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Experiments in Astigmatism Detection and Correction Techniques for the SEM

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Astigmatism in the scanning electron microscope may arise from a number of sources such as machining errors, polepiece inhomogeneity, and lens winding asymmetry, and more temporary issues such as contaminated apertures [1]. The latter issues entail that astigmatism correction must be repeatedly undertaken, rather than being a one-off careful instrument calibration that could be accomplished by the microscope manufacturer during installation. Human microscopists exploit the fact that astigmatism causes multiple focal points in the imaging plane, which manifests as directional stretching in over-focussed and under-focussed images, providing a visual means to guide the user in iteratively adjusting the settings of x- and y-stigmator controls to remove the astigmatism. Unsuccessful correction will leave the image blurred even when the image is properly focused. Astigmatism identification and correction is a difficult skill for microscopists to acquire, and has been a target for effective automation for decades.

Many approaches to detecting and correcting astigmatism have been pursued, some converting the image into the Fourier domain to apply FFT-based analysis [2, 3], others using variance-based calculations of the image in the spatial domain [4, 5]. Previous work investigated the combined focusing and autostigmatism algorithm developed by Ong and co-workers [2], developing a GPGPU implementation reported in [6]. However, the fixed size offsets proved to be problematic for both identifying best focus and correcting astigmatism, although varying the step size according to magnification and focus metric showed promise. Lu and co-workers' more recent algorithm utilises only a single under- or over-focused image, applying a filter to the Fourier transform to mitigate against noise effects, but their algorithm is most effective with samples that generate FFTs with radial symmetry [3]. Erasmus and Smith's algorithm proposed sweeping the x-stigmator and y-stigmators across their range of values, computing the image variance at each stigmator value combination, exploiting the assumption that high variance images are less blurred than low variance images [4].

Astigmatism in photographic cameras does occur (albeit infrequently) and is usually caused by misalignment of optical lenses. Objects moving faster than the exposure rate of the camera will cause motion blur in photographs. Although the causes of SEM astigmatism and light photography motion blur are different, the resulting image artefact has sufficient similarities to warrant some investigation of translating motion blur solutions across to the SEM.

The Laplacian operator is a two-dimensional isotropic measure of the second spatial derivative of an image, and highlights regions of rapid intensity change and may be used for edge detection and to discern changes in focus. The Laplacian filter is however sensitive to noise; to mitigate against shot noise in SEM images, a prepass Gaussian blur should be applied to the image before utilising the Laplacian filter. A series of experiments were conducted to determine if the "Laplacian after Gaussian" combination could generate image variance scores that tracked improvements or degradations in astigmatism. The instrumental setup for this work was a Carl Zeiss 1430VP SEM operating in high vacuum mode with a tungsten thermal-emission firing unit. Programmatic access to the SEM was through a Python API wrapper to the SmartSEM API, both provided by Carl Zeiss, with image processing routines utilising the Python implementation of the OpenCV library and custom written Python scripts. The Tkinter library was employed to create a simple GUI to run the experiments. The process was a straightforward application of a 3-by-3 Gaussian blur followed by the Laplacian filter operator. As the results of individual pixels received values outside of the normal 0-255 greyscale range, the processed image was rescaled for visual display. Image variance was then simply calculated. Initial results showed that the image variances quantified and tracked image blur.

Multiple micrographs of a gold-on-carbon standard specimen were captured as "astigmatic" sequences. Careful examination of the image variance results showed that the most astigmatic images did have the highest variance results in general. However, an image which had both focal blur and some astigmatism also generated a high variance result as a consequence of the Gaussian blur providing additional "edge" artefacts discoverable by the Laplacian. As astigmatic images tend to have areas of focus and of blurring in the direction of astigmatism, this prompted additional experiments on subdividing images into tiles to compute variance per tile to see if there was any relationship between high variance and astigmatism directionality. The image was variously sliced into 2-by-2 and 16-by-16 tiles. Once again, although the first results showed promise, additional scrutiny of the results from the 16-by-16 tiled images revealed that tiles containing substantial background pixel regions also had lower variance and there was no clear evidence of blurring in any particular direction.

Time constraints meant that the project could not pursue algorithmic amendments to handle the problem issues. Thus these experiments proved inconclusive in delivering an implementation of an astigmatism detection and correction that was robust against confounding factors such as out-of-focus. Nevertheless astigmatism detection and correction remains an area for future work [7].

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