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Using Wavelets to Adjust Focusing of a Scanning Electron Microscope

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At California State University, Hayward, undergraduate and graduate students in the IRSA project, under the direction of Dr. Christopher Morgan, are developing software for remote control of scientific instruments, in particular electron microscopes [1]. As part of this work, he and his students (Shalini Vikas and subsequently Lihua Sun) are applying wavelet-based multi-resolutional techniques to the automatic focusing of a Scanning Electron Microscope (SEM). They have demonstrated an adaptive algorithm that under certain conditions can be used to automatically focus a Philips XL 40 Scanning Electron Microscope. Preliminary results have been published in a master's thesis by Shalini Vikas under Dr. Morgan's supervision [2].

The algorithm is designed to reduce network bandwidth requirements by reducing the number of images that must be sent to focus the microscope. Such an algorithm is important to remote operations because images generally require considerable time to transmit, especially over a slow communication link such as a modem on an ordinary telephone line. However, automatic focusing algorithms can also improve user interaction with instruments even when the user is connected through a high-speed network or is sitting in front of the microscope.

The algorithm improves upon a previous "manual" algorithm that requires user intervention at each step. With the manual algorithm, the user repeatedly selects the best image of a group of five images taken at equally spaced intervals along the focal distance parameter axis. The next set of values centers around the selected value. If the user selects an image at extreme values, the gap between values remains the same. If the user selects an image at internal values, the gap between values narrows by a factor of two. This provides a binary search that normally rapidly centers in on and converges to an acceptable value for the focal distance.

The new algorithm automates this process by computing a series of quantities (metrics) for each image that measure the "detail" at each of six different resolutions. It then finds the level of resolution that has the most variation (relative to the average magnitude) of the detail and selects the focal distance whose image has the greatest detail at that resolution. It repeats this process until the image is sufficiently focused. Various stopping conditions were explored for terminating the loop.

Currently, we are using a two-dimensional variation of the Haar wavelet and scaling functions to compute a measure of the detail. (See Mallat [3] and Strang and Nguyen [4] for a discussion of wavelets and multiresolutional analysis.) At each step, pixels are averaged together to create one low-pass subband and differenced against these averages to compute three high-pass subbands. The averages at one step become the pixels at the next step. The resolution level becomes progressively lower at each step. The differences represent the detail of the image at various resolution levels. The magnitude of the detail at each level is computed as the usual Euclidean norm of the sum of three high-pass components at that level.

The justification for the algorithm is that well-focused images appear to have more detail than unfocused images. A multi-resolutional approach is appropriate because out-of-focus SEM images appear to have "real" detail at intermediate resolutions, but tend to have mostly "noise" at higher resolutions.

The averaging and differencing process is reversible and is used by our software to send images progressively. The system can be described as a perfect reconstruction filter bank. (Again, see Mallat [3] and Strang and Nguyen [4].) Work on progressive image transmission for this project was done by Dr. Morgan while he served as a visiting scientist at FEI's Philips Electron Optics facility in Eindhoven, Netherlands [5], and by Larry Lee as part of his master's thesis [6].

Progressive image transmission has the advantage of providing remote users with rough versions of images first, allowing them to decide sooner whether to wait for the entire image to appear or to move on to capture another image with different stage position, magnification, or other parameters. In essence, it sends the most important parts of the image first to speed the user decision process.

Work continues with other types of wavelets besides the Haar wavelets. The idea is to better match the defocusing effect with the low-pass filter and thus better represent focusing effects in the high-pass components. Results of this work should soon be available in a thesis by Lihua Sun under the direction of Dr. Morgan [7].

References

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