Fourier Domain Zero-Padding and Convolution for Image and SNR Enhancement in Confocal Microscopy

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Introduction:

Image quality in reflectance confocal microscopy is primarily quantified by the Signal to Noise Ratio (SNR). Maximization of SNR is crucial for acquiring clear images with diagnostic potential. Reflectance based confocal microscopy (RCM) is a high-resolution scanning laser imaging application that enables detailed, non-invasive visualization of cellular structures and other material surfaces. RCM characteristically suffers from low SNR due to high tissue scattering and low reflected signal from sample surfaces.

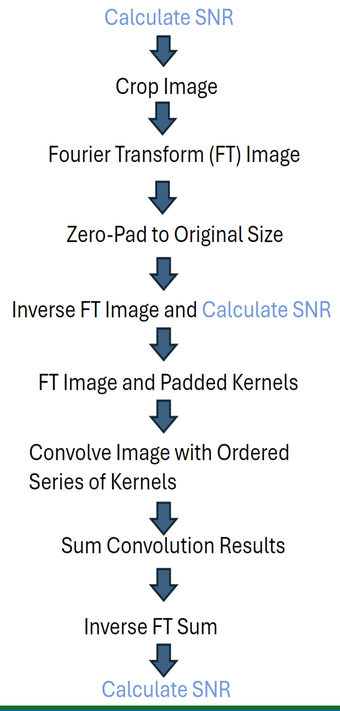
In this work, we devised a regimen of Fourier domain techniques, specifically zero-padding and convolution, to serve as a uniform SNR enhancement step for our RCM system. Zero-padding in the Fourier domain can artificially inflate spatial resolution without altering the original sample data, allowing us to capture finer details. Additionally, Fourier domain convolution is leveraged to selectively enhance sample features, thereby enhancing overall SNR.

Methods:

We built a custom MATLAB script to increase the SNR of our system's images through postprocessing in the Fourier domain. First, the SNR of the raw image was calculated. Then the image was cropped down to retain only the sample containing region. The cropped image is then Fourier transformed and zero padded back to the original matrix size of 1024x1024. Inverse Fourier transforming the matrix results in a 1024-by-1024-pixel image of the isolated sample region. The SNR was calculated again at this stage for comparison.

Next the image along with a series of padded kernels was Fourier transformed for convolution. The Zero-Padded image was convolved with a smoothing kernel to eliminate noise, and the resulting denoised image was convolved with a series of selective edge detecting kernels. The smoothed image was added to the sum of the edge detection images in the Fourier domain. The result is inverse Fourier transformed and renormalized leaving an image with less noise and enhanced sample features.

Below is a flowchart showcasing the workflow of the MATLAB script. The blue text indicates points at which the SNR's from the comparison in figures (3-5)d are calculated. Figures 1 and 2 show visualizations of zero-padding and convolution, respectively.



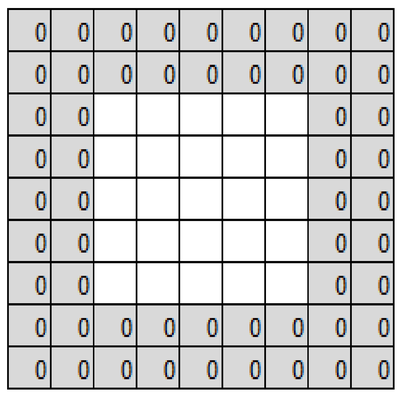


Figure 1: [2] Zero Padding Visualization

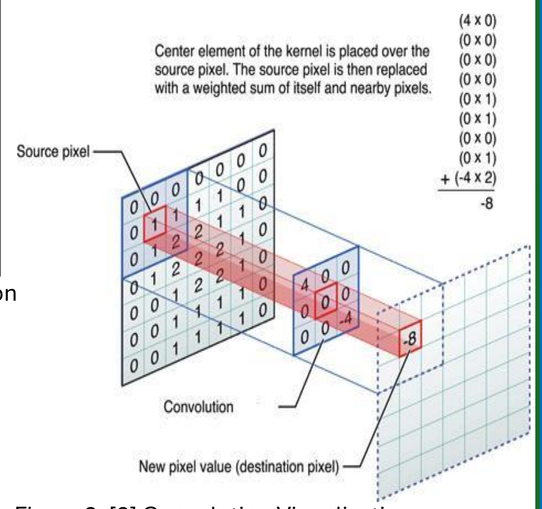


Figure 2: [3] Convolution Visualization

Results:

Figures 3-5 show 3 sample images across 3 stages of processing along with a bar graph comparison of image SNR at each stage. The increase in SNR from the zero padding was monumental for our systems images. The SNR impact for the noise reducing, edge enhancing convolution was less significant but still always increased the SNR of the images. The visibility of distinct image features appears to improve impactfully with both steps of processing. The SNR impact of convolutional processing could be strengthened with individualization of kernel choice and order of convolution for each image. The goal of this work was to establish a standardized process for enhancing visibility and SNR of our systems images, and the results seem to demonstrate that this goal was achieved.

Figure 3a: Pre-FFT Confocal Image of Lung Carcinoma Slide

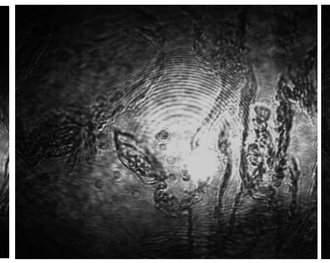


Figure 3b: Zero Padded Confocal Image of Lung Carcinoma Slide

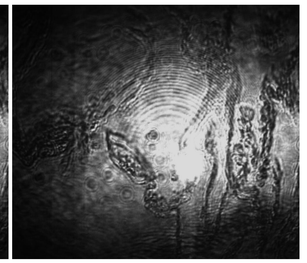


Figure 3c: FT Enhanced Confocal Image of Lung Carcinoma Slide

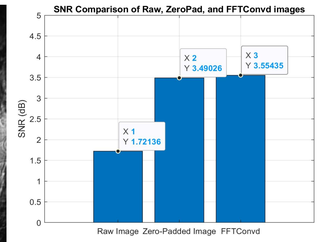


Figure 3d: Mean-to-Variance SNR comparison at each stage

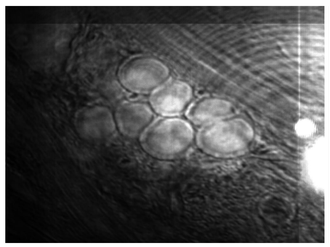


Figure 4a: Pre-FFT Confocal Image of Skeletal Muscle Striations Slide

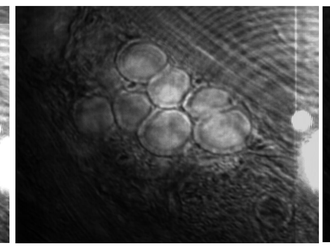


Figure 4b: Zero Padded Confocal Image of Skeletal Muscle Striations Slide

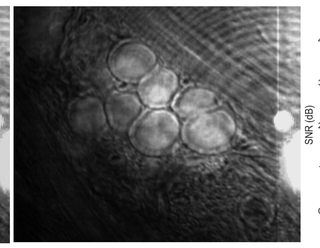


Figure 4c: FT Enhanced Confocal Image of Skeletal Muscle Striations Slide

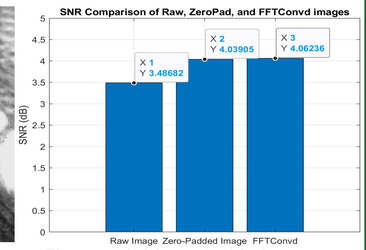


Figure 4d: Mean-to-Variance SNR comparison at each stage

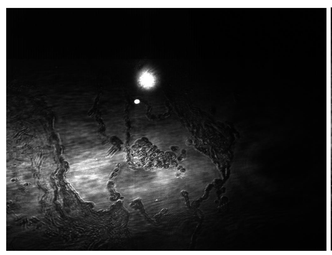


Figure 5a: Pre-FFT Confocal Image of Lung Carcinoma Slide

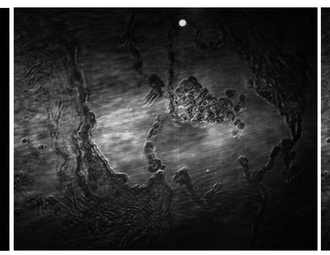


Figure 5b: Zero Padded Confocal Image of Lung Carcinoma Slide

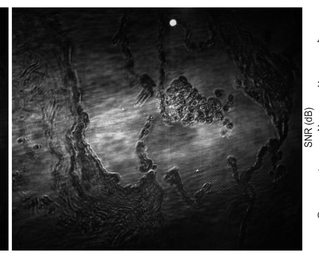


Figure 5c: FT Enhanced Confocal Image of Lung Carcinoma Slide

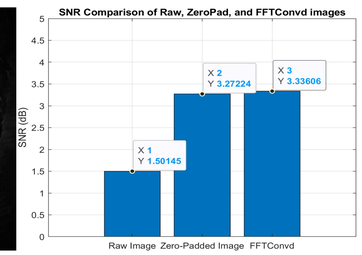


Figure 5d: Mean-to-Variance SNR comparison at each stage

Conclusion:

This poster demonstrates and outlines the development of a standardized regimen of Fourier domain techniques for enhancing the visibility of sample features and improving the SNR of images produced by our custom confocal system. By refining this process, we achieve clearer, more reliable imaging results, which can enhance the analysis, interpretation, and diagnostic potential of low-intensity reflectance confocal images.

Acknowledgements:

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References:

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[2]Wahyudi Setiawan, et al. Telecommunication Computing Electronics and Control; (2019).
[3]Madhushree Basavarajaiah. Medium; (2019).