Optical Coherence Tomography:
Mitigation of Scattering Using DSP Techniques

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Optical Coherence Tomography (OCT) is a non-invasive method of producing 2-Dimensional images of biological tissues. The practice came into prominence in 1991 from the developments of Huang et al. Since its introduction advancements in laser diode technology and imagery has allowed for micrometer resolution and is widely used in the Ophthalmology.[2] Although OCT produces great resolution there are drawbacks. OCT is notorious for producing a phenomenon called speckle noise. This review will utilize previous work done using imagery filters to reduce speckle noise and as well create our own simulations to confer.

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FIG. 1. On the left is an image put through a speckle filter in Matlab. On the right is the original image.

A. Introduction

Optical Coherence Tomography (OCT) is a non-invasive method of producing 2-Dimensional images of internal tissues in a method comparable to that of ultra-sound imaging.[3][10] The practice came into prominence following the developments of Huang et al. at the Massachusetts Institute of Technology in 1991. [3]

I. OCT IDENTIFIED PROBLEM AND SUGGESTED SOLUTION

A. The Problem of Speckle Noise

A problem with using an OCT interferometer is that speckle noise exists, which ultimately reduces the quality of the image. Speckle is a phenomenon that is caused by interference of the reflected wave at the photo-detector. Speckle noise is evident when trying to image non-fluid structures (such as hard tissue). As the wave propagates it becomes distorted due to low-angle multiple forward scattering and diffuse multiple backscattering of coherent photons. [9]

In OCT interferometry imaging, photons are detected after one backscattering event for most relevant information, but when a wave is propagated through a dense biological sample it experiences numerous scattering events (in OCT interferometry). These scattering events increase the likelihood for photons to change their travel distance comparative to their airborne path which results in speckle noise reducing the image quality. [9]

To display the effects of speckling on an image refer to

Figure 1. Using $imnoise(I,'speckle',v)$ in Matlab to create a filter that would add multiplicative noise to an image. As seen on the left the image resolution is decreased significantly after adding speckling noise especially in the area of high light reflectivity off of the table.

B. Possible Solutions for Speckle Noise

As technology progress in imaging processing, techniques are being developed to help reduces the effects of speckle noise when using OCT. Some of these methods include decreasing spatial and temporal coherence of the laser used. While more trivial techniques such as phase-domain processing and zero-adjustments are used to improve image quality due to speckle noise. [9]

II. OCT IMAGE AQUISITION AND PREPARATION

A. Aquiring and Visualizing OCT Images

While many published reports contain printed images of OCT captures, getting raw data was necessary to make realistic observations on the effects of using digital filtering. 3D OCT captures of healthy individuals were obtained from a publised proceeding comparing OCT scans of healthy individuals [12]. The scans were provided in .mat file format. The size of each volume provided by these scans was 650 x 512 x 128 voxels. Each voxel had a resolution of 11.72 x 46.88 x 3.54 μm. We were able to view an interactive 3D volume from the provided .mat files using a script published on MathWorks file exchange titled '3D Volume Visualization' [11]. A capture of the visualizan can be seen in Figure 2.

B. Slicing and Preparing a 2D Image for Processing

Upon importing the .mat files into Matlab, they took the form of a 650 x 512 x 128 double data type named d3. The Matlab code shown in Listing 1 shows the process of taking the middle XY slice and creating a greyscale image.

```
%Take Slice of 3D Volume
SliceL = d3(:,:,64);
ImgSliceL = mat2gray(SliceL, [0 255]);
imshow(ImgSliceL);
```

Listing 1. Take Slice of 3D Volume
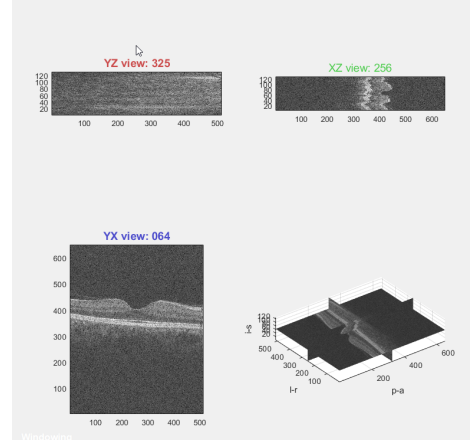
An example unaltered aquired image is shown in Figure 3.
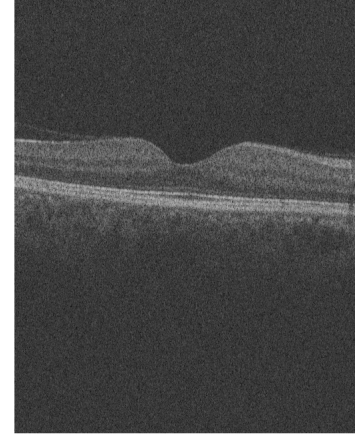

FIG. 2. 3D Volume Visualization Capture

FIG. 3. Unaltered 2D Slice of 3D Volume

III. QUALITY METRICS: SIGNAL TO NOISE LEVEL, AND ESTIMATED NOISE LEVEL

The results of quality measurements for each applied filter method are listed in Table (**ADD REFERENCE TO TABLE). The methods for obtaining the quality metrics are described in the following paragraphs.

A. Contrast to Noise (CNR) Estimation

The code shown in Listing 2 outlines the process for aquiring the contrast to noise estimation. The process starts with taking the 2D image matrix and converting it into a 1D array.

The maximum and minimum values are extracted from the 1D matrix, and then the standard deviation is calculated. The final CNR is calculated equivalent to the formula:

$$CNR = (\frac{Max - Min}{\text{Standard Deviation}})$$

```
1   % Measure contrast−to−noise ratio
2   img=ImgSliceL;
3   img=double(img(:));
4   ima=max(img(:));
5   imi=min(img(:));
6   mse=std(img(:));
7   cnr=((ima−imi)./mse)
8
```

Listing 2. Estimate Contrast to Noise Ratio

B. Estimated Noise Level

The Estimated Noise Level (ENL) is calculated using a method implemented in a Matlab function by Ashish Meshram [6]. This implementation is based off of the paper titled *Single-Image Noise Level Estimation for Blind Denoising* by Xinhao Liu, and team [4].

C. Naturalness Image Quality Evaluator (NIQE) No-Reference Image Quality Score

Due to the fact that all obtained images need to be evaluated as is, with no reference image to compare to, it is advantageous to use a metric that does not require a reference image. Matlab has a built-in function called niqe that returns a value (lower is better, indicating higher perceptual quality) using the Naturalness Image Quality Evaluator based off the work of Anish Mittal and team [7].

IV. SCOPE OF DSP METHODS USED

This report will focus on 2D image filtering methods which can be applied using Matlab.

(Talk more about types of methods used.)

A. Wiener Filter

The 2D Wiener filter is a processing technique which is capable of not only improving resolution but as well signal-to-noise (SNR) ratio of particular image. This low-pass filter is an optimal trade-off between inverse filtering and noise smoothing. This filter is also referred to as a local linear minimum mean square error which means [LLMMSE] it is the optimal estimator in the sense of mean squared error (MSE). Where LLMMSE and MSE

is determined by:

$$\begin{bmatrix} R_{xx}[0] & R_{xx}[-1] & ... & R_{xx}[1-N] \\ R_{xx}[1] & R_{xx}[0] & ... & R_{xx}[2-N] \\ \vdots & \vdots & \ddots & \vdots \\ R_{xx}[N-1] & R_{xx}[N-2] & ... & R_{xx}[0] \end{bmatrix} \begin{bmatrix} h[0] \\ h[1] \\ \vdots \\ h[N-1] \end{bmatrix}$$

$$= \begin{bmatrix} R_{yx}[0] \\ R_{yx}[1] \\ \vdots \\ R_{yx}[N-1] \end{bmatrix}$$

$$R_{ee}[m] = R_{yy}[m] - R_{yy}[m] = R_{yy}[m] - h[m] \times R_{xy}[m]$$

Where R_{xx} is the received signal, N is the length, then there are N equations in the N unrestricted values of h[n] and h[m] is the impulse response of the filter [8].

B. Enhanced Lee Filter

The Lee filter applies a spatial filter to each pixel which filters data based on local statistics calculated within a square window. The value of the center pixel is replaced by a value calculated using the neighbouring pixels. Implements similar characteristics of the Wiener filter in the sense it uses MSE but also has edge preserving features [5]. The pixels are classified into:
Homogenous: where the pixel value is replaced by an average of the filter window
Heterogenous: where the pixel value is replaced by a weighted average
Point: where the pixel value is unchanged.

The resultant gray value R for the pixels is then represented as:

$$R = I_m \text{ for } C_i \leq C_u$$

$$R = I_m \times W + I_c \times (1 - W) \text{ for } C_u < C_i < C_{max}$$

$$R = I_c \text{ for } C_i \geq C_{max}$$

Where:
I_m = mean value of intensity within the kernel
I_c = center pixel in the kernel
C_i = S/I_m
$C_u = \sqrt{1/(number of flocks)}$
W = $\exp -\zeta(C_i - C_u)/(C_{max} - C_i)$
S = standard deviation of intensity within the kernel [1]

C. Kuwahara Filter

The Kuwahara filter is an edge preserving non-linear smoothing filter.

V. CONCLUSION

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