A LIGHT TRANSMISSION MODEL
FOR BIOLOGICAL MATERIALS

by

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For presentation at the 1984 Winter Meeting
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

Hyatt Regency, New Orleans, Louisiana
December 11-14, 1984

SUMMARY:
This paper describes a model to predict light transmission in biological materials. The model can be used for any shaped sample. Scattering and absorption coefficients are used in the model and may be varied throughout the sample, thus allowing both uniformly distributed and concentrated defects to be modelled.
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ABSTRACT

A light transmission model is described here in. The model assumes that the light source is a high intensity non-diffusing source (i.e. laser). Absorption and scattering coefficients may be given for each element. Thus both uniformly distributed and concentrated defects can be entered in the model. The model assumes a spherical shaped region but can be modified for any shape.

INTRODUCTION

Light transmission as a non-destructive method for determining interior quality of fruits, vegetables, and animal products has been firmly established. The application of this technique started in the 1950s and has continued since. A reference list containing many of the products worked on is contained in an ASAE paper by Gunasekaran et al. (1984). Past research has generally been limited to the application of this method. Several researchers have tried to use existing theories to explain (model) light transmission in biological materials (Birth, 1971, 1978; Kumar and Silva, 1973). A satisfactory model has yet to be developed.
The earliest theories to explain light scattering were developed by John William Strutt, later known as Lord Rayleigh and Gustav Mie. Both of these theories are based on single particle scattering. Rayleigh scattering is accurate when the particle diameter is one tenth the wavelength. Light is scattered in a circular torus shape (Figure 1). As the particles become larger than the wavelength Mie scattering dominates where most of the light is scattered forward (Figure 1). Kortum (1969) reported that Theissing (1950) and Hartel (1940) studied multiple scattering of densely packed particles and they indicated that it is angularly isotropic. Two well known theories using this principle are "self-illumination" and "Kubelka-Munk". The development and resulting equations for these theories can be found in several books (Kortum, 1969; Wendlandt and Hecht, 1966; Judd and Wyszecki, 1975) This paper reports on our continuing research involving light transmission.

THE MODEL

The approach that we have taken is also based on isotropic angular distribution of light due to multiple scattering. There are two material properties that must be known for the sample. They are Alpha, the scattering coefficient and Beta, the absorption coefficient. They do not need to remain constant through out the sample. We have chosen to work with a sphere for the shape of the sample, though this model
could be adapted to any geometric shape.

The model is developed in several levels. Level 0 is the formation of a line source within the sample due to the incident radiation. Level I is the radiating of the line source to all points within the sample. Level II is the radiating of adjacent points in the sample to any other point, \( P_i \). Level III and higher is the continued scattering (principle of level II) within the sample until steady state is reached. A list of symbols and definitions are on page 7.

Level 0

We assume that a nondifuse source of light, such as a laser is shined on the sample. As the light progresses through the sample, a line source of light is created. Cartesian coordinates for the sample are aligned so that the X axis is parallel to the line source. Looking at an incremental section of this line source we have the following:

\[
(a + \theta) \, dx \, I \\
I \rightarrow \quad \quad \quad \quad \quad \rightarrow I + \frac{\partial I}{\partial x} \, dx
\]

(1)

As the light passes through the increment, there is scattering and absorption taking place. From this we obtain the Eqn. 2, the light intensity anywhere along the line source.
The next step is to see how the line source radiates to the sample. Assuming an isotropic angular distribution of light, as we move radially from the source, the light intensity reaching this point decreases due to the increasing surface area of the sphere surrounding the point source. The light also undergoes absorption and scattering. Eqn. 3 is the intensity of light reaching any point, \( P_i \), in the sample (Figure 2).

\[
I_i = I_o e^{-(\alpha + \beta)X} \frac{-(\alpha + \beta)D}{4\pi D} \quad (3)
\]

For any point, \( P_i \), the total light intensity at that point is found by integrating along the line source, Eq 4.

\[
I_{i,1} = \frac{\alpha I_o}{4\pi} \int_{X_1}^{X_2} e^{-(\alpha + \beta)(X + D)} \frac{1}{D} \quad (4)
\]

Thus the light intensity can be predicted for any point in
the sample due to the line source.

Level II

Now take into consideration the effect of light being scattered by adjacent points on Pi. Again, the light at each point is radiating equally in all directions. By integrating over the whole sample, the effect of all points on Pi can be determined. This is shown in Eq. 5 and Figure 3.

\[ I_{1,2} = \int \frac{-\alpha I_1 e}{\frac{4\pi}{d^2}} \, dv \]  

Level III

The concept occurring in Level II can be expanded to additional levels (multiple scattering) until all the input light has been either absorbed or has left the sample through surface transmission.

MODEL SOLUTION

The model is now being put on a microcomputer and therefore we have no model verification at this time. Before we can verify the model, we need the scattering and absorption coefficients. Experiments are now being designed to obtain them. This involves measuring the incident, scattered, and
transmitted light for very small (single cell layer) samples.

CONCLUSION

We have proposed a model for light transmission in biological materials. It allows for varying geometric shapes, concentrated and uniformly distributed defects. Verification of the model is the next step in our work. If the model is accurate, it will aid us in further understanding light transmission as a tool in non-destructive testing of biological materials.

REFERENCES


**SYMBOLS AND DEFINITIONS**

\[ \alpha \quad \text{scattering coefficient} \]

\[ \beta \quad \text{absorption coefficient} \]

\[ d \quad \text{distance between any two points in the sample} \]

\[ D \quad \text{distance between the line source and point } P_i \]

\[ i \quad \text{intensity of light reaching } P_i \text{ due to a} \]

\[ \text{single point on the line source} \]

\[ I_{i,j} \quad \text{intensity at any point, } P_i \text{ in the sample} \]

\[ \text{due to level } j \text{ contribution} \]

\[ I_L \quad \text{intensity along line source} \]

\[ I_0 \quad \text{intensity of incident radiation} \]

\[ P_i \quad \text{the } i \text{ point within the sample} \]

\[ X \quad \text{distance along line source from point of incident} \]

\[ \text{radiation} \]

\[ X_1 \quad \text{beginning } X \text{ coordinate of the line source} \]

\[ X_2 \quad \text{ending } X \text{ coordinate of the line source} \]

\[ V \quad \text{volume of the sample} \]
Figure 1. Angular distribution in Rayleigh and Mie scattering.

Figure 2. Light scattering at Level I.

Figure 3. Light scattering at Levels II and higher.