Celebrating the Year of Light….. from medicine to security with Optical Coherence Tomography

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Optical Coherence Tomography

Light based techniques are becoming increasingly popular because they offer noninvasive methods of detection or treatment and can be adapted to more than one application. One such technique is Optical Coherence Tomography (OCT) which can
be used to detect skin cancer or as a forensic device. OCT is a 'young' technique that has made significant strides since it was first reported by in 1991 by Huang[1] and can currently be seen in use for eye examinations by some South African ophthalmologists.

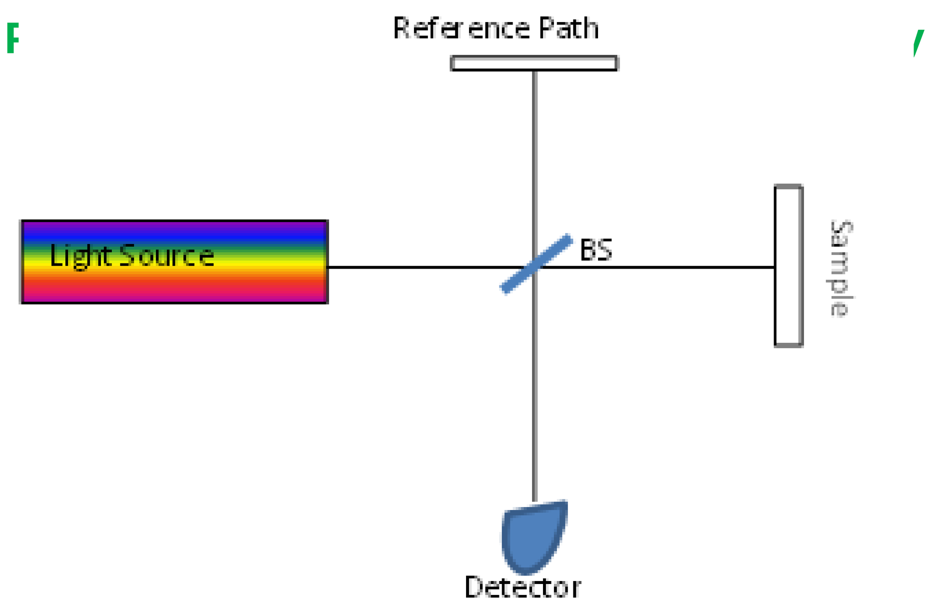
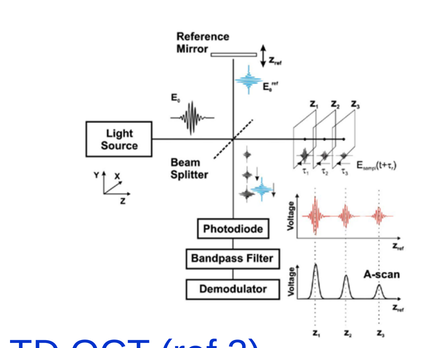
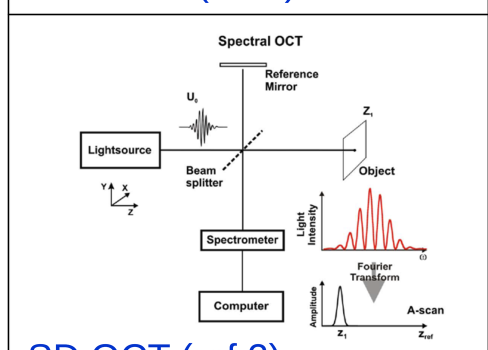
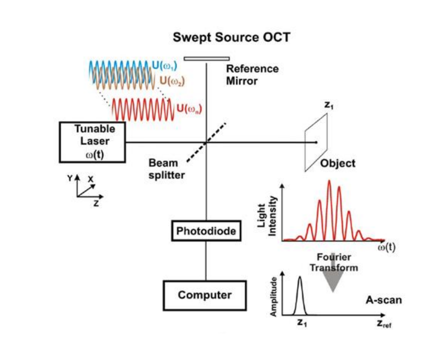


Figure 1: General schematic representing OCT principle

- OCT is often described as the optical analogue to ultrasound.
- The back scattered light cannot be measured electronically due to the high speed of light- OCT uses the technique of low coherence interferometry.
- A broadband or tunable light source is split between a sample and a reference mirror (reference path). When the difference between the distance travelled for the light and sample and the reference path is within the coherence length of the light then interference will occur at the detector.
- OCT measures the echo time delay and intensity of backscattered light. The depth (axial) resolution is dependent on the spectral bandwidth of the light source, the broader the bandwidth, the lower the coherence length and the higher the depth resolution.

Types of OCT systems

There are a few different configurations of OCT, all based on the same principle i.e Time Domain (TD) OCT and Fourier Domain (FD) OCT obtains A-scans with a fixed reference mirror and measures the spectral response of the interferogram. The interferogram is encoded in optical frequency space and undergoes a fourier transform to yield the reflectivity profile of the sample.

 TD OCT (ref 2)	**Time Domain (TD) OCT**-A-scans are acquired by scanning the reference mirror back and forth to match different depths in the sample to within the coherence length of the light source.
 SD OCT (ref 2)	**Spectral Domain (SD)** requires a broadband lightsource for illumination and separating the spectral components with a spectrometer. (**FD OCT**)
 SS OCT (ref 2)	**Swept Source (SS) OCT** uses a light source which probes the sample with different optical frequencies sequentially (swept source). The power is then measured with a single photo detector. (**FD OCT**)

Designing/Choosing an OCT system

Buying or building an OCT system depends on the application and need. End users such as ophthalmologists will opt to buy whereas researchers often opt to build their own system which gives flexibility in terms of data acquisition, final appearance, system modifications as required. However a few factors need to be considered.

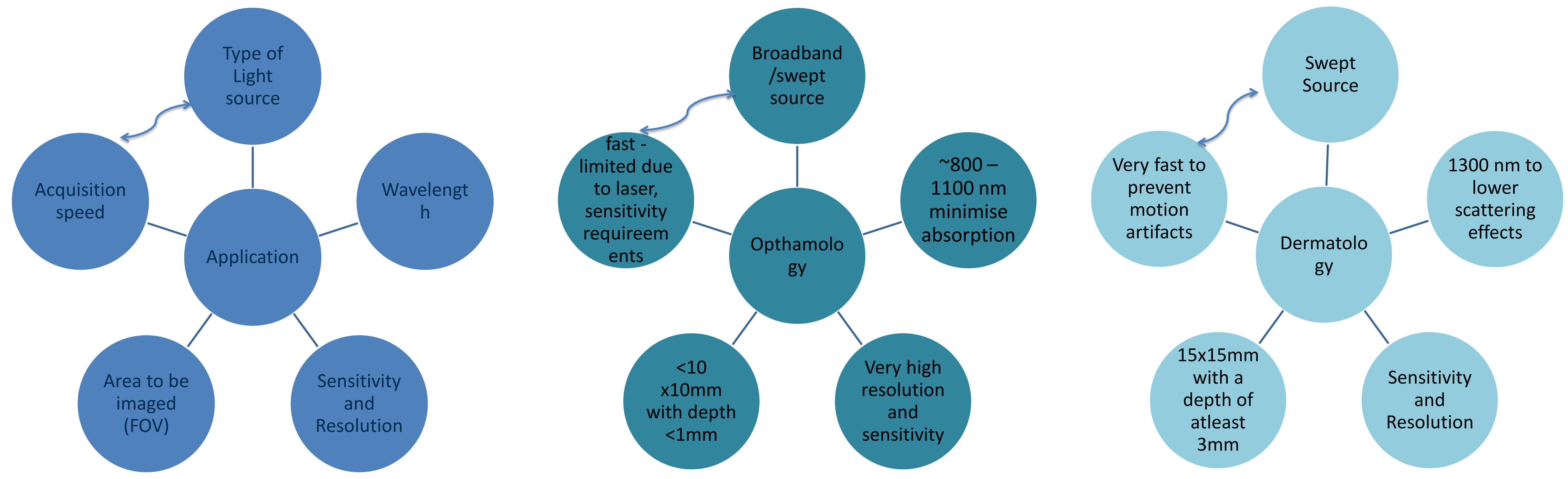


Figure 2: Schematic indicating parameters to consider when buying/building an OCT system

Factors affecting resolution, speed and imaging depth of OCT system

Acquisition Speed – is affected by the configuration chosen, scan rate and area/volume to be imaged. TD OCT is the slowest due to the moving reference mirror. For FD OCT the scan rate depends on the laser sweep rate (SS OCT) and the camera speed of the detection spectrometer (SD OCT). There is a trade off between higher scan rate and the system sensitivity, however high scan rates reduce motion artefacts. Finally the larger the area/volume imaged, the lower acquisition speed although in theory a 200 kHz swept source could acquire a 15x15x3mm scan in <2s.

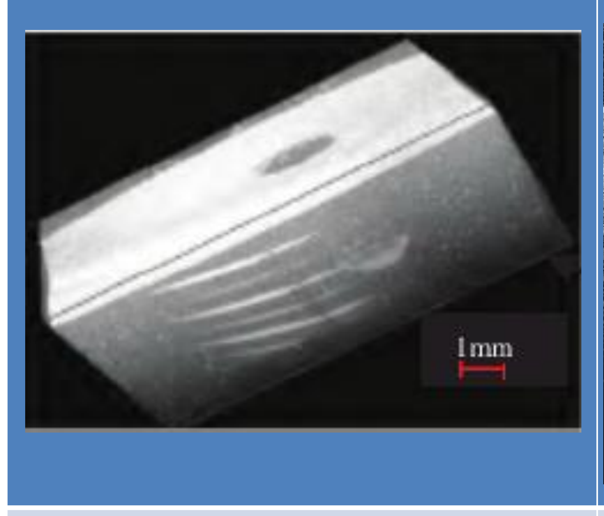
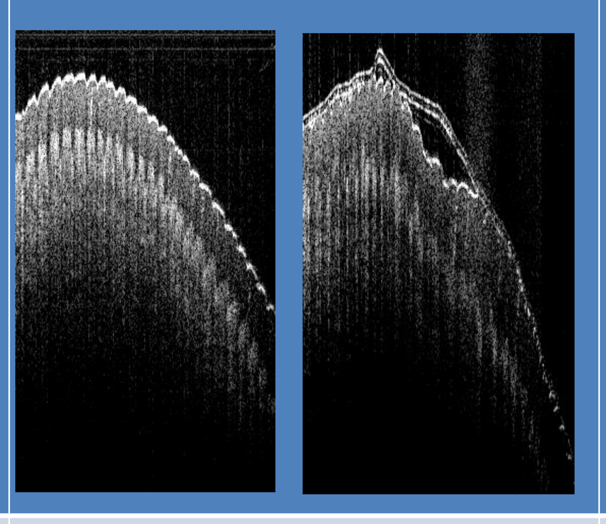
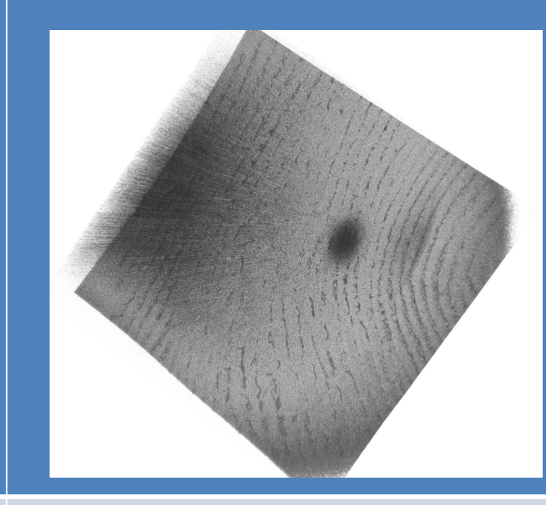
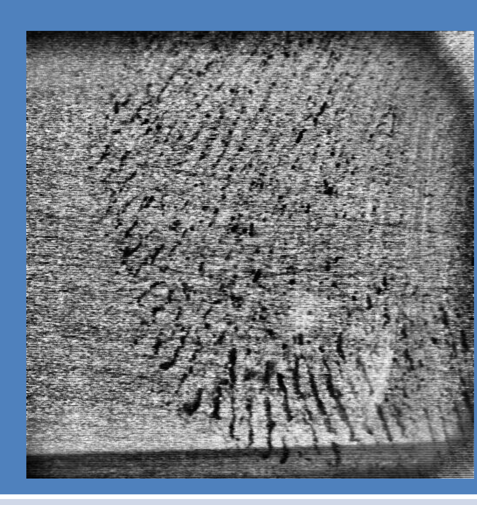
Resolution – the axial (depth) and lateral (XY) resolution is separated in OCT.

Axial – depends on the coherence length of light source. $\Delta_z = 0.44\left(\frac{\lambda_0^2}{\Delta\lambda}\right)$=0.44	Lateral – depends on the optics used. $\Delta_x = \left(\frac{4\lambda_0}{\pi}\right)\left(\frac{f_{obj}}{d}\right)$=0.37$\left(\frac{\lambda_0}{NA}\right)$ where $NA = n\left(\frac{D}{2f}\right)$
So for a wavelength of 1300 nm and a coherence length of 100 nm $\Delta_z = 0.44\left(\frac{1300mm*1300mm}{100nm}\right)$=7.44µm in theory	So for a wavelength of 1300 nm, a refractive index of 1, pupil size of 8 mm and focal length of 110 mm Δ_x=0.37$\left(\frac{1300nm}{1\left(\frac{8mm}{2*110mm}\right)}\right)$ =13µm in theory

Imaging depth is affected by the laser chosen, the optics used as well as the optical properties of the sample.

Application areas

OCT has been applied to many different areas such as biomedical imaging, polymers, material science, security with some studies in detection of artwork and jewellery. An interesting area of application is in forensics and the detection of latent fingerprints[3]. To date possibly only 1 or 2 papers have looked at this application. We have successfully been able to extract latent fingerprints from paper, glass and plastic. These included naked fingerprint impressions left on the substrates as well as impressions left using used motor oil and vaseline.

			
Phantom illustrating use of OCT for non-contact surface analysis of material or depth detection of defects	Deciphering between real and fake fingerprints	Latent lifted from paper	Latent lifted from plastic

References:

1. Huang D, et al. "Optical coherence tomography," Science 254(5035):1178–1181 (1991)
2. Maciej Wojtkowski, "High-speed optical coherence tomography: basics and applications," Appl. Opt. 49, D30-D61 (2010)
3. R. Khutlang, A. Singh, F.V. Nelwamondo, "Segmentation of Forensic Latent Fingerprint Images Lifted Contact-less from Planar Surfaces with Optical Coherence Tomography," CFSE 2015: The 7th IEEE International Workshop on Computer Forensics in Software Engineering, Taichung, Taiwan, (July 1-5, 2015)
4. K.V. Larin, Y. Cheng, "Artificial fingerprint recognition by using optical coherence," Appl. Opt. 45 (36) , 9238-9245 (2006)