenuation coefficient by linear regression and Monte Carlo methods

	780 nm	780 nm (Monte carlo)	808 nm	808 nm (Monte carlo)
Meat	1,96	5,71	1,53	5,14
Skin	0,90	4,53	0,84	4,48
Bone	2,49	6,40	2,25	6,25

The measurement results show that the attenuation value decreases based on the increase in wavelength. The results show that the bone attenuation coefficient is higher, while the skin material is the lowest. Compared with the results of the method that has been carried out using thCompared with the results method that has been carried out using the line method on the beam profile and confirmation of the attenuation coefficient using the non-linear method, using the curve area method and verifying the attenuation coefficient using Monte Carlo results do indeed have differences. The difference in results is not that different.e line method on the beam profile and the confirmation of the attenuation coefficient of the non-linear method, there are differences, but they are not significant.

Before image acquisition is carried out, a form of flesh, skin, and bone material is arranged in such a way that the thickness of the three materials is the same. This arrangement is shown in Figure 6 below.

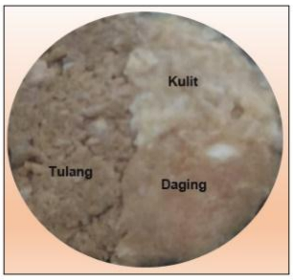
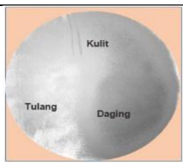


Figure 5 Material composition[18]

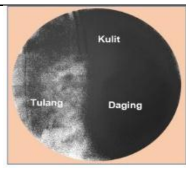
The results of calculating the attenuation coefficient in equation 4 are then entered into equation 8. The image results based on this thickness function are then displayed. The results of this selectivity tomography image are shown in Figure 6.

λ	$\mu_\lambda = \beta_0 + \beta_1 \frac{1}{d_i^1}$	$Monte\ Carlo$

780 nm



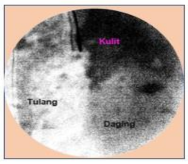
(a)



(b)

808 nm

(a)



(b)

Figure 6. Selectivity Image Results for Wavelengths 780 nm and 808 nm

From the image, it can be seen that at a wavelength of 780 nm, using the method of linear regression does not produce selectivity because the difference in brightness level between materials is not clear. Meanwhile, using the Monte Carlo method, there appears to be a difference in brightness levels between the three materials. The brightness levels of skin and flesh materials appear to be slightly different. From the image, it can be seen that at a wavelength of 808 nm, using the method of non-linear regression does not produce selectivity because the materials are all white. Meanwhile, using the Monte Carlo method, there appears to be a difference in brightness levels between the three materials. The brightness levels of skin and flesh materials appear to be slightly different. This is characterized by different levels of brilliance in the degraded material. Both meat, skin, and bone materials show different levels of brilliance. Where the skin material appears blacker, the flesh looks grayer, and the bones look whiter.

In this case, the Monte Carlo method shows the best selectivity at a wavelength of 808 nm. The experiment did not produce perfect selectivity images, such as in the bone area. In the bone image area, there is still black. This can happen because the position of the material is placed horizontally and the material is pounded, so the density level of the material can change.

The experimental results show that determining the attenuation coefficient value using Monte Carlo probability shows more selectivity. This can be seen in the level of contrast ratio between materials, so that the level of contrast between materials appears to be different. the result. Using the Monte Carlo simulation above, improvements need to be made, especially in the coefficient values between bone and skin, which produce adjacent values. Besides that, in the image results of separating the components, there is one component that has not been completely separated, resulting in an image that was not expected. The algorithmic calculation also needs to be refined. In the experiment above, it is assumed that the equation is close to linear; the results are not optimal, so it needs to be done using a non-linear approach. When calculating the absorption coefficient value, it should produce a constant horizontal line on the object with any thickness value, but in this experiment, there were uneven values. This may need improvement in future experiments.

V. CONCLUSION

Monte Carlo probability can be used to measure the attenuation coefficient. The results of this measurement can show the selectivity of meat, skin, and bone materials. One of the parameters is to show the level of contrast ratio between differently graded meat, skin, and bone materials. The research results showed that the 780 nm wavelength could not show selectivity, while the 808 nm wavelength succeeded in showing selectivity. Each material has characteristics of certain near-infrared wavelengths. The use of wavelength affects the level of image quality using the attenuation coefficient. For further research, it is necessary to develop other methods to determine the level of selectivity and image quality more accurately by adding the number of lasers with different wavelengths and adding types of material.

VI. ACKNOWLEDGMENTS

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