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A Review on the use of Optical Coherence Tomography in Medical Imaging

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Abstract: Optical Coherence Tomography (OCT) is a Three-dimensional imaging technique with ultrahigh spatial resolution even in highly scattering media. It is based on measurements of the reflected light from tissue discontinuities. Optical coherence tomography delivers high resolution images, because the test is based on light, rather than sound or radio frequency. Optical coherence tomography provides a 1 to 15 µm resolution but only a depth of 1 to 2 mm can be imaged in opaque tissues such as arteries or skin. In transparent tissues such as the eye, greater imaging depths are possible. In addition, optical coherence tomography is capable of providing information about tissue composition. This paper, aims at reviewing the working principle of Optical Coherence Tomography and the quality of the image produced through this technique. A major drawback of Optical Coherence Tomography image is that, it suffers from speckle noise.

Keywords: Optical Coherence Tomography, Spatial resolution, Speckle Noise.

I. INTRODUCTION

Optical Coherence Tomography (OCT) is a technique for obtaining subsurface images of translucent or opaque human tissues. OCT enables a medical examination without harming the tissues and acquires the cross-sectional images of tissue by measuring back-reflected light. [1]An optical beam passes through the suspected area, and a small portion of this beam that reflects from sub-surface features is collected. As the light passes a small portion of the light scatters and does not form an image. With the help of OCT technique, scattered light can be removed completely. Every small portion of the reflected light that is not scattered can then be detected and used to form the image in, e.g., a scanning OCT system employing a microscope. OCT images from in vivo OCT systems typically have a resolution of 10 to 15 µm, and are thus best suited for visualizing structures in the range of tens to hundreds of microns, such as tissue layers or glands. Many normal and abnormal tissues lack visible structures in this size range, so it may appear that OCT is unsuitable for identification of these tissues. However, examination of poor structure OCT images reveals that they frequently display a characteristic texture that is due to speckle. [2] The main advantages of OCT are high resolution both in depth and transversally, as well as non-invasive and contact-free imaging. A disadvantage is a limited penetration depth in scattering media.

II. HOW OCT WORKS?

Generally, OCT employs an interferometer. Light from a light source (for example, a broadband light source) is split (for example, by a beam splitter) and travels along a sample arm (generally comprising the sample) and a reference arm (generally comprising a mirror). [3] A 2x2 coupler is utilized to split the light into two fibers. One fiber focuses into the tissue while the second one leads to a reference mirror. Light reflected off the reference mirror is then re-coupled into the fiber leading to the mirror. At the same time, light reflected from a mismatch in refraction index in the tissue is re-coupled into the fiber leading to the tissue. Light which has been back-reflected from the reference arm and from the tissue are recombine within the 2 × 2 coupler. When the distance travelled by light in the sample arm is within a coherence length of the distance travelled by light in the reference arm, optical interference occurs, which affects the intensity of the recombined light. The intensity of the combined reflected light varies depending on the sample properties. Thus, variations for the intensity of the reflectance measured are indications of the physical features of the sample being tested. An optical detector is used to detect the interference between the tissue and reference. An optical interferometer is used to remove the scattered light from the reflected light to produce the needed image. In this process depth and intensity of light reflected from a sub-surface feature is obtained and hence a three-dimensional image can be built up by scanning. During the imaging process, the reference-arm mirror is scanned at a constant velocity. This allows for depth scans to be made.

[4]Several data points over 2 mm of depth are integrated by the interferometer to construct a tomogram of retinal structures. Image thus produced has an axial resolution of <10 microns and a transverse resolution of 20 microns. The operating wavelength of OCT probe beam is typically in the near infrared (800 nm) and thus minimally visible to the patient. The tomogram, which shows a single plane of an object in very specific detail, is displayed in either grey scale or false color on a high resolution computer screen. It allows measurement of eyelid thickness from the

tomograms by means of computer image-processing techniques.

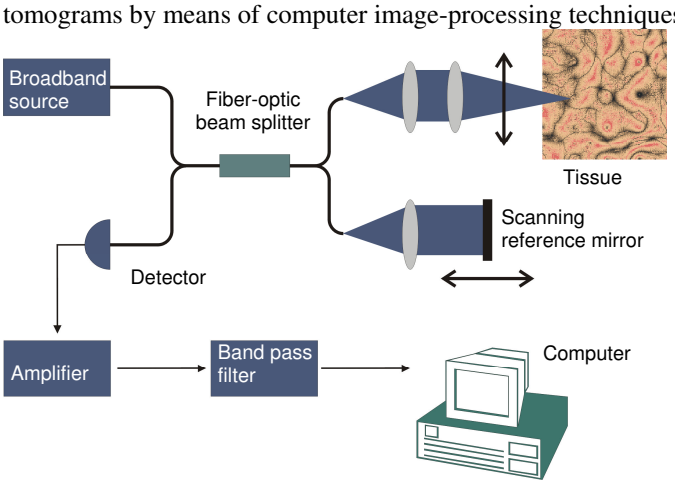

Figure1. Working of OCT

III. METHODS OF OCT

There are basically, two techniques for acquiring OCT images, they are Time Domain OCT (TD-OCT) and Frequency Domain OCT (FD-OCT). [1] In time domain OCT the path length of the reference arm is translated longitudinally in time. A property of low coherence interferometry is that interference, i.e. the series of dark and bright fringes, is achieved only, when the path difference lies within the coherence length of the light source. In time-domain OCT, the length of the reference arm can be varied (for example, by moving one or more reference mirrors). The reflectance observed as the reference arm distance changes indicates sample properties at different depths of the sample. In frequency domain OCT the broadband interference is acquired with spectrally separated detectors. In frequency-domain OCT, the distance of the reference arm can be fixed, and the reflectance can then be measured at different frequencies. For example, the frequency of light emitted from a light source can be scanned across a range of frequencies or a dispersive element, such as a grating, and a detector array may be used to separate and detect different wavelengths. Fourier analysis can convert the frequency-dependent reflectance properties to distance-dependent reflectance properties, thereby indicating sample properties at different sample depths.

IV. QUALITY OF OCT IMAGES

An OCT image is a collection of one dimensional depth of the samples. The reflectivity of the tissue at each depth along the sample line is recorded. If an OCT image has low signal strength, then it is difficult to see the eye's physiology, making correct diagnosis difficult. Quality for whole images can be determined automatically [5], but, sometimes only a portion of the image is bad. Various factors affect OCT image quality. Somfai et al. [6] discuss common causes of poor quality OCT images: defocus, depolarization, and improper centering. OCT machines assess quality of images as a whole, reporting overall signal to noise ratio and signal strength.

V. SPECKLE NOISE IN OCT

In images of highly scattering biological tissues, speckle has a dual role as a source of noise and as a carrier of information about tissue microstructure. Speckle is the sparkling effect produced by the cross-interference of random phase fields. Speckle noise reduces contrast and makes boundaries between highly scattering structures in the tissue making it difficult to resolve. OCT images, as well as all other imaging modalities that involve a coherent light source, are affected by speckle noise. Speckle, arising from constructive and destructive interferences of the backscattered waves appears as a random granular pattern [7] that significantly degrades image quality and complicates further image processing tasks, like image segmentation and edge detection. In addition to the optical properties (like multiple scattering and distortion of the image because of the propagating light beam) and target motion, the speckle formation is also influenced by the physical parameters of the imaging device: size and temporal coherence of the light source and the aperture of the detector [8].

A. Characteristics of Speckle in OCT

The speckle characteristic, such as size is estimated as one value for the entire image or a plurality of values. The plurality of values each corresponds to the entire image or to the different regions in the entire image. For example, the speckle size is estimated locally. The estimation is performed separately for the same, smaller or larger regions as used for the local mean in identifying spatial transitions. The regions for estimation may overlap, but provide different, same or similar values for adjacent locations in the same frame of image data. The estimation is performed for the soft tissue regions, such as along parallel lines through the soft tissue regions. Distinct estimates with the same or different values are provided for different regions of medical image.

Speckle size or the other characteristic is calculated from the spatial transition. A single speckle size value is provided for each location, region or the entire image. More than one value may be provided, such as providing one or more speckle size values corresponding to analysis or estimation along two or more spatial directions or corresponding to different speckle size calculations. Where multiple values are provided, the multiple values are averaged or combined or are maintained separately. The adapted image processing applies to the image data is used to estimate the speckle characteristics. A feedback loop applies the image processing to the same data. Alternatively, the image processing adapts based on the image data is applied to the subsequent image data. As each frame of image data is input, the speckle characteristic from a previous, such as the immediately previous, frame of image data is used in image processing.

B. Speckle reduction techniques

Speckle reduction techniques fall into four main categories: polarization diversity, spatial compounding, frequency compounding and digital signal processing.

[a] Polarization diversity

Polarization diversity in OCT can be achieved simply by illuminating the sample with unpolarized light and interfering the back scattered light with an unpolarized reference beam. A limitation of this method is that, it increases the signal to noise ratio of a fully developed speckle pattern by a factor of √2 at most.

[b] Spatial compounding

In spatial compounding, the absolute magnitudes of signals derived from the same sample volume or slightly displaced volume are averaged to form a new signal with reduced speckle noise. It is essential that the signals add on a magnitude basis because the addition of the amplitude of signals derived from different speckle patterns does not improve the signal to noise ratio. The effectiveness of this approach depends on the number of signals averaged and their mutual coherence. An advantage of this approach is that, the number of detectors can be tailored for optimal separation of the signal carrying speckle from the signal degrading speckle.

[c] Frequency compounding

Frequency compounding, takes advantage of the reduced correlation between speckled images recorded within different optical frequency band. Reduction of speckle noise could be done adaptively by varying the compounding bandwidths of the recorded image. Thus frequency compounding may provide a means of distinguishing the signal carrying and signal degrading speckle.

[d] Digital Signal Processing

Digital signal processing in the complex domain can also be used to implement a form of adaptive frequency compounding. Post signal processing techniques have been reported, including a zero-amplitude procedure, deconvolution, and rotating kernel transformation. The zero-amplitude procedure ZAP, which operates in the complex number domain, shows speckle reduction in OCT images but blurs boundaries between tissue structures. Other complex-number domain processing methods applied to OCT include iterative point deconvolution and constrained iterative deconvolution. Deconvolution techniques require some prior knowledge of the point spread function of the imaging optics, as well as the optical properties of the imaged sample. The computation time of the rotating kernel transformation technique, applied by Rogowsk and Brezinski1 increases substantially with kernel size.

VI. CONCLUSIONS

OCT has provided ophthalmologists with depth resolutions in imaging the posterior and anterior segment of the eye, previously only achievable with histology. The recent development of very short coherence optical sources has impacted the in vivo imaging of microstructural morphology. Although scattering in the tissue affects the quality of OCT images, speckle reduction methods have been addressed by several investigators. Optical Coherence Tomography technique can be used to detect the eyelid cancer at the earlier stage.

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