SFU FACULTY OF SCIENCE

Lab Report

ENSC 477 - Biomedical Image Acquisition

Lab 2

Group 9

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Introduction:

Computed tomography (CT) is a medical imaging technique which reconstructs the density of the particular body part by calculating the attenuation coefficient of the emitted x-ray beams. The different combinations of x-ray measurements taken from different angles produce slice images, a group of cross-sectional images create a 3D representation of the body part.

Optical imaging uses long wavelength light, unlike x-rays, which is ionizing radiation that can be harmful if used in large dosage. Optical coherence tomography (OCT) is an imaging modality which is an optical analog of an ultrasound, it uses light instead of sound.

Visible light is often delivered to illuminate the tissue during endoscopic procedures. The red light penetrates through the epithelium and scatters back (diffuse reflectance). The blue light goes deeper through the stroma, where fluorescence is added along with the scattering, the intensity of the light coming back from the tissue is measured to study the biochemical properties of the tissue.

Part 1: Comparing Photons from Different Imaging Techniques

Discussion

Region of the Spectrum	Photon Energy [eV]	Wavelength [m]	Frequency [Hz]
Diagnostic X-rays	12.4e3 - 124e3	100e-12 – 1e-12	3e18 – 3e19
Visible Light	1.77 - 3.1	700e-9 – 400e-9	4.3e14 - 7.5e14
Near-Infrared Light (NIR)	0.496 – 1.24	2.5e-6 – 1e-6	1.24e14 - 3e14

Table 1. *The EM Spectrum*

The electromagnetic spectrum can be characterized by wavelength. Since all light travels at the same speed in a vacuum, the frequency of a light wave is calculated by dividing the constant c (the speed of light in a vacuum) by the wavelength of the light wave.

Photon energy is determined from the Planck-Einstein relationship[1], which relates the energy of one photon to the frequency of the wave multiplied by Planck's constant h.

[1] https://en.wikipedia.org/wiki/Photon_energy#:~:text=Photon%20energy%20is%20the%20energy,frequency%2C%20the%20higher%20its%20energy

The properties of Diagnostic X-rays and Visible Light are well defined, but Near-Infrared Light is not. Commonly, it refers to only the lowest wavelengths of the Infrared Spectrum which have the highest photon energy[2].

Visible and NIR light have low energies yet can penetrate through the soft tissues on the surface. Due to different properties of molecules, light is absorbed and scattered differently, therefore tissues are easily distinguished from one another. However, x-rays can pass deeper through the body, because of the higher energy that ionizes the atoms with Compton and photoelectric effects.

Part 2: Optical Coherence Tomography

Method

The OCT system uses a broadband light source which is split before the light waves hit the sample. One part of the beam reflects off the sample, and one reflects off a total reflecting mirror. The two beams recombine, and light waves of the same wavelength undergo constructive (and destructive interference depending on their phase). The longer the wavelength, the further into the tissue the light has travelled, meaning it has penetrated further into the sample and been reflected by a deeper layer. With the amplitudes of the wavelengths altered, the light source is split by a spectrometer and the amplitudes of the separate wavelengths between 1000nm and 1100nm are recorded as one A-scan. Sweeping the system axially across the sample, a B-scan is recorded.

An unprocessed interferometric data of a single OCT B-scan, a collection of 400 A-scans, is provided for further processing steps. The amplitude of the overlapping spectra is represented as a plot, where the x-axis is a wavenumber (1 / wavelength) with a central value set to 0.95μm^{-1} and range of 100 μm^{-1}.

To isolate the interferometric 'fringes' which are superimposed on a low frequency, a DC spectrum is created by averaging all the A-scans and used to subtract from the spectra. Next, the OCT image is generated by taking the logarithm of 1D Fourier transform of the interferometric signal and considering only positive frequencies for the image display. And finally, the effects of using a narrower optical spectrum, a multiplication of the DC-subtracted A-scans by a Gaussian function with a mean of 512 and standard deviation of 170 taken prior the Fourier transform of the interferometric signal, are used to compare the image results obtained from the full spectrum.

[2] https://www.shimadzu.com/an/service-support/technical-support/analysis-basics/tips-ftir/nir1.html#:~:text=Near%2Dinfrared%20light%20generally%20refers,the%20vibration%20of%20the%20material

Results

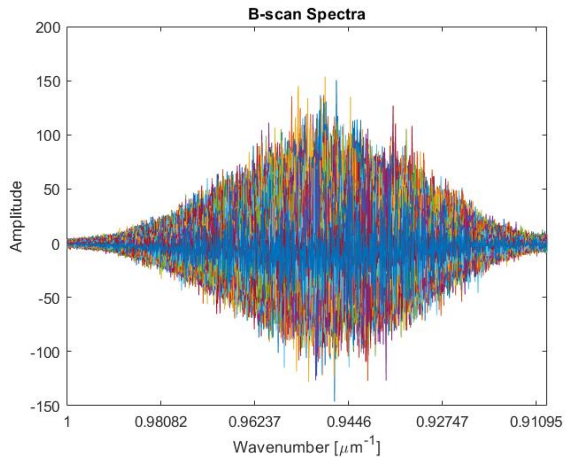

Figure 1. *The line plot of the recorded amplitude of 400 A-scans*

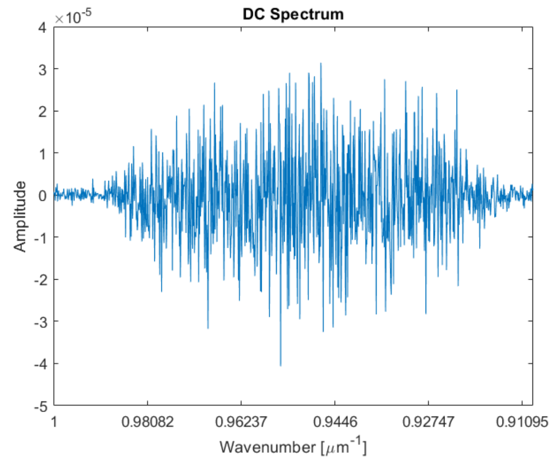

Figure 2. *The DC spectrum derived from averaging all A-scans*

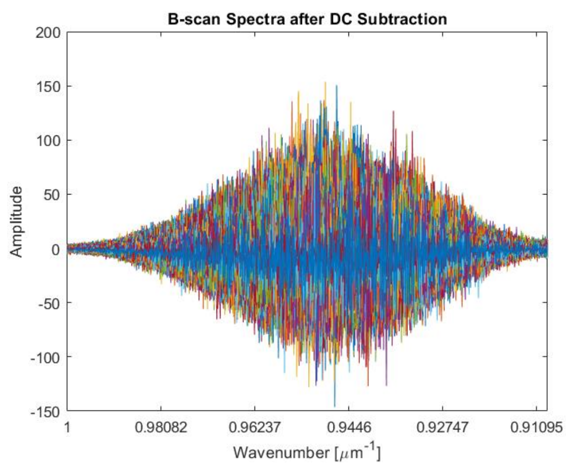

Figure 3. *A-scans after subtracting the DC spectrum*

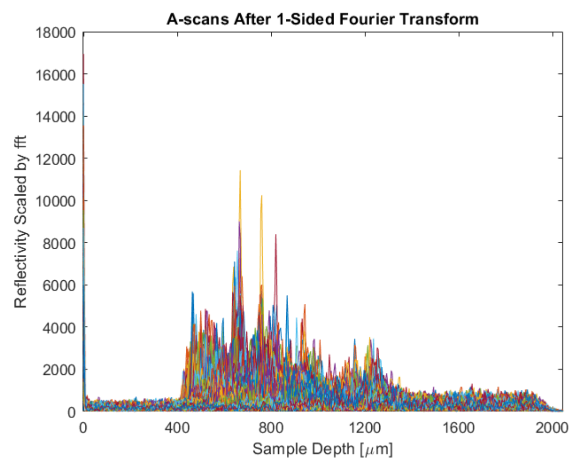

Figure 4. *The Fourier Transform of the interferometric signal*

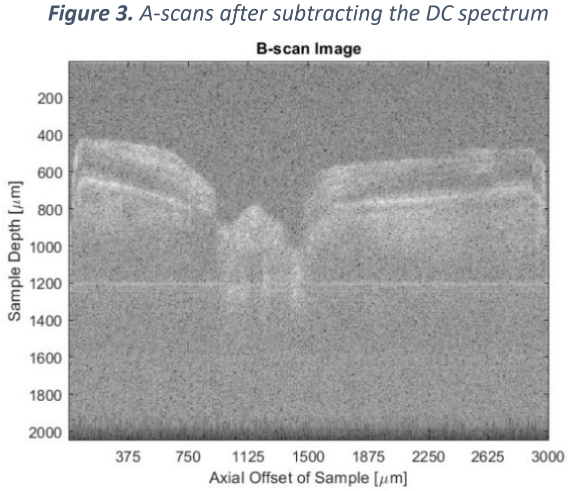

Figure 5. *Processed B-scan image*

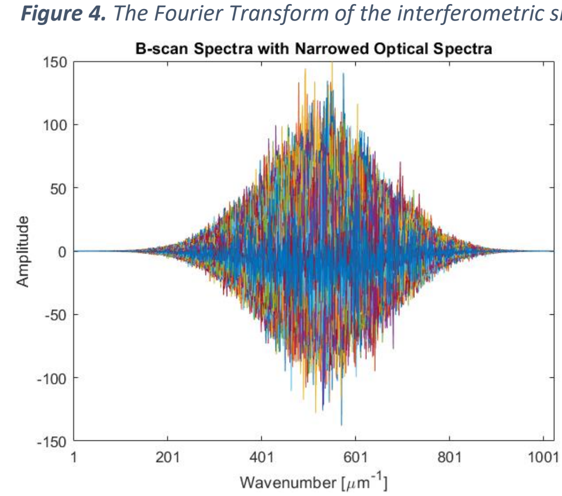

Figure 6. *The line plot of the DC-removed A-scans*

using 1-sided Fourier Transform

multiplied by a Gaussian centered at the central wavenumber

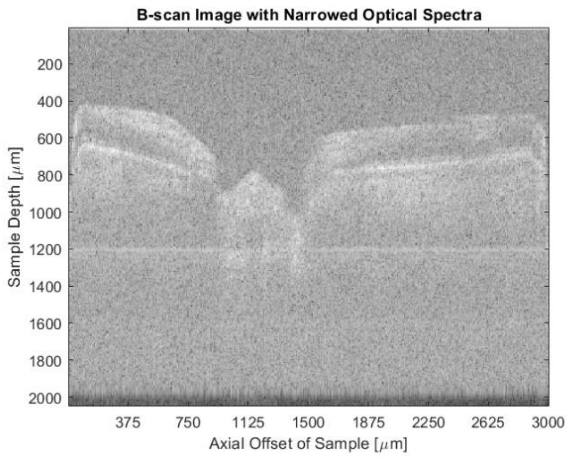

Figure 7. *Processed B-scan image after multiplying by Gaussian*

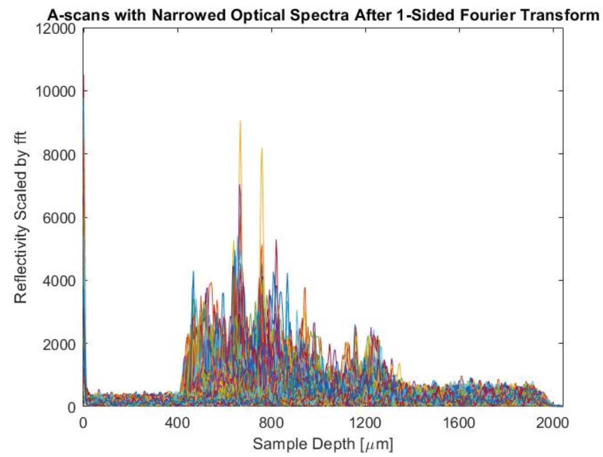

Figure 8. *Fourier Transform of the interferometric signal after multiplying by Gaussian*

Discussion

The broad band light source used by the OCT system carries its own amplitudes of the wavelengths recorded by the OCT system. Since only the changes in the amplitude caused by the reflected light waves represent different reflectivity at each sample depth, the DC spectrum is removed.

The one-sided Fourier transform is used when transforming the DC removed spectrum because a Fourier transform is symmetric around the centre frequency with half of the power of the signal contained within negative frequencies. In the case of OCT, this means all the information within the image is present within one side and the full Fourier transformed signal would display two symmetric images.

Displaying the image with visible contrast, the B-scan is scaled logarithmically. Either amplitude or intensity could be used to display the image, as intensity is the square of the amplitude and squaring a function before taking the logarithm only multiplies the result by two. Multiplying the entire image by a constant does not change the image.

After obtaining the B-scan image, the effects of a narrower optical spectra are examined by multiplying the DC-subtracted B-scan by a gaussian. Our A-scans are a collection of sinusoidal light waves at various frequencies which become two delta functions via the Fourier transform. Multiplying those sinusoidal light waves with a narrow Gaussian before transforming is equivalent to convolving the transformed signal with a Gaussian wide. The convolution of any signal with a delta function is the same signal, multiplied by the amplitude of the delta function and shifted by the delta function's position. So overall, by narrowing the optical spectra, we have widened the effect of each wavelength in the signal while the image has remained the same length. This overlap causes blurring, and the narrower the optical spectra the lower the contrast and the worse the resolution.

Appendix:

```
%% Part a)
%Load the data
data = load('Bscandata.csv');

%% Part b)
wavelengthRange = linspace(1000, 1100, 1024); %nm
wavenumber = 1./wavelengthRange * 1000; % um^-1
charVal = strsplit(num2str(wavenumber)); %create char
values for x-axis
figure(1)
plot(data);
xlim([0 1024]);
set(gca,'XTick',1:200:1024); set(gca,'XTickLabel',
charVal(1:200:end));
title('B-scan Spectra');
xlabel('Wavenumber [\mum^{-1}]'); ylabel('Amplitude');

%% Part c)
%avg all A-scans
DCspectrum = mean(data, 2);
figure(2)
plot(DCspectrum);
xlim([0 1024]);
set(gca,'XTick',1:200:1024); set(gca,'XTickLabel',
charVal(1:200:end));
title('DC Spectrum');
xlabel('Wavenumber [\mum^{-1}]'); ylabel('Amplitude');


figure(3)
%remove the DC Spectrum from the signal
interferometricSig = data - DCspectrum;
plot(interferometricSig);
xlim([0 1024]);
set(gca,'XTick',1:200:1024); set(gca,'XTickLabel',
charVal(1:200:end));
title('B-scan Spectra after DC Subtraction');
xlabel('Wavenumber [\mum^{-1}]'); ylabel('Amplitude');

%% Part d)
```

```
figure(4)
FT = fft(interferometricSig, [], 1); %FFT of the
interferometric signal
plot(abs(FT(1:end/2,:)));
xlim([0 512]);
set(gca,'XTick',1:100:512);
xlabel('Sample Depth [\mum]'); ylabel('Reflectivity Scaled
by fft');
set(gca, 'XTickLabel', strsplit(num2str(0:400:2000)));
title('A-scans After 1-Sided Fourier Transform');
figure(5)
imagesc(log10(abs(FT(1:end/2,:)))); colormap(gray); %log
plot
title('B-scan Image');
xlabel('Axial Offset of Sample [\mum]');
charValAxial = strsplit(num2str(0:3000/8:3000));
set(gca, 'XTick', 0:50:400); set(gca, 'XTickLabel',
charValAxial);
ylabel('Sample Depth [\mum]');
charValDepth = strsplit(num2str(200:200:2000));
set(gca, 'YTickLabel', charValDepth);

%% Part e)
% Create narrower optical spectra
fltrIF = interferometricSig.*gaussmf(linspace(1, 1024,
1024), [170, 512])';
figure(6);
plot(fltrIF);
xlim([0 1024]);
set(gca,'XTick',1:200:1024);
xlabel('Wavenumber [\mum^{-1}]'); ylabel('Amplitude');
title('B-scan Spectra with Narrowed Optical Spectra');


FT2 = fft(fltrIF,[],1); %FFT of the narrower
interferometric signal
figure(7)
plot(abs(FT2(1:end/2,:)));
xlim([0 512]);
set(gca,'XTick',1:100:512);
xlabel('Sample Depth [\mum]'); ylabel('Reflectivity Scaled
by fft');
set(gca, 'XTickLabel', strsplit(num2str(0:400:2000)));
```

```
title('A-scans with Narrowed Optical Spectra After 1-Sided
Fourier Transform');
figure(8)
imagesc(log10(abs(FT2(1:end/2,:)))); colormap(gray); %log
plot
title('B-scan Image with Narrowed Optical Spectra');
xlabel('Axial Offset of Sample [\mum]');
set(gca, 'XTick', 0:50:400); set(gca, 'XTickLabel',
charValAxial);
ylabel('Sample Depth [\mum]');
set(gca, 'YTickLabel', charValDepth);
```