UNIVERSITY OF MORATUWA, SRI LANKA
Faculty of Engineering
Department of Electronic and Telecommunication Engineering
Semester 5 (Intake 2020)

BM3122 - Medical Imaging

Optical Coherence Tomography (OCT)

AMARASEKARA A. T. P.
200023C

Abstract

Optical Coherence Tomography (OCT) has seen significant growth in medical applications, enabling non-invasive, real-time imaging and analysis of human tissues. This report thoroughly explores the operational fundamentals, versatile applications, and essential quality assurance protocols applicable to OCT technology within the medical sector.

Table of Contents

1. Introduction

Optical Coherence Tomography (OCT) is a medical imaging technology, used to visualize and understand biological tissues. Incorporating light waves, OCT enables the acquisition of detailed two- and three-dimensional cross-sectional images of biological structures with micrometer-level precision. In recent years, OCT has been used in diverse medical applications, offering non-invasive, high-resolution imaging that has transformative implications for diagnosis, treatment, and research.

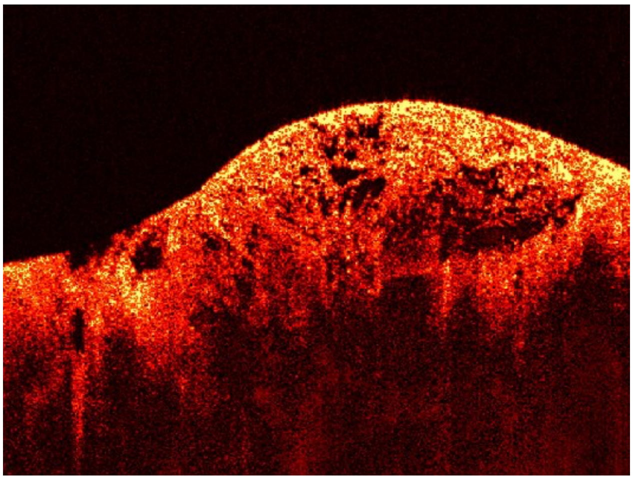

Fig 1 – OCT image of a sarcoma

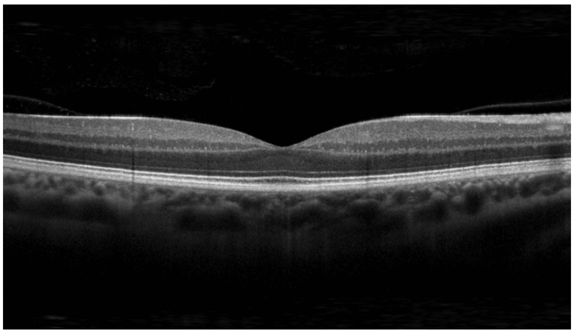

Fig 2 – A normal, healthy macular OCT image

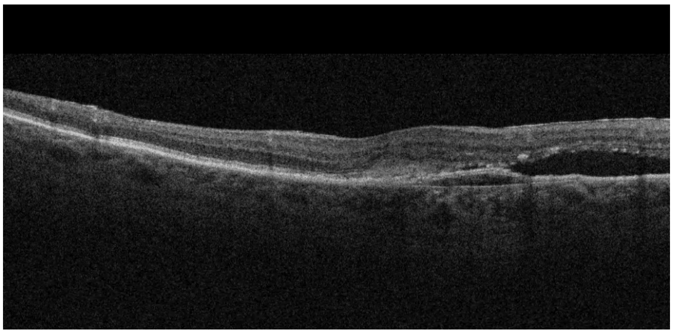

Fig 3 – Wet age-related macular degeneration

Gif 1 – 3D Optical Coherence Tomogram of a fingertip

2. Principle of Operation

There are two main methods of Optical Coherence Tomography, Time Domain (TD-OCT) and Spectral Domain (SD-OCT). SD-OCT is particularly interesting as it simplifies depth scanning, a task that TD-OCT usually accomplishes using mechanical means. SD-OCT can be implemented in two ways: spectrometer-based (SB) or by using a tunable laser or a swept source (SS). Each method, SB-OCT or SS-OCT, has its own strengths and weaknesses. The resolution achieved depends on the optical source's bandwidth in TD-OCT and SB-OCT, and on the tuning bandwidth in SS-OCT.

2.1 Time Domain OCT (TD-OCT)

In TD-OCT, a setup involves an optical source and an interferometer, which includes components like a Reference Mirror and an optical Splitter. These elements create a reference beam. Light from the Splitter travels to the Object to be examined and then to a Processing Unit. This Processing Unit handles the interference of light between the reference beam and the beam sent back by the Object. It also processes and analyzes the interference signal.

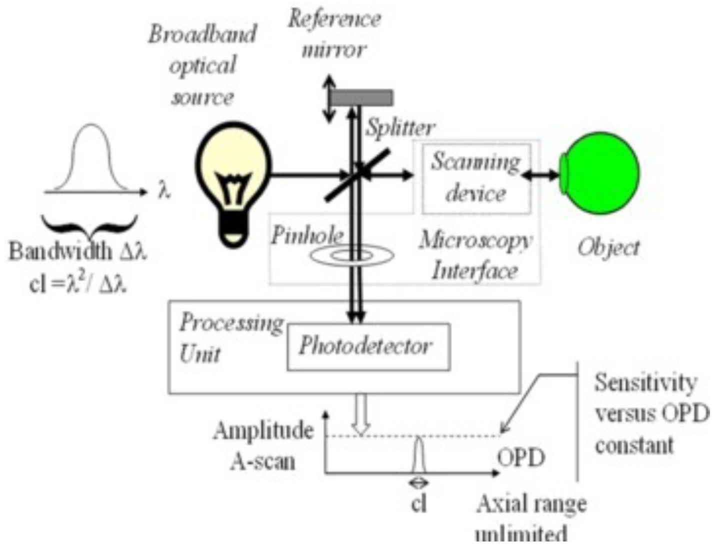

Fig 2 – TD-OCT Setup

The key concept here is partial coherence interferometry which works utilizing the different layers of the object at different depths, as shown in Figure 3. Each layer reflects light back, but with a time delay. By moving the Reference Mirror, you can select the layer that matches the reference beam in terms of timing. When this happens, you get a strong signal of interference, indicating that the Object's depth matches the reference path length. By scanning this optical path difference (OPD), TD-OCT produces a depth profile called an A-scan. Repeating this process for different lateral positions gives you a cross-sectional image known as a B-scan. This method is called longitudinal (or axial) TD-OCT.

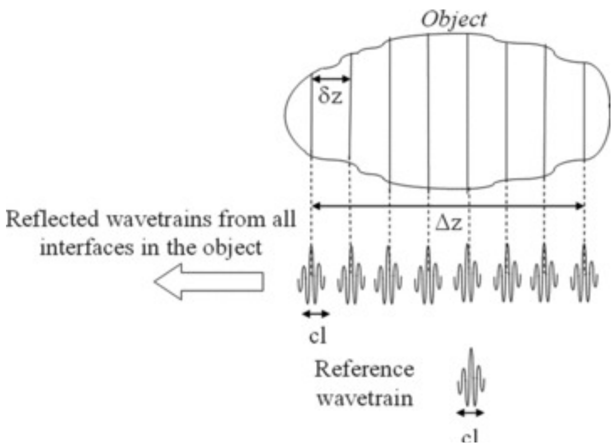

Fig 3

Another version of TD-OCT is *en face* OCT. It's based on one-dimensional reflectivity profiles (T-scans), collected by moving the light spot laterally while keeping the axial coordinate constant (Reference mirror at rest). This setup can generate a C-scan (constant depth) image in real time.

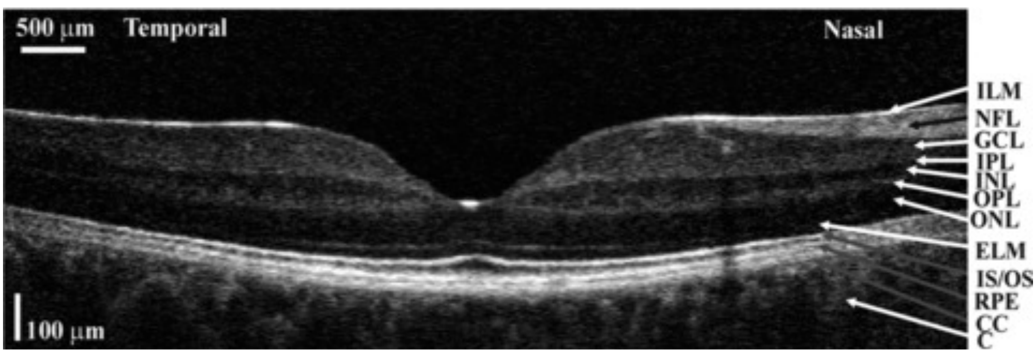

Fig 4 – Cross-section image of the retina using an *en face* time domain OCT system

2.2 Spectral Domain OCT (SD-OCT)

SD-OCT, on the other hand, involves spectral interference of the spectrum at the interferometer's output. There are two possibilities, SB-OCT and SS-OCT.

In SB-OCT, a broadband optical source is used, and a spectrometer processes the spectrum which is usually built using a prism or a linear photodetector array. The spectrum exhibits peaks and troughs, and the number of peaks corresponds to the OPD in the interferometer. A fast Fourier transform of this signal translates the spectrum's periodicity into depth information, giving an A-scan profile.

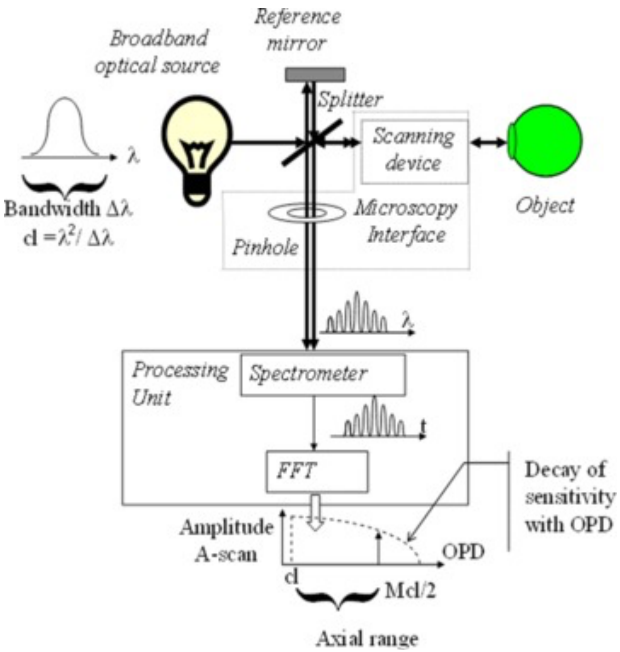

Fig 5 – SB-OCT Setup

SS-OCT uses a tunable laser, and a Photodetector similar to TD-OCT. In this case, the laser line must be much narrower than the spectral distance between adjacent peaks. The photodetected signal is transformed using a fast Fourier transform to produce an A-scan profile.

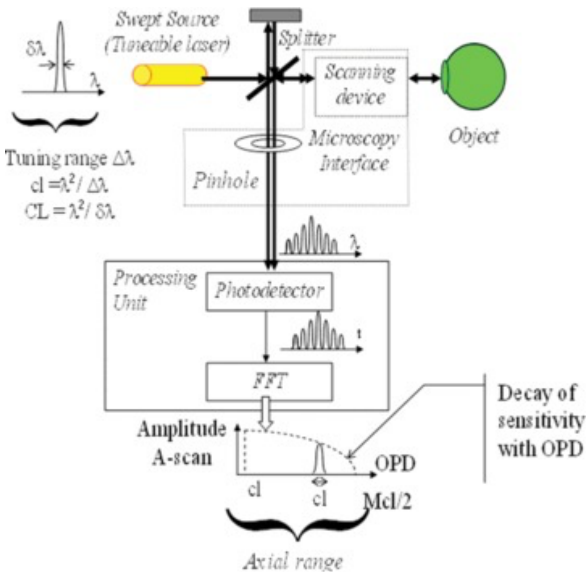

Fig 6 – SS-OCT Setup

SB-OCT became popular for retina imaging because of its sensitivity and fast digital linear cameras. In contrast, SS-OCT is known for its extremely fast scanning speed, making it suitable for high-quality *in vivo* imaging of tissue.

3. Applications in Medical field

3.1 Ophthalmology

Optical Coherence Tomography (OCT) has had a significant impact on the field of ophthalmology by providing high-resolution, non-invasive imaging of the retina, retinal nerve fiber layer (RNFL), and the optic nerve head.

3.1.1 Age-related Macular Degeneration (AMD)

AMD eyes exhibit thinner choroids, and the correlation between age and choroidal thickness is significant. Choroidal thickness analysis can help differentiate neovascular AMD from conditions like central serous chorioretinopathy (CSCR) and polyploidal choroidal vasculopathy (PCV).

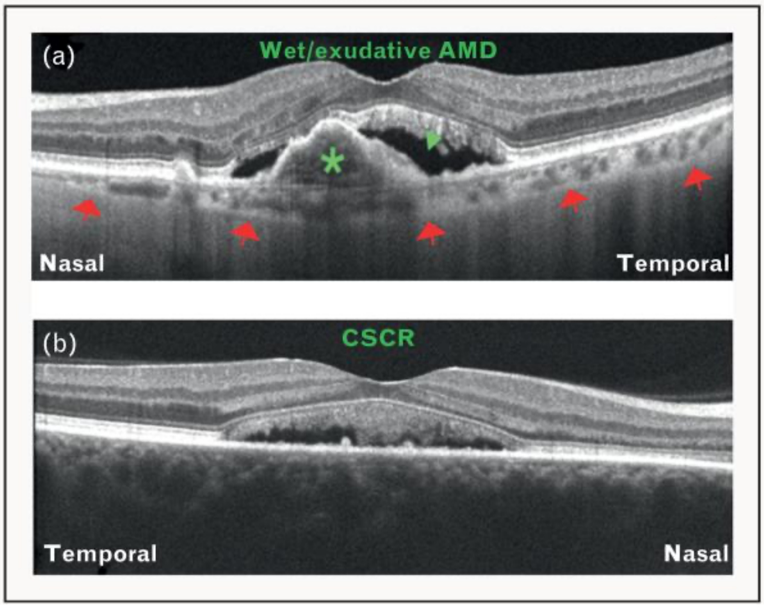

Fig 7 – Differentiation of diseases using choroidal thickness as a parameter

3.1.2 Diabetic Retinopathy

Diabetic retinopathy is the leading cause of visual impairment in working-age adults worldwide. Choroidal thickness analysis using SD-OCT can assess disease severity in diabetic retinopathy, particularly in cases with proliferative diabetic retinopathy(PDR) and diabetic macular edema(DME).

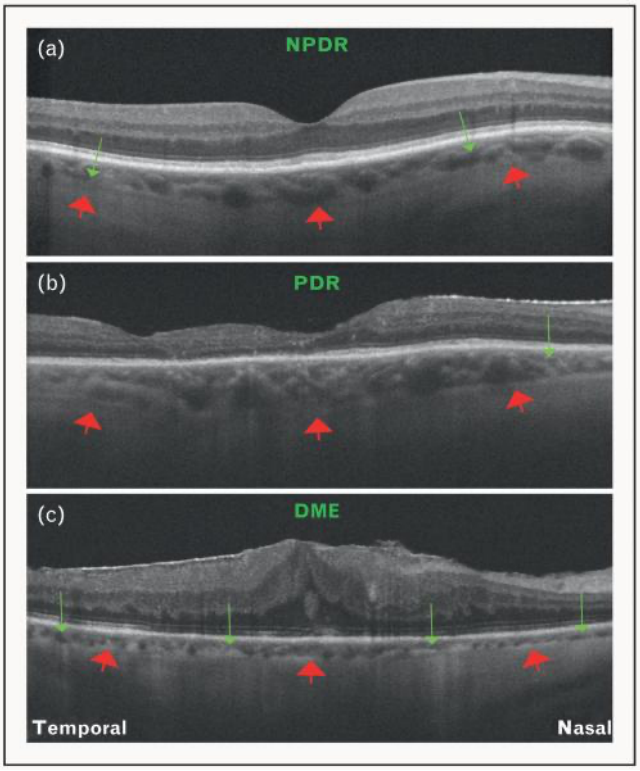

Fig 8 – OCT features of diabetic retinopathy

3.1.3 Intraocular Tumors

SD-OCT enables the characterization of intraocular tumors, including choroidal melanomas, nevi, and osteomas. It helps delineate tumor borders and analyze blood vessels within tumors.

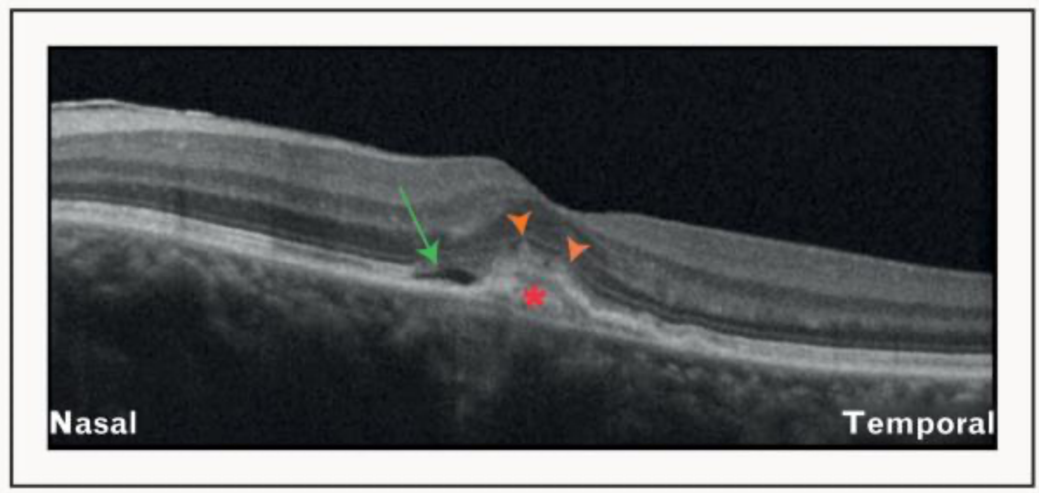

Fig 9 - OCT features of an eye with choroidal osteoma

3.2 Cardiac Catheterization

In addition to its applications in the field of ophthalmology, OCT is used during interventions like angioplasty, where cardiologists use a small balloon attached to a catheter to clear blockages in coronary arteries. OCT allows cardiologists to see the inside of an artery in 10 times more detail than an intravascular ultrasound. Cardiologists are able to view the placement of the stent and if the stent is correctly holding the artery open. Also, OCT allows accurate measurements of vessel dimensions before and after stent placement. This precision ensures that stents are appropriately sized to match the vessel's diameter and length, optimizing the intervention's success.

3.3 OCT in Dermatology

Optical Coherence Tomography is a valuable imaging technique in dermatology, offering non-invasive visualization of skin layers. OCT provides detailed images of the epidermis, dermal-epidermal junction, and dermis, making it useful for various dermatological applications including, penile lesions, acne lesions, basal cell carcinoma and systemic sclerosis.

3.4 OCT in Gastroenterology

Optical Coherence Tomography aids in diagnosing and categorizing gastrointestinal diseases, providing high sensitivity and specificity for conditions like celiac disease, esophageal carcinoma, and Barrett's adenocarcinoma. Additionally, OCT guides surgical procedures, minimizing risks during operations for conditions like achalasia and improving the assessment of tissue changes post-treatment in Barrett's esophagus.

4. Quality Assurance in Clinical OCT

Quality assurance (QA) methods for Optical Coherence Tomography (OCT) systems in medicine are essential to ensure the accuracy, reliability, and safety of OCT imaging for diagnostic and research purposes.

Calibration and Standardization:

- Regularly calibrate the OCT system using appropriate artificial optical samples or phantoms and standards to ensure accurate measurements.
- Establish and maintain standardized imaging protocols to ensure consistency in image acquisition.

Performance Verification:

- Conduct routine performance verification tests to assess the system's stability and accuracy.
- Test the system's axial and lateral resolution using appropriate targets.

Image Quality Assessment:

- Evaluate image quality parameters such as signal-to-noise ratio (SNR), contrast, and spatial resolution.
- Use test objects with known optical properties to assess the system's imaging performance.

Quality Control Protocols:

- Develop and implement quality control protocols to monitor the performance of the OCT system over time.
- Regularly check and document key parameters such as light source power, beam alignment, and detector sensitivity.

Image Artifacts Detection:

- Identify and mitigate common image artifacts such as motion artifacts, speckle noise, and shadowing.
- Develop software tools or algorithms to automatically detect and correct artifacts when possible.

Operator Training:

- Ensure that operators are adequately trained in OCT imaging techniques and system maintenance.
- Provide ongoing training to keep operators updated on best practices.

Data Management and Archiving:

- Establish a robust data management system for storing and retrieving OCT images and associated patient information securely.

References

1. Optical Coherence Tomography – Wikipedia
2. Optical Coherence Tomography - NLH
3. What is Optical Coherence Tomography (OCT)?
4. OCT Application
5. OCT during cardiac catheterization
6. Application of OCT