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Fast Automatic Focusing of the Scanning Electron Microscope using a GPU-accelerated PC

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This work forms part of our ongoing research into enhancing and improving the scanning electron microscope (SEM) and was one of a number of projects undertaken to explore methods for automatic correction of focus while avoiding effects due to magnetic hysteresis in the electron-optical lens system. This project centred on adjustment of an SEM, Carl Zeiss model 1430VP (manufactured c. 2000), using the instrument's own control computer fitted with a high-performance graphics card to support the procedure's computational needs and achieve good speed of operation. No additional computer was required to achieve this.

There has been much research into techniques for automatic focusing of the SEM, and a number of different approaches have been explored. Recent advances in computing hardware have made possible compute-intensive procedures that could not realistically have been contemplated prior to their adoption. Ong et al. have given an excellent summary of early work on correction of focus and astigmatism and reported on the development of a Fourier-based technique that ran on a high-performance workstation separate from the SEM [1]. Our own investigations used as a start-point the methodology of Ong, with the added constraint that the software must run solely on the SEM's own integrated control computer and must reach acceptable focus faster than most human operators could achieve. An additional approach pursued in this work emulates tried-and-tested techniques that originated in the early development of the instrument. In many SEMs an oscilloscope display allowed the video waveform corresponding to a one-dimensional line-scan to be viewed directly, and a well-established approach to identifying focus much used by experienced operators was based on adjusting the objective lens to sharpen the appearance of this waveform. In broad terms, the sharpest waveform corresponds to optimal focus in that part of the image. Analysis shows that this approach amounts to maximizing the high frequency components in the waveform, and it can be emulated by computation. Early attempts at automated focus detection using this method were greatly limited owing to their sensitivity to noise. More modern methods based on consideration of the power spectrum have shown more promise.

There are several other challenges that need to be overcome when achieving efficient automated adjustment of focus in the SEM. Some of these stem from the nature of the electron-optical system, based on magnetic lenses. Firstly, adjustment of focus by varying the objective lens current must be done with regard to the dynamics of the magnetic lens system, as step-changes in excitation current are liable to exhibit both delay and hysteresis. The former sets a limit to the speed of operation, while the latter causes changes in focus according to whether focus is being approached from a longer or a shorter working distance. Van Bree et al. have described practical models for hysteresis in magnetic electron lenses [2]. These issues may not be problematic when small manual changes to focus are sufficient; however, an automated system is of most value if it can quickly find focus after major stage adjustments or after specimen changes, following which the correct working distance may change radically. It must therefore be resilient to such effects. Noise has already been referred to, and its presence restricts the speed at which the state of focus can be accurately detected; in practice, a trade-off may need to be accepted in which the closest approach to focus can only be achieved by improving the signal-to-noise ratio, normally by reducing the image frame rate.

For small adjustments to focus, the method reported by Ong was used, in which power spectra of images at two offset objective lens settings were compared mathematically as the objective lens working distance was changed. A characteristic reversal of polarity occurs as the optimum focus is passed. The detection of the onset of this condition allows the computer to optimize the step, offset and scan-rate as needed to reach focus accurately. It was found possible to achieve good results with a single line of image data, allowing for very fast acquisition and data processing. However, this method is effective only over a very limited range close to focus. Attempts to use this approach when the image was seriously defocused e.g. immediately after a specimen change were unproductive. Accordingly, a coarse adjustment was developed. Under slightly different operating conditions, the objective lens was stepped through a wide range of working distance settings, at intervals of order 1mm. Direct examination of the normalized power spectra was found to give a useful approximate value for focus, suitable as a start-point for the fine algorithm just described. In order to reduce the effects of hysteresis, care was taken to vary the lens current in a regular manner from start to finish of the coarse focus run, and a degaussing procedure was run before the adjustment.

The coding for this project was done using the SEM's own control PC, with the algorithms described written in Python 3, an interpreted language ideal for rapid development and adaptation, but not optimized for speed. In order to achieve sufficiently fast analysis of SEM data, much use was made of a range of mathematical libraries developed for Python. Further, the PC was fitted with an enhanced graphics card, a relatively low-cost accessory embodying a Graphics Processing Unit. GPU technology is available from a number of manufacturers. While its original purpose was to enhance operations such as advanced gaming, in which the fastest possible graphics performance is sought, other groups have devised Python library routines based on this hardware for digital signal and image processing [3]. These execute at many times the speed of the unaided PC. In this instance, the ability of the GPU to accelerate computation of Fast Fourier Transforms was a major factor in its choice.

With the coarse and fine algorithms running in tandem, it is possible to reach focus in under ten seconds with the specimen in an arbitrary position. The search extends over the full practicable range of working distances for the instrument, around 6mm to 20mm. The coarse run can be performed in such a way as to avoid effects due to hysteresis. While the fine run cannot straight-forwardly eliminate hysteresis effects, it operates over a much-reduced range of working distances, and simply continues until optimum focus is reached. Subjective inspection indicated that the results obtained were usually as good as a human operator can achieve.

This project has successfully demonstrated the feasibility of creating a low-cost system for rapid focusing of the SEM. The system shows considerable potential for extension to other kinds of adjustment, including astigmatism and SEM electron gun alignment.

References:

[1] Ong et al, SCANNING, Vol. 19, p. 553-563 (1997)
[2] Van Bree et al, IEEE Transactions on Magnetics, Vol 45, No 11, p. 5235-5238 (2009)
[3] CuPy, https://cupy.dev/ (accessed February 15, 2022)

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