Signal Properties of Optical Coherence Tomography from Turbid Medium Doped by Gold Nano-particle

Mei ZHANG 1,a, Lin LIN2,b,* and Lei YANG1,c

1College of Electronic Engineering, Dongguan University of Technology, Dongguan, China
2School of Information Engineering, Guangdong Medical University, Dongguan, China
azhangm@dgut.edu.cn, blynwindsent@163.com, cyangl@dgut.edu.cn
*Corresponding author

Keywords: Gold nanorods (GNRs), Standard Particle, Turbid Medium, Optical Coherence Tomography (OCT).

Abstract. The signal properties of gold nanorods as a contrast agent of spectroscopic optical coherence tomography system is studied and evaluated. The absorption and scattering characteristics of nanoparticles were studied by comparison with standard particles. Besides absorption, gold nanoparticles also have some scattering effects. The signal to noise ratio of coherent signal is also evaluated as an important index. The combination of GNRs and other image agents for dual or multi-modality imaging is promising for small scale and high precision imaging.

Introduction

Optical coherence tomography has been applied to kinds of clinical diagnosis such as lymphoma[1], kidney neoplasms[2], oral cancer [3] and rectal cancer[4]. Although can perform high resolution structure imaging, the lack of functional imaging capabilities limits its application in identify tissue lesions and component detection. Gold nanoparticles have become functional imaging contrast agent and marker carrier for MRI, CT, photoacoustic tomography (PT) and fluorescence imaging because it provides strong absorption in near-infrared region as result of surface plasmon resonance[5-9]. For OCT system, the behavior of gold nanoparticle is more complicated that is influenced by many factors such as absorption, scattering and polarization state. On the one hand, strong absorption increases the local contrast of OCT image. On the other hand, the stronger the absorption, the lower the signal to noise ratio (SNR). Therefore, SNR is an important parameter to evaluate the image enhancement effect of gold nanoparticles.

We have research on the behavior of gold nanoparticle in turbid phantoms by spectroscopic optical coherence tomography(SOCT) which works in near infrared waveband. The experimental study on the characteristics of the depth dependent coherent light signal is carried out and compared with the properties of dyeing agent and standard particle. we analyze SNR based on extended Huygens-Fresnel principle [10], which is valid for both single and multiple scattering regimes.

Spectroscopic Optical Coherence Tomography (SOCT) System

The structure of SOCT system is shown in Fig.1 which includes a super luminescent diode with center wavelength of 850nm, a 50/50 fiber coupler. The reference arm consists of double
lens and one reflecting mirror fixed on a stage. In the sample arm, incident light is collimated to a galvanometer and focused on the turbid sample by an objective lens. The galvanometer can perform X-Y scanning. The optical intensity along z-axis can be described by light current

\[ i(z) = k \exp[-(\mu_s + \mu_a)z] \cdot \phi(z) \] (1)

where \( k \) is system calibration factor which is related to backscattering coefficient, \( \mu_s \) and \( \mu_a \) are scattering coefficient and absorption coefficient respectively and \( \Phi(z) \) point spread function of focusing Gaussian beam is given by

\[ \phi(z) = 1/\sqrt{1 + (z-z_f)^2/\left(\alpha z_0\right)^2} \] (2)

In which \( z_0 \) represents the Rayleigh range, \( z_f \) is the focus position and \( \alpha \) accounts for the influence of scattering in the Rayleigh range.

Figure 1. Schematic presentation of the SOCT at 850nm wavelength.

According to extended Huygens-Fresnel (EHF) principle, with shot-noise limited condition, the SNR can be expressed as:

\[ SNR(z) = \frac{4P_B \eta \Psi(z)}{hvB_w} \] (3)

where \( \Psi(z) \) is the heterodyne efficiency factor, \( B_w \) is the bandwidth of system; \( P_s \) is the power of sample beam; \( z \) is the probing depth; \( \eta \) is the detector quantum efficiency; \( \nu \) is the optical frequency and \( h \) is Planck’s constant. For a given OCT system, SNR is dependent on wavelength \( \lambda \), probing depth \( z \), scattering coefficients \( \mu_s \), and asymmetry parameter \( g \). The signal to noise ratio of the image should be equal to the ratio of the power spectrum of the signal to the noise, but it is difficult to calculate the power spectrum. In our study, the local variance of all pixels in the image is calculated, and the maximum value of the local variance is considered as the signal variance. Find the ratio of the above two values and make corrections if necessary.

\[ SNR_i = 10 \log_{10} \left( \frac{1}{mn} \sum_{j=1}^{m} \sum_{k=1}^{n} ||I_{i,j} - E_{i,j}||^2 \right)^2 \] (4)

Where \( Max \) is local maximum value, \( m \) and \( n \) represent the size of image, \( I(i) \) is the signal value and \( E(i) \) is mean square deviation of the \( i \)th pixel.
Experiment and Data Process

Gold nanorods (GNRs) comes from Sigma-Aldrich Co. LLC with a peak resonance of 850 nm (748005) and 808 nm (748998). We use polystyrene microsphere (PS) as scattering particles and India ink as absorber for comparison. The basal medium includes water and gelatin to simulate tissue environment. Phantoms were homogenized by ultrasonic treatment. The system performed B-scan on each phantom at speed of 20 frames per second. The spectrum data obtained at CCD were Fourier transformed to generate depth-relevant signal. In addition to the resonance absorption properties, gold nanoparticles also have some scattering effects as shown in Fig.2b, which cannot be ignored in imaging. Fig.2a gives the TEM image of GNRs and Fig.2c shows the result of A-scan.

![Figure 2. SOCT results of GNRs with absorption peak of 850nm](image1)

- a. TEM picture
- b. B-scan image
- c. A-scan data

![Figure 3. B-scan results of a. 0.05μm PS, b. 0.5μm PS and c. 1μm PS.](image2)

- a. 0.05μm PS
- b. 0.5μm PS
- c. 1μm PS

![Figure 4 a. Average results of 100 A-scan of different phantoms and b. maximum probing depth in PS solution.](image3)

- a. Average results of 100 A-scan
- b. Maximum probing depth in PS solution
As shown in Fig.3, the grey scale of B-scan represents particles of different sizes. The coherent signal of PS and gold nanoparticles solution is given by Fig.4a. The microsphere concentration is proportional to the scattering coefficient, so the maximum detection depth decreases with the increase of scattering as shown in Fig.4b. But in the homogeneous solution, the SNR cannot be improved the enhancement of absorption. In multilayer structure, the enrichment of nanoparticles on the interface can improve the image contrast.

Conclusion

In conclusion, we have tried to evaluate the signal characteristics GNRs in the 850nm SOCT system. Unlike uniform distribution of pixels in PS solutions and GNRs (808nm), the images of GNRs solutions(850nm) was discrete and not even. The average data shows that GNRs with different aspect ratios gave similar depth relevant signal. Besides absorption, gold nanoparticles also have some scattering effects. It is necessary study the combination of GNRs and other image agents for dual or multi-modality imaging.

Acknowledgment

This work was supported by Natural Science Foundation of Guangdong Province (2014A030310258), Educational Commission of Guangdong Province (YQ201402) and Guangdong science and technology plan project (2015A020214024).

References


