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A Review on Development of a High Resolution Imaging System at 635 nm and 840 nm

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Abstract: This Optical Coherence Tomography (OCT) technique is a non-invasive technology used in medical as well as in non-medical applications. It is used to produce high resolution images. It provides the cross-sectional images of an sample in X & Y direction. It provides the depth as in millimeter range with the resolution in micrometer range. A broadband source of light is used so as to get the more bandwidth. The light beam is get splitted by the sample arm & reference arm respectively. An optical detector is used to detect the back-scattered light from the sample & reference arm. The matlab algorithm is used to process the signal. By moving the sample in X & Y direction, we can get the appropriate 2D & 3D images.

Keywords: OCT, non-invasive, resolution, broadband source, optical detector, MATLAB etc.

I. INTRODUCTION

Optical Coherence Tomography (OCT) is non-invasive imaging technique which is used to take cross sectional images of an object or sample in the depth direction. The resolution is in the micrometer range while the depth is in millimeter range. This technique is based on the Michelson Interferometer principle. OCT technique is similar to the Ultrasound sonography technique. The sound is used in ultrasound sonography while in OCT technique, the laser is used. OCT is based on a low coherence interferometry which uses a broadband light source to get more resolution. The shorter wavelength is used to get more resolution. The axial resolution is measure of how fine the structures can be resolved in a depth direction. The OCT technique can be used in several applications like ophthalmology, gastroenterology, dentistry, cancer diagnosis, cerebral blood flow detection, tumour margining etc. OCT performs cross sectional imaging by measuring magnitude & the echo time delay of backscattered light. Measuring the echo time delay of several reflections generates the axial scans (A-scans). This set of A-scans generates B-scans which is a 2-D image. Further, this set of B scans produces a 3-D image. The OCT systems can be classified as Time domain OCT, spectral domain OCT & swept source domain OCT. The spectral domain & swept source domain OCT techniques are more popular because of their fast acquisition time. The Zaber plates are used to scan an object in X & Y direction respectively. So that, a 2-D & 3-D image can be created by scanning the sample laterally as well as longitudinally. Here, mainly a broadband source is used to increase the axial resolution. The absorption is seen higher in biological samples. Matlab script is used to process the acquired data. The Magnetic Resonance Imaging (MRI) technique cannot resolve object smaller than 0.3 mm. The resolution achieved by using MRI technique is 10 to 100 micrometer. By using the ultrasound sonography, depth obtained is in a few centimeters and the resolution is 0.1 to 1 mm. The high frequency ultrasound of 50 MHz gives resolution upto 20 micrometer while the ultrasound with 100 MHz frequency provides resolution upto 15 to 20 micrometer. The resolution of the computed tomography (CT) scan image is 50 micrometer. By using this OCT technique, we get resolution upto 1 to 15 micrometer while the penetration depth is upto 1 to 3 millimeter. The setup of Michelson Interferometer consists of a broadband laser source, a beam splitter, a sample & a reference arm and a photo-detector. A beam splitter is used in a bulky optical source while a coupler is used in the case of optical fiber. The light beam gets split by the beam splitter & one ray of light falls on sample arm while the other on the reference arm. Some amount of incident light is get absorbed & some get reflects back from the sample arm. The light reflected from the sample and reference arm return back to beam splitter & both waves interferes with each other. So that an interference pattern is formed which is detected at optical detector. Then this data of interference spectrum is processed by using Matlab script, so that we get A-scan image & further the B- scan image is formed by using multiple 'A' scan data.

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II. LITERATURE SURVEY

A. Applications of dental optical coherence tomography (OCT) in oral tissue images, caries, periodontal disease and oral cancer

Yao-Sheng Hsieh et al., [1] described the applications of dental optical coherence tomography (OCT) in oral tissue images, caries, periodontal disease and oral cancer. The background of OCT, including basic theory, system setup, light sources, spatial resolution and system limitations, is provided. The comparisons between OCT and other clinical oral diagnostic methods are also discussed.

B. Near-infrared imaging of dental decay at 1310 nm wavelength

Daniel Fried et al., [2] described the near-infrared imaging of dental decay at 1310 nm wavelength. The various NIR imaging methods are described in this paper. Carious lesions were visible in the NIR with high contrast and can be viewed from multiple surfaces to aid in diagnosis. These studies indicate that the NIR imaging may offer significant advantages over the conventional visual, tactile and radiographic caries-detection methods.

C. Optical coherence tomography—principles and applications

Wolfgang Drexler [3] described ultrahigh-resolution OCT system with number of experimental results and images. He also explained State-of-the-art-light sources that permitted ultrahigh-resolution OCT, covering the whole wavelength region from 500 to 1600 nm, which were reviewed, and fundamental limitations of OCT image resolution were discussed. He also compared ex vivo ultrahigh-resolution OCT tomograms with histological results, He presented first clinical in vivo ultrahigh-resolution OCT and preliminary spectroscopic OCT results and their impact for future clinical and research applications.

D. Signal Processing Overview of Optical Coherence Tomography Systems for Medical Imaging

Murtaza Ali and Renuka Parlapalli [4] described signal processing overview of OCT systems for medical imaging. This paper gives brief idea about the signal and image processing of OCT images.

E. Optical design of a scanner for OCT system

Mohammad Kamal et al. [5] described optical design of a scanner for OCT system. They report an optical design of a line focused forward-viewing OCT scanner for high-speed endoscopic imaging. In this work, a feasibility study was carried out on the use of a reflective-optics-focused line scanner in OCT imaging, instead of the traditional refractive optics scanner.

F. Theory of Optical Coherence Tomography

J.A. Izatt and M.A.Choma [6] describes theory of OCT with mathematical modelling. This paper brief theory of each OCT system and their theoretical results.

G. Experimental setup of fourier domain OCT system

Branislav Grajciar et al., [7], described experimental setup of fourier domain OCT system. They presented a parallel Frequency Domain OCT (FD-OCT) system and the first in vivo tomograms obtained with such system. They also mentioned structure, which was free of any motion artifacts, since the transverse as well as the depth information was obtained in parallel. They also compared the transversal resolution for a thermal light source with an SLD.

H. Recent advances in OCT for the diagnoses of lung disorders

Randy Hou et al., described [8] recent advances in OCT for the diagnoses of lung disorders. They also discussed the current uses of OCT, its potential applications, as it relates to specific pulmonary diseases, and the future directions for OCT.OCT using frequency sweeping source had a sensitivity of 88 dB and axial resolution of 8.3 µm.

I. OCT as an emerging technology for biomedical and biopsy for performing high-resolution imaging

James G. Fujimoto and Costas Pitris's [9] was the important and first paper which described OCTs technology. It described OCT as an emerging technology for biomedical and biopsy for performing high-resolution imaging. This paper also compared different biomedical imaging technologies such as Ultrasound imaging, Confocal microscopy and described the basic principal of OCT.

J. SD-OCT System for glaucoma imaging and compared result of SD-OCT system with TD-OCT system

Joel S. Schuman [10] described Spectral Domain OCT in this paper. This paper drew various differences between TD-OCT, SD-OCT and SS-OCT. It explained SD-OCT for glaucoma imaging and compared result of SD-OCT system with TDOCT system. This paper gave brief history of OCT. It also described different OCT systems such as TDOCT, SD-OCT, SS-OCT and their resolutions.

K. Ultrahigh resolution optical coherence tomography for in vivo endoscopic imaging system

P. R. Hem et al., [11] described Ultrahigh resolution optical coherence tomography for in vivo endoscopic imaging of the rabbit and axial resolution of their OCT system which is 4 micron.

L. OCT system for Ophthalmic imaging

Michael R. Heel et al., [12] described use of OCT system for Ophthalmic imaging which gave micron scale resolution. This paper describes fiber optic OCT scanner, which was part of SD-OCT system.

M. Ultrahigh resolution of OCT system with image enhancement technique by speckle noise reduction

W. Drexler et al., [13] described ultrahigh resolution of OCT system with image enhancement technique by speckle noise reduction. This paper also mentioned edge detection technique of OCT image by comparing it with ultrasound imaging technique.

N. Evaluation of the process of spectral shaping of the BBS output into spectral windows

Ramona Cernat et al., [14] reported investigations into the spectral shaping of an optical broadband source (BBS) which provided through a combination of highly non-linear components with light from 450 nm to 1750 nm in an all fiber configuration. In this paper evaluation of the process of spectral shaping of the BBS output into several spectral windows using two methods: an optical filter and a double-pass prism sequence (a cube beam splitter (BS), two equilateral prisms and a metallic mirror) were done.

O. Analysis of the imaging contrast limits on a single-mode fiber OCT system

Yingtian Pan et al., [15] described analysis of the imaging contrast limits, which was performed, on a single-mode fiber OCT system. This paper mentioned experimental setup for the same. It also gives the fundamental difference between time-resolved and coherence-gated imaging modalities in scattering media, which was analyzed in terms of their optical transfer functions.

P. Applications of OCT for different imaging techniques

W.Drexler, James G. Fujimoto [16] described OCT technology including basic principle of OCT, signal processing of OCT, and different techniques of spectral noise removal. Applications of OCT for different imaging techniques like dermatology, dentistry, and ophthalmology. It also contain data analysis of OCT signal as well as all theoretical and mathematical analysis of OCT signal and Fourier domain OCT system. It also explained different types of OCT systems and their advantages and disadvantages.

Q. Developments in optical coherence tomography (OCT) for three-dimensional non-invasive imaging

Tomlins and Wang [17] reviewed the developments in optical coherence tomography (OCT) for three-dimensional non-invasive imaging. A number of different OCT techniques were discussed in some detail including time-domain, frequency-domain, full-field, quantum and Doppler OCT. A theoretical treatment was given and some relevant comparisons were made between various implementations. The current and potential applications of OCT were discussed, with close attention paid to biomedical imaging and its metrological issues.

R. Extraction of tissue optical properties from OCT images for diagnostic purposes

Lars Thranea, et al., [18] described extraction of tissue optical properties from OCT images for diagnostic purposes. Analytical and numerical models for describing and understanding the light propagation in samples imaged by OCT systems were presented in this paper. They also derived an algorithm for extracting tissue optical properties for multi-layered tissues. The algorithm was first verified for various optical properties and geometries using numerical simulations. The applicability of the algorithm for extraction of tissue o
ptical properties was then demonstrated for vascular tissue samples ex vivo.

S. Basic properties of an OCT system

Michael H. Frosz et al., [19] described the basic properties of an OCT system, such as coherence and interference are presented. A 1.3µm light source and a 1.5µm source is examined and used in OCT imaging for comparison of penetration depth. No improvement was shown with the 1.5µm system, but was expected theoretically. A simple inexpensive 1.5µm source was also examined for use in OCT, and shows promising results, based on a spectral analysis. They also measured the noise and SNR experimentally for a given system.

T. Development of a reflective optics-based line-scan spectral domain OCT system for high-quality three dimensional imaging

Mohammad Abu Hana Mustafa Kamal [20] describes development of a reflective optics-based line-scan spectral domain OCT system for high-quality three dimensional imaging. He used cylindrical mirror for focusing to eliminate

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chromatic aberration and provides a flat scan field. He used line scanning to reduce the requirement of scanning to one axis and thereby making the image acquisition faster. He mentioned a novel reflective optics based line-scanning system with a spectrometer which was designed, and also the scanning system had been verified experimentally.

U. Processing of SD-OCT data with the non-uniform fast Fourier transform (NFFT)

Kenny K. H. Chan and Shuo Tang [21] described the processing of SD-OCT data with the non-uniform fast Fourier transform (NFFT) which could improve the sensitivity fall-off at maximum depth by greater than 5 dB concurrently with a 30 fold decrease in processing time compared to the fast Fourier transform with cubic spline interpolation method. They also compared processing speed of different algorithm techniques such as NDFT, which improved the sensitivity fall-off, but its processing speed is slow and cannot perform real-time imaging. The NFFT can significantly improve the image processing speed while maintaining the same sensitivity fall-off as NDFT.

V. Effects of dispersion and absorption in ultrahigh-resolution OCT

Timothy R. Hillman and David D. Sampson [22] described and examined the effects of dispersion and absorption in ultrahigh-resolution OCT, particularly the necessity to compensate for high dispersion orders in order to narrow the axial pointspread function envelope. They presented a numerical expansion in which the impact of the various dispersion orders was quantified, absorption effects were evaluated numerically. Assuming a Gaussian source spectrum (in the optical frequency domain), they focus on imaging through water as a first approximation to biological materials. Apart from this they also mentioned theory of OCT system and mentioned some results.

W. Development of a swept laser at 1.7 µm wavelength and conducted OCT or optical frequency domain imaging (OFDI)

Utkarsh Sharma et al., [23] developed a wavelength swept laser at 1.7 µm wavelength and conducted OCT or optical frequency domain imaging (OFDI) for the first time in this spectral range. The constructed laser was capable of providing a wide tuning range from 1.59 to 1.75 µm over 160 nm. When the laser was operated with a reduced tuning range over 95 nm at a repetition rate of 10.9 kHz and an average output power of 12.3 mW, the OFDI imaging system exhibited a sensitivity of about 100 dB and axial and lateral resolution of 24 µm and 14 µm, respectively. They imaged several biological samples using 1.3 µm and 1.7 µm OFDI systems and found that the depth-dependent signal decay rate was substantially lower at 1.7 µm wavelength in most. Their results suggested that this imaging window may offer an advantage over shorter wavelengths by increasing the penetration depths as well as enhancing image contrast at deeper penetration depths where otherwise multiple scattered photons dominated over ballistic photons.

X. Implementation of endoscopic OCT system

A. M. Sergeev et al., [24], described implementation of endoscopic OCT and materials used for the same. They mentioned results of endoscopic applications of OCT for in vivo studies of human mucosa in respiratory, gastrointestinal, urinary and genital tracts that were presented in this paper. They created a novel endoscopic OCT (EOCT) system which was based on the integration of a sampling arm of an all-optical fiber interferometer into standard endoscopic devices using their biopsy channel to transmit low coherence radiation to investigated tissue. They had studied mucous membranes of esophagus, larynx, stomach, urinary bladder, uterine cervix and body as typical localization for carcinomatous processes. They also recorded and analyzed images of tumor tissues versus healthy tissues and they successfully saw violations of well-defined stratified healthy mucosa structure in cancerous tissue by EOCT, thus making this technique promising for early diagnosis of tumors and precise guiding of excisional biopsy.

Y. Line-field SD-OCT (LF-SDOCT) using parallel SD-OCT technique for 3D metal surface profiling and skin investigation

Yoshifumi Nakamura et al., [25], demonstrated line-field SD-OCT (LF-SDOCT) using parallel SD-OCT technique for 3D metal surface profiling and skin investigation. In this study, they optimized LF-SDOCT for an in vivo 3D retinal imaging. By optimizing the camera integration time for the sample motion, the in vivo 3D human retinal structure was visualized at very high-speed, and the resulting images were sufficiently free of motion artifacts. This was the first demonstration of the visualization of in vivo 3D retinal imaging by LF-SDOCT technique.

Z. Dermatological investigation by three-dimensional line-field fourier domain OCT

Yoshiaki Yasuno et al., [26] describes dermatological investigation by three-dimensional line-field fourier domain OCT. They demonstrated three-dimensional OCT using only one dimensional mechanical scanning. They also explained their system uses the principle of fourier domain OCT for depth resolution, one-dimensional imaging for lateral vertical resolution, and mechanical scanning by a galvanometer for lateral horizontal resolution. They also investigated in vivo human finger pad three-dimensionally.

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III. CONCLUSION

The comprehensive survey of OCT technology has been studied. The literature survey provides the various applications of OCT technique in various fields. The optical coherence tomography technique has its applications in several areas like ophthalmology, dentistry, surgical guidance for tumour, dermatology, cancer diagnosis, microlayer diagnosis of a biological & non-biological object. The signal processing algorithm is done using Matlab algorithm. It is seen that in many researches, the SD-OCT system has been used because of its high data acquisition speed. Now-a-days, the swept source OCT technique is also been used in many applications. The scanning mechanism can be improved by employing circulators in the B-scan setup.

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BIOGRAPHIES

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