

APPLICATION OF LIDAR-LIKE EQUATIONS TO OCT SIGNAL ANALYSIS FOR TOTAL EXTINCTION COEFFICIENT DETERMINATION

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RESUMO

Tomografia por coerência óptica (OCT) é uma técnica interferométrica que utiliza fontes de baixa coerência, explorando as características de retroespalhamento do meio para construir imagens de seção transversal. Utilizada para adquirir imagens de tecidos biológicos, o OCT alcançou aplicação na oftalmologia como única técnica capaz de realizar imagens histológicas de estruturas do olho. Apesar da técnica de explorar as características de retroespalhamento da amostra o sinal carrega informação até agora não explorada. O Sinal retroespalhado utilizado em OCT é similar ao encontrado no do problema LIDAR, esta similaridade indica uma direção para solução do sinal OCT. O objetivo deste trabalho foi desenvolver um modelo LIDAR para analisar o sinal OCT e determinar o coeficiente de extinção total de uma amostra. Para determinar o coeficiente de extinção total três métodos de inversão foram utilizados os métodos: inclinação, ponto de contorno e profundidade óptica. Para validação foi medida a transmitância e refletância espectral de uma amostra de Al₂O₃ utilizando uma esfera integradora. Desta medida o coeficiente de extinção total foi calculado e comparado com o resultado obtido usando OCT e os três métodos. A análise destas propriedades podem no futuro ser utilizada para diagnóstico clínico quando aplicado à tecidos biológicos.

Descritores: Tomografia por Coerência Óptica, equação LIDAR, Coeficiente de Extinção Total.

ABSTRACT

Optical coherence tomography (OCT) is an interferometric technique, using a low

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coherence light source, that explore sample backscattering feature to acquire in depth cross-section images. Design to provide biological tissue image, OCT is used in ophthalmology to do eyes histological images. Although, due to technique explore sample backscattering feature, the backscattering signal carries unexplored information until now. The backscattering problem is similar to those found on LIDAR problem, this similar situation indicate the path that should be followed to solve the OCT problem. The aim of this work was to develop a LIDAR-like equation model to analyze the measured OCT signal and determine the total extinction coefficient of a sample. To determine the total extinction coefficient three inversion methods solution: the slope, the boundary point and the optical depth. To validate these solution methods an Al₂O₃ sample the spectral reflectance and transmittance was measured using an Integrating sphere, the spectral absorbance was extracted from the first two. From this measure the total extinction coefficient was calculated and compared with the results acquired using OCT and the three solution methods. The analysis this property can in the future help clinical diagnoses when applied on biological tissues.

Keywords: Optical Coherence Tomography, LIDAR equation, Total Extinction Coefficient.

INTRODUCTION

Optical Coherence Tomography, also broadly known as OCT is a relatively new technique which relies on low coherence length interferometry [1]. The OCT technique derives from studies of optical fibers faults location [2] in 1987. However, the breakthrough occurred

when this methodology was applied to perform tomographic images of delicate live structures, such as eyes structures [3-5] and other biological tissue [6-8]. Despite the fact that OCT can be considered as an established diagnostic tool, especially by biomedical areas, the technique has less than two decades of conception and still are under development.

Many researches centers around the world has dedicated groups of OCT studies, which denotes that OCT it is far from technological saturation. These groups (including our) are constantly creating new application or new setup configurations.

This technique, known as a biological tissue image technique, can also be used to imaging another delicate samples like some kinds of ceramics, textile products or papers for example.

The most common OCT setup uses a Michelson interferometer to provide a cross section image of a scattering samples with noninvasive and no contact parts. In this setup, the light is conducted by the optical fiber to a 2x2 coupler and in this way the light is divided in two beams: one part of the light goes to a reference mirror and the other part goes to sample (Figure 1).

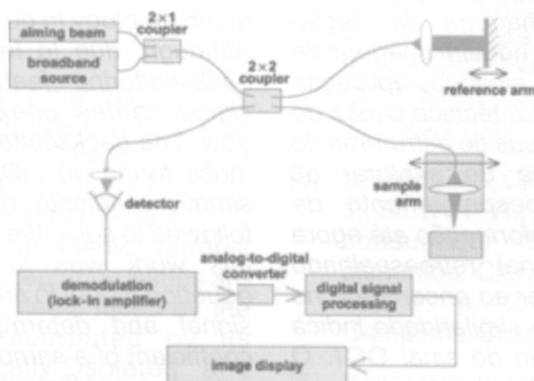


Figure 1: Schematic representation of OCT system.

The mirror and sample backscattering radiations recombine forming an interferometric pattern in the detector. Because light source have low coherence length, broad spectral band, the interference occurs in the detector only when the optical length difference between sample's arm and reference arm is shorter than the coherence length, i.e., only the photons once scattering have the information necessary to generate the interferometrics pattern.

Nowadays, OCT is used just as an image technique, but the backscattered signal has more information about sample than those explored. The backscattering sample propriety used in OCT image formation is similar to those found on LIDAR (Light Detection And Ranging) problem, this similar situation indicate the path that should be followed to solve the OCT signal.

A light beam propagating through a scattering medium is attenuated along way[9],

in each interaction with molecular or particle present in de medium. The scattered radiation is emitted in all directions, but only a portion of radiation return to system in the same direction and back way, it is known as backscattering.

$$P(r) = C_0 T_0 \frac{\beta_\pi(r)}{r^2} \exp \left[-2 \int_{r_0}^r \kappa_t(x) dx \right] \quad (1)$$

$\beta_\pi(r)$ is the total backscattering coefficient, $\kappa_t(r)$ is the total extinction coefficient and C_0 is a constant that only depends the system. In this scenario the aim of this work was to develop a LIDAR-like equation model to analyze the measured OCT signal and determine the total extinction coefficient of a sample, characterizing their optical properties.

MATERIALS AND METHODS

To determine the total extinction coefficient three different inversion methods used in the LIDAR [9] were implemented: (1)

the slope method solution, (2) the boundary point method solution and (3) the optical depth method solution, implemented.

(1) Slope method solution. The first method can be applied when the medium total extinction coefficient and backscattering coefficient can be assumed constant over the path. Then taking the logarithm of equation 1 it can be reduced to a linear equation (equation 2).

$$\ln\left(\frac{P(r)r^2}{T_0 C_0}\right) = \ln(\beta) - 2\kappa_t r \quad (2)$$

When the total extinction coefficient and backscattering coefficient change along the path, and assuming that the ratio between them is constant (known as LIDAR ratio), the other two methods must be applied, but is necessary know, or measure, some parameter, as shown below.

(2) Boundary point method solution. This method can be used when the total extinction coefficient changes along the path, but is necessary to know its value in some position. Knowing or measuring this value in the r_b position the solution reduces to equation 3.

$$\kappa_t(r) = \frac{Z_r(r)}{\kappa_p(r_b) + 2 \int_{r_b}^r Z_r(r') dr'} \quad (3)$$

Were

$$Z_r(r) = \frac{P(r)r^2}{T_0 C_0}$$

$\kappa_p(r_b)$ and $Z_r(r_b)$ are the total extinction coefficient and $Z_r(r)$ in the r_b position.

(3) Optical Depth method solution. As the previous method, this solution assume that the LIDAR ratio is a constant, but in this method is necessary to measure de sample transmittance (T_{max}), so the total extinction coefficient can be determinate using the equation 4:

$$\kappa_t(r) = \frac{0,5 Z_r(r)}{\frac{T_{r,max}}{1-T_{max}^2} + 2 \int_{r_0}^r Z_r(r') dr'} \quad (4)$$

The three solutions methods algorithms were implemented on LabVIEW® environment, first a backscattering signal were simulated and the computational error were

evaluated, and then using a commercial OCT an image of a ceramic alumina (Al_2O_3) sample were performed (Figure 2) and used to determine the total extinction coefficient.

Using an integration sphere the spectral reflectance and transmittance of Alumina sample was measured, the spectral absorbance was extracted from the first two.

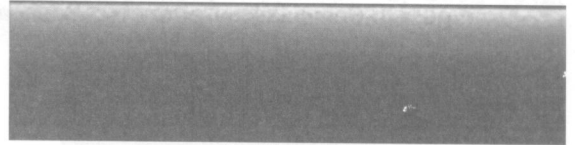


Figure 2: OCT image of a Al_2O_3 sample.

RESULTS AND DISCUSSION

The computational error were evaluated in the three method used to solve LIDAR equation by a simulated backscattering signal. In the slope method no computational error were performed, in the Boundary point and Optical Depth method solution the associated computational error were less than ~0.6% (figure 3).

After perform this evaluation, an Al_2O_3 sample was measured using OCT (figure 2) and this image signal was introduced in the three method solution. The figure 4a shows the linear fit to calculate the total extinction coefficient, the figure 4b and c show the program screen graphics of total extinction coefficient along the path. Finally, figure 4d shows the transmittance, reflectance and absorbance measured with the integration sphere, the transmittance value at 930nm (20%) was used to evaluate the optical depth solution method.

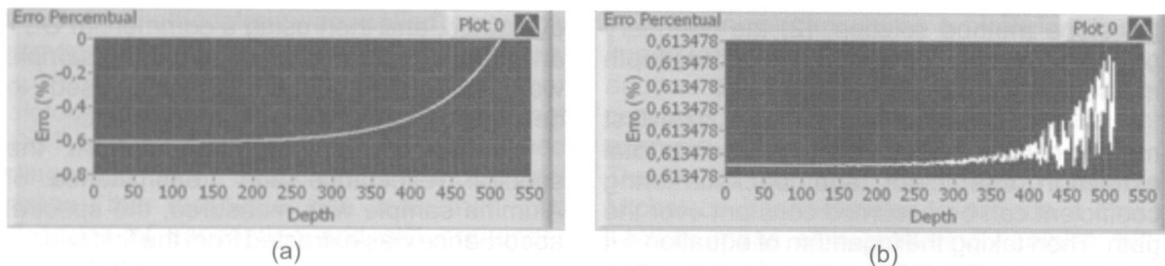
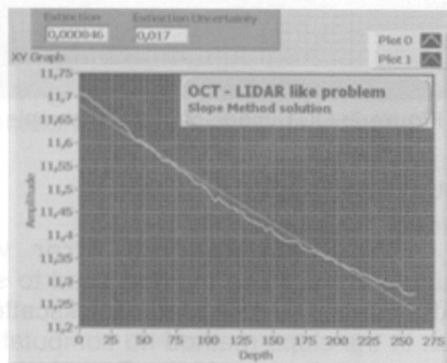
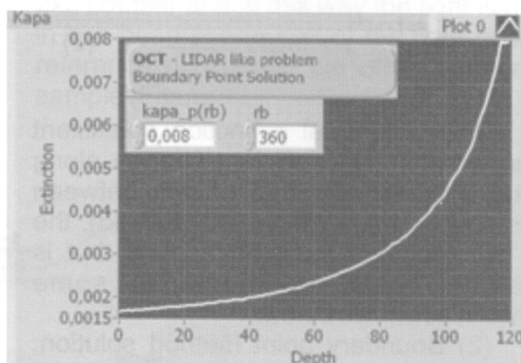


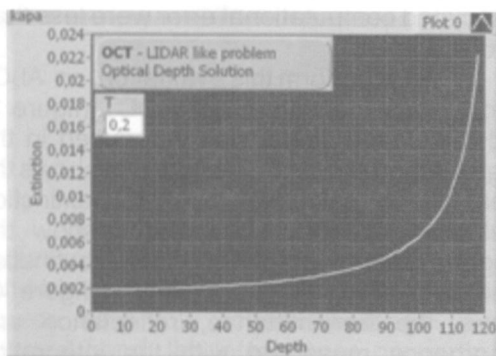
Figure 3: Computational error of (a) Boundary Point and (b) Optical Depth solution method.



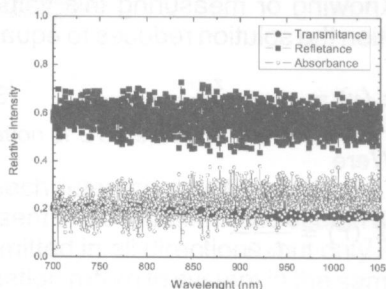
(a)



(b)



(c)



(d)

Figure 4: (a) Slope, (b) Boundary Point, (c) Optical Depth solution method applied to a simulated Backscattering signal; (d) Integration Sphere measurements.

The total extinction coefficient obtained with the slope method was 8×10^{-4} but the uncertainty was 1.7×10^{-2} , because the extinction coefficient is not a constant over the path. The results obtained using the other two methods agree with each other as can be seen on Figure 4a e 4b.

CONCLUSIONS

Sample backscattering signal used in OCT to generate image cross-section is similar to LIDAR backscattering signal, from

this fact LIDAR equation could be used to determine extinction coefficient in the OCT case. The three most used LIDAR solution algorithm was implemented in LabVIEW® and a simulated OCT signal was used to quantify the computational error introduced when the extinction coefficient is determine. The extinction coefficient determined, on the simulation, by Slope Method Solution showed the best agreement with extinction coefficient used to generate the simulated signal, but it assumes that the extinction coefficient is a constant over range, what was not true. The

Boundary Point Solution presents a small difference (0.6%) between extinction coefficient determinate and the simulated signal, the disadvantage of this method is that the extinction coefficient must be known in a some point of the sample, but the method provide a extinction coefficient in agreement with those determined using de Slope Method. The last method, Optical Depth Solution, as the last one, provide a computational error of about 0.6% when compared the simulated and the determined extinction coefficient. Using an integration sphere the transmittance of Alumina was determined and used to determine the extinction coefficient.

This work was important to understand the LIDAR solution behavior for OCT signal, both computational error and application on real scattering sample. The next step will be improve the real application, specially when the extinction coefficient change along the scattering sample.

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