Mitigating Image Artifacts from Inertial Non-Linearity in High-Frequency Galvanometer Scanning Systems

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MARQUETTE UNIVERSITY
BE THE DIFFERENCE.

Introduction:

Dual-axis galvanometer scanners struggle to entrain mirror motion to driving signals at high scan frequencies. The mechanical inertia of galvanometer mirrors at higher frequencies poses a significant challenge to accurate scanning and, for imaging systems, results in ghostly artifacts of the sample that distort images. This effect worsens exponentially as scan frequency increases and; as a result, significantly limits the acquisition time of usable, accurate images.

This poster demonstrates a postprocessing solution to correct these inertial based inaccuracies in biomedical scanning laser systems to restore imaging capability at higher scanning frequencies. We also highlight a more upstream, permanent solution for future development. Figures 1a-1c show examples of these artifacts as they change with scan speed in Hz. Figure 2 shows an approximate line of best fit imposed on a graph of pixel shift in micrometers vs scan speed.

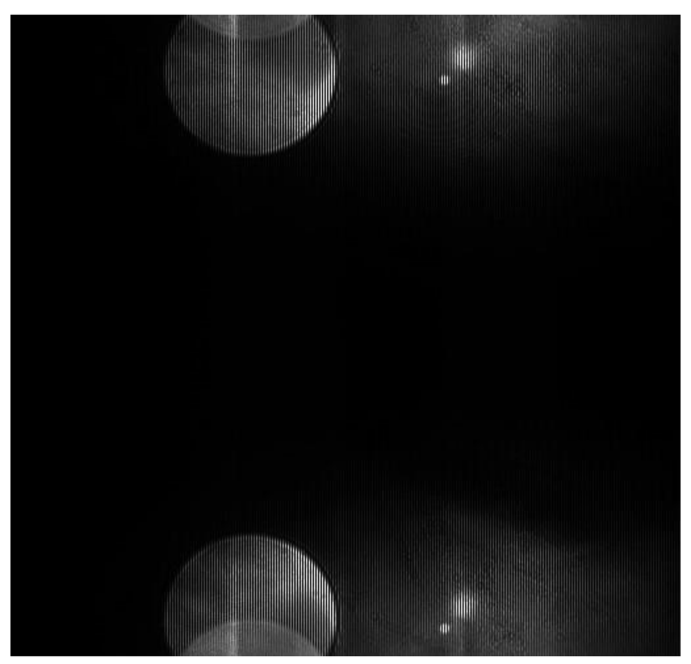


Figure 1a: Circle on Control Slide Imaged at 5000Hz

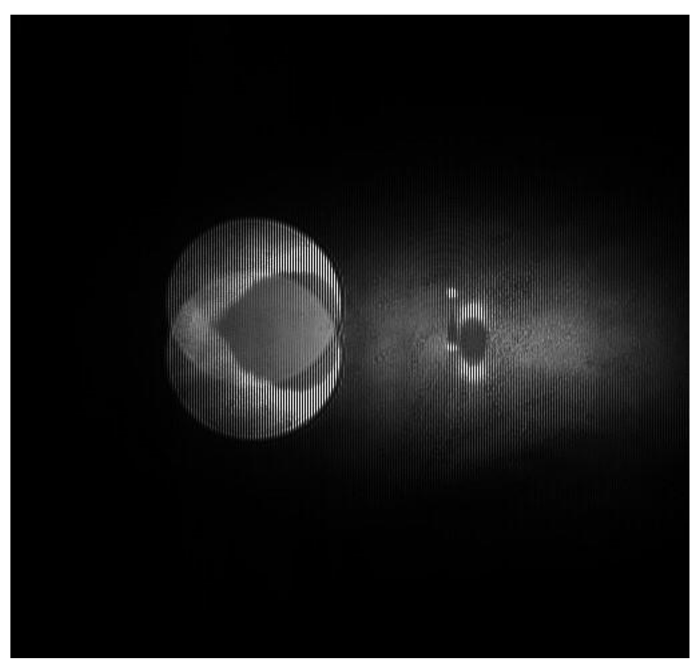


Figure 1b: Circle on Control Slide Imaged at 2000Hz

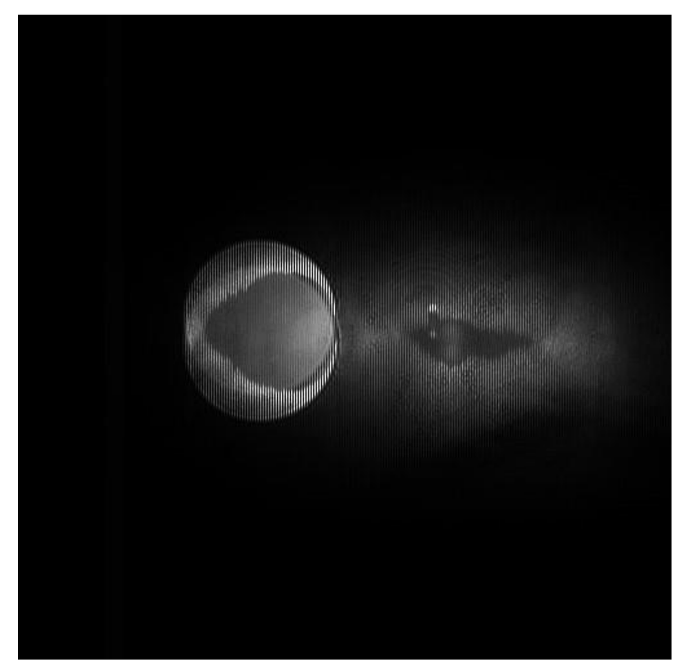
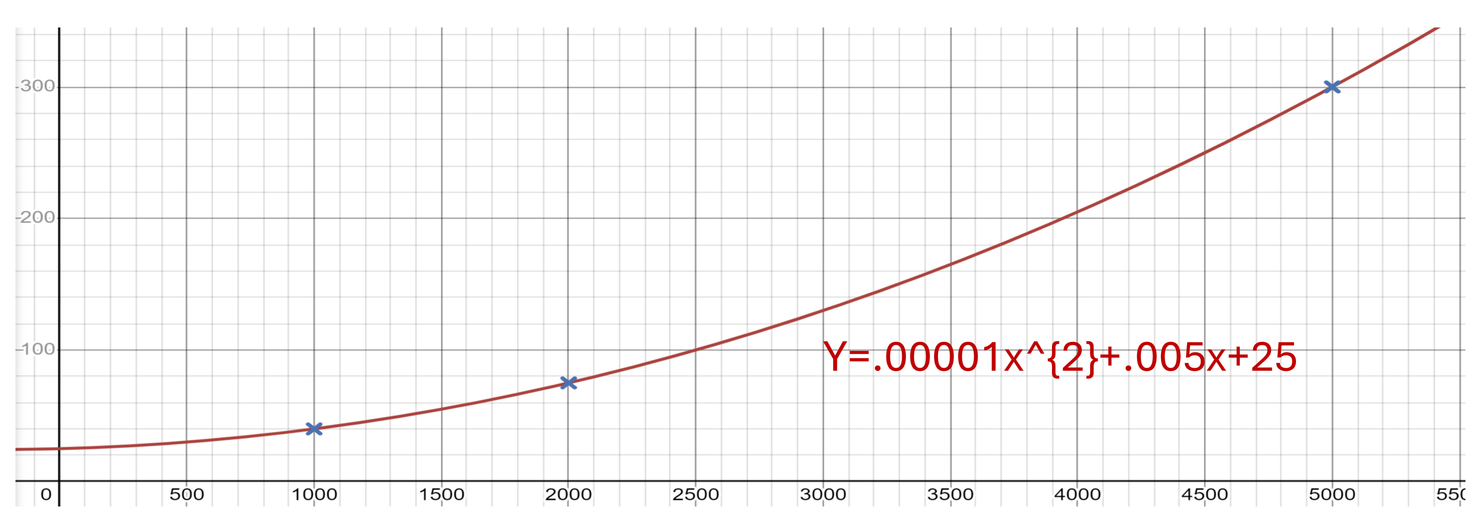


Figure 1c: Circle on Control Slide Imaged at 1000Hz

Figure 2: Line of Best fit Approximated to Estimated Column Shifts (Y-Axis in micrometers) at each scan frequency (X-Axis in Hz). The equation for the line of best fit is under the line to the right in red text.



Methods:

Given proper alignment, the data from the artifacts appears in every other column of the images. Because of this we were able to separate the images into an image constructed of only the even columns and another of only the odd columns. We then shifted one of these images vertically until it was properly aligned with the other. After this we re-concatenated the columns with their proper columns in order and interpolated between the columns to fill in the data of the affected region. The figures below show the steps of the process for a 1024x1024 image of a circle on our test slide taken as a control at 2000hz.

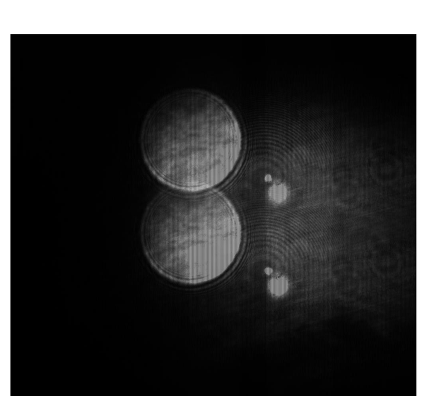


Figure 3a: Raw Confocal Image of Circle on Control Slide

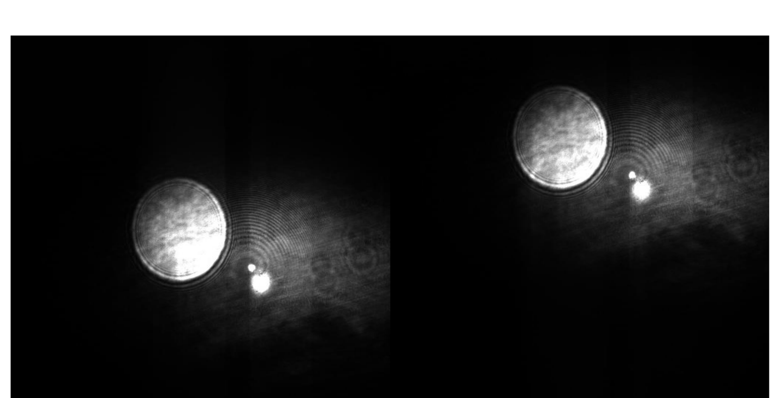


Figure 3b: Control Slide Circle Confocal Image Split by Even and Odd Columns

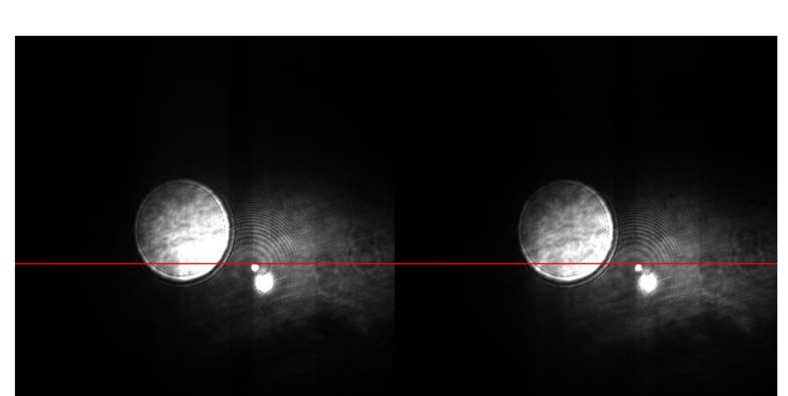


Figure 3a: Control Slide Circle Confocal Image Split Shifted to Proper Y-Alignment

Figure 3d: Final Control Slide Circle Confocal Image after Concatenation

Results:

Given the consistency between cell structures displayed in the corrected confocal images and the widefield references, our method appears to work as a backend solution for correcting the implicit mechanical error of our galvo at high frequencies. With this solution, optimal images on our system require a balance between scan size and scan speed such that the images represent the sample accurately, retain an adequate FOV, and can be taken at a reasonable speed.

Since this fix fails to completely restore image data of our full FOV at our maximum frequency (5000hz), in the future we aim to implement modifications to our output voltages that correct for the expected non-linearity of the galvanometer's response. This has been showcased to work [3] and there are designed "distorted ramp signals" that successfully correct for this error up to 3000hz. Our future steps are to design, test, and implement 5000hz variants of these distorted ramp signals to our system to allow for ideal imaging capacity at our maximum scan rate.

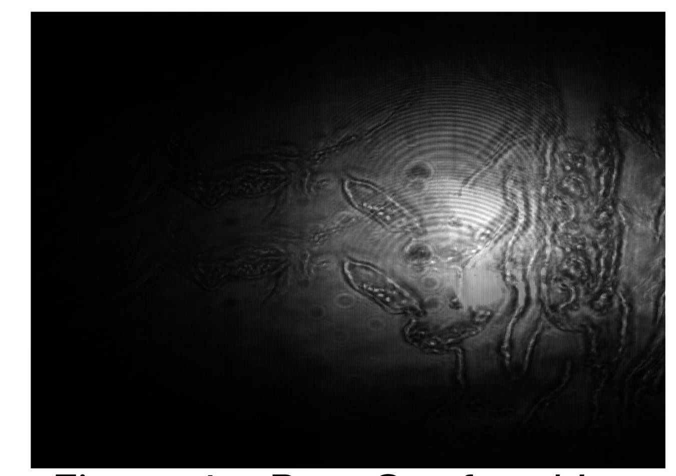


Figure 4a: Raw Confocal Image of Lung Carcinoma Slide

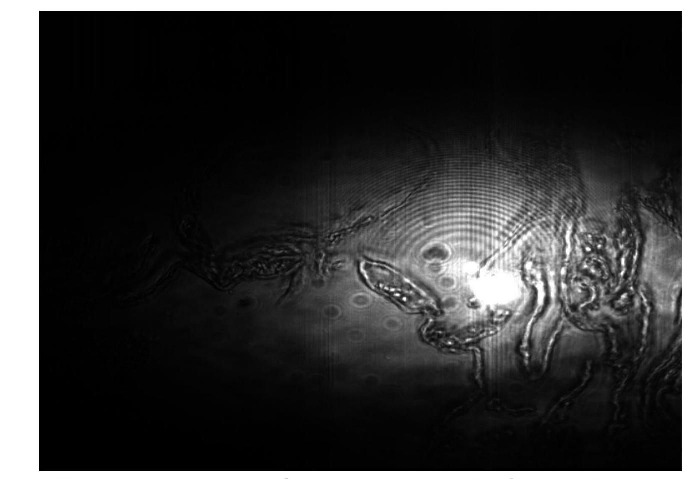


Figure 4b: Corrected Confocal Image of Lung Carcinoma Slide

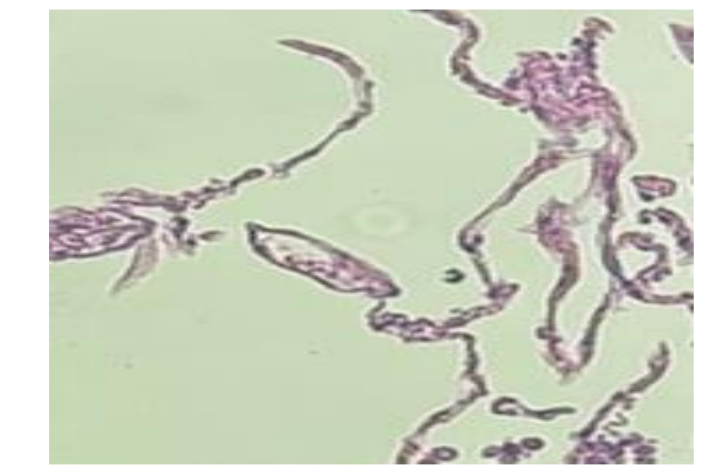


Figure 4c: Widefield Image of Lung Carcinoma Slide

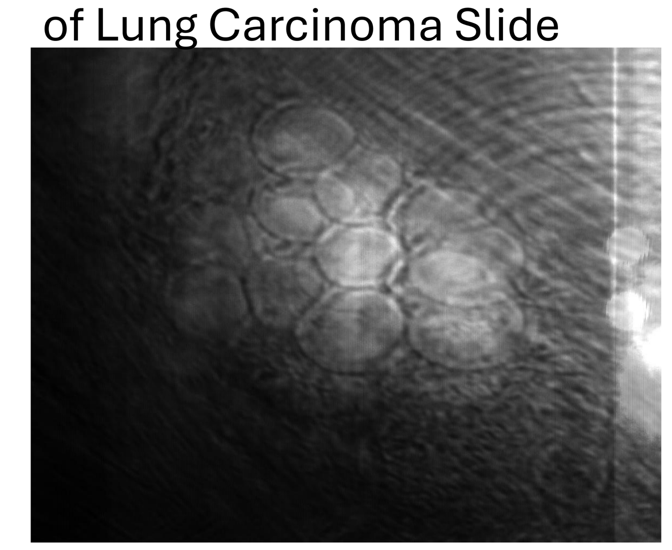


Figure 4d: Raw Confocal Image of Skeletal Muscle Striations Slide

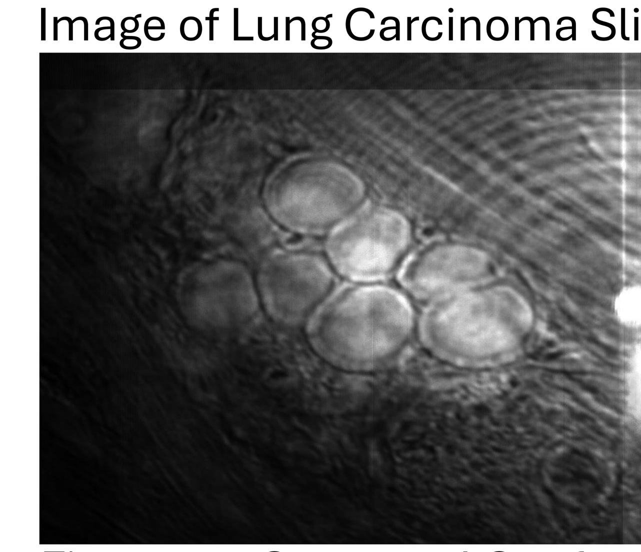


Figure 4e: Corrected Confocal Image of Skeletal Muscle Striations Slide

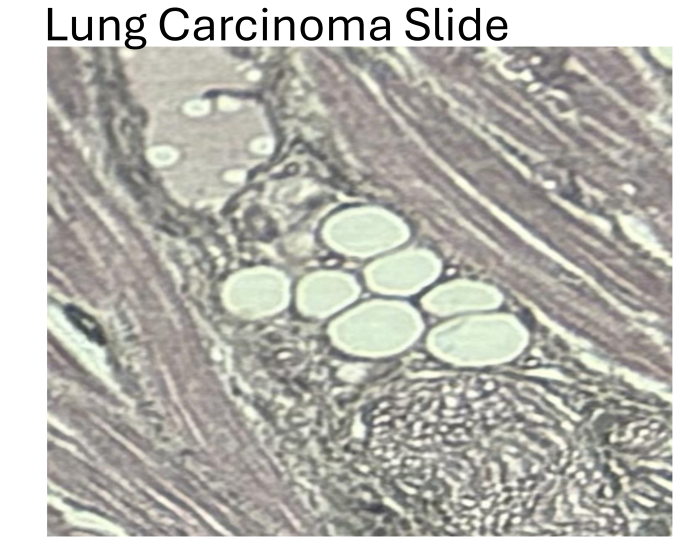


Figure 4f: Widefield Comparison Image of Skeletal Muscle Striations

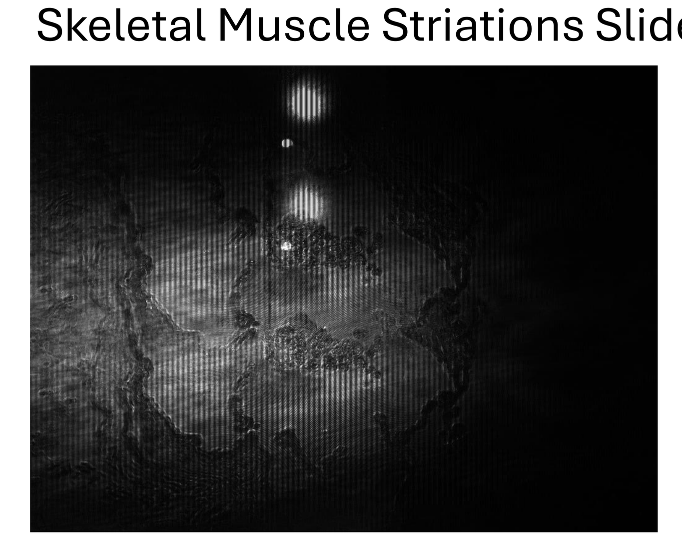


Figure 4g: Raw Confocal Image of Lung Carcinoma Slide

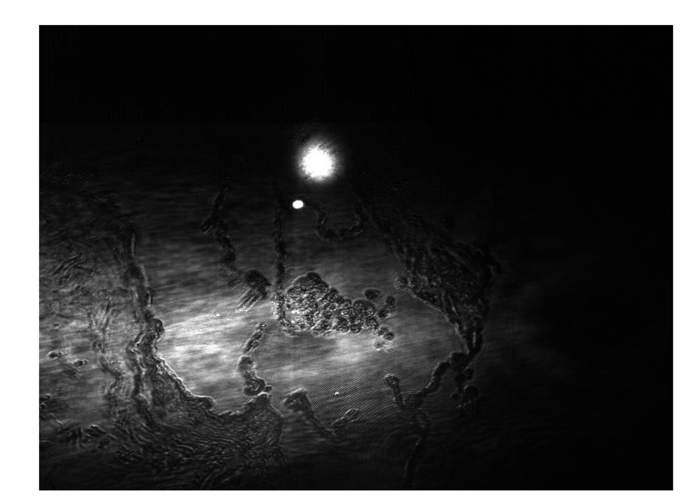


Figure 4h: Corrected Confocal Image of Lung Carcinoma Slide

Figure 4i: Widefield Image of Lung Carcinoma Slide

Conclusion:

Our devised method is sufficient for recovering accurate sample image data. It does, however, sacrifice acquisition time and field of view. As a result, we will continue to investigate further solutions. The most promising future direction is to drive the galvanometer with modified "ramp functions" that counteract the expected nonlinearity of the galvanometer's response to input voltages. This would allow for accurate imaging at our maximum scan rate and is our next step for improving spatiotemporal resolution of our system.

Acknowledgements:

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References:

1] Thorn, Kurt. "Optical Sectioning and Confocal Microscopy". IBiology Techniques; (2009)
[2] Franck, Christian. Society for Experimental Mechanics; (2007)
[3]Hariri, Ali, et al.The International Society for Optics and Photonics; (2016).
[4] Pawley, James. Pennington Biomedical Research Center; (2010).