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# Extending Depth of Field in LC-SEM Scenes by Partitioning Sharpness Transforms

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When imaging a sample, it is desirable to have the entire area of interest in focus in the acquired image. Typically, microscopes have a limited depth of field (DOF) and this makes the acquisition of such an all-in-focus image difficult. This is a major problem in many microscopic applications and applies equally in the realm of scanning electron microscopy as well. In multifocus fusion, the central idea is to acquire focal information from multiple images at different focal planes and fuse them into one all-in-focus image where all the focal planes appear to be in focus. Large chamber scanning electron microscopes (LC-SEM) are one of the latest members in the SEM family that has found extensive use for non-destructive evaluations. Large objects (~1 meter) can be scanned in micro- or nano-scale using this microscope. An LC-SEM can provide characterization of conductive and non-conductive surfaces with a magnification from 10× to 200,000×. The LC-SEM, as with other SEMs, suffers from the problem of limited DOF making it difficult to inspect a large object while keeping all areas in focus.

*Figure 1: A large chamber scanning electron microscope (LCSEM) used by the Y-12 group of the Oak ridge National Research Laboratory*

The LC-SEM used for this data acquisition, operated by the Y12 National Security Complex, is shown in Figure 1.

Multifocus fusion is the process of unifying focal information from a set of scanned input images into a single image. Each input image has certain regions of the scene in focus, and an image partition is that region or a set of regions in an input image that fall on the same focal plane. The crux of our method is to isolate and attribute such partitions to one particular input image. A sharpness transform is calculated for every input image $I_i(x,y)$, using $S_i(x,y)=\left\{I_{xi}^2(x,y)+I_{yi}^2(x,y)\right\}^{1/2}$, where $I_{xi}(x,y)$ and $I_{yi}(x,y)$ are horizontal and vertical gradient maps. When the sharpness transform of the input image $I_i(x,y)$ is examined with its $N$-1 counterparts for regions of sharper focus, one image partition, $P_i(x,y)$ is isolated by, $P_i(x,y)=S_i(x,y)>S_{\{k\neq i\}}(x,y)$, for all $k\neq i$. The union of the partitions, $P_i(x,y)$'s, forms the fused image space and the intersection of the partitions is the null set, *i.e.* the blurred sections of all the input images. The image partitions are then seamlessly mosaiced to form the fused image, from the synthesis using, $F_N(x,y)=\bigcup_{i=1}^{N}\left[P_i(x,y)\dot{\times} I_i(x,y)\right]$ where $\dot{\times}$ denotes pixel-wise multiplication. Due to the completeness of the partitioning, there is no need for any blending at the peripheries and the entire fused image space is partitioned and all the pixel locations are populated. The pixel values are not modified at any point in the algorithm and thus, the algorithm provides an undistorted representation of the area of interest. Redundant information does not disturb the stability of the system. The texture is penultimate in rendering on top of any three dimensional surfaces developed. Our fully automatic method can handle partial defocus and has no hardware constraints. A schematic of the process is given in Figure 2.

We present an example area of interest (an image of a curved surface) in Figure 3(a-e). Multiple shots of the area of interest are required to gather information from all focal planes, due to the narrow DOF. In Figure 3(f), the result of tiling via Tenengrad (TVT) is presented, where image stacks are segmented into blocks and one tile per block is chosen based on the Tenengrad Sharpness measure [1]. The input images are divided into sets of blocks and selected based on the Tenengrad criterion [2]. In Figure 3 (g), results from a widely used multiscale decomposition (MSD) fusion method are presented [3]. This method uses the widely accepted coiflet wavelet family and performs fusion by picking the maximum coefficients during the synthesis of the fused image. In Figure 3 (h), image partitioning of the fused image space is shown by color coding. In Figure 3 (i), our method enhances the DOF to elicit information

| | SMD | FE | Tenengrad |
|---|---|---|---|
| **TVT** | 2.60E+01 | 5.27E+00 | 8.67E+07 |
| **MSD** | 2.05E+01 | 3.67E+00 | 5.31E+07 |
| **Our Method** | **3.84E+01** | **5.45E+00** | **9.70E+07** |

*Table 1. Comparison of overall sharpness of TVT and MSD fusion methods with the proposed method using the global Tenengrad sharpness metric[2], and the SMD and FE sharpness metrics [1]. Note that the overall sharpness of the 3d scene fused using our method is higher than TVT and MSD fused images.*

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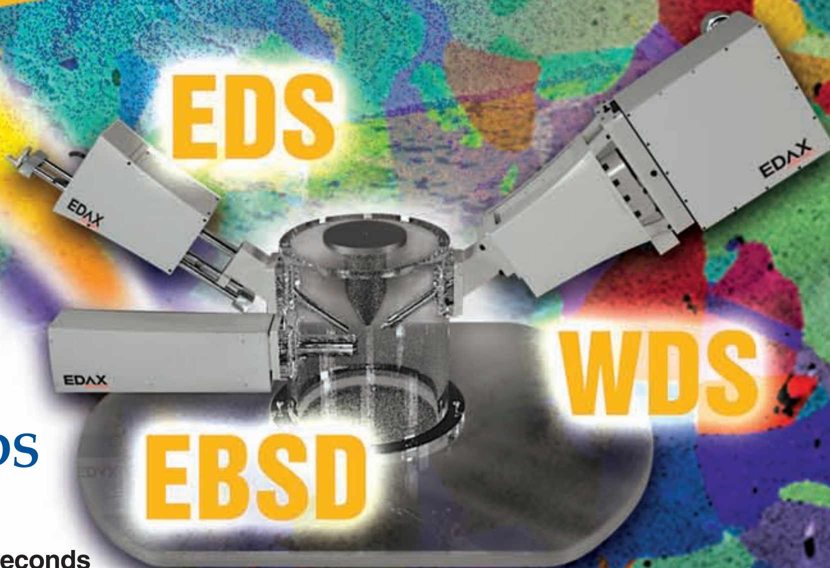


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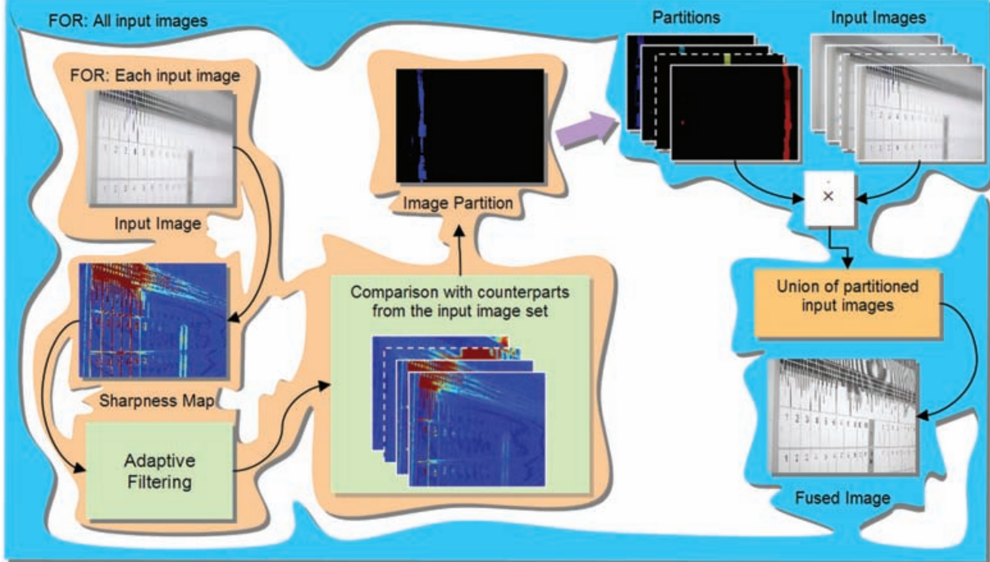


*Figure 2: A schematic of the proposed adaptive focal connectivity (AFC) multifocus fusion algorithm.*

from all focal planes. The fused images were quantized for overall performance using reputed focus measures (*i.e.*, sum modified difference (SMD), frequency entropy (FE) and the Tenengrad) [1]. In Table 1, a comparison of overall sharpness using TVT and MSD fusion is made against our method. We observe that the overall sharpness of our method is higher than contending methods. Our method is extendable to various microscopic systems with narrow DOF and illumination constraints. ■

## References

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*Figure 3. Comparison of overall sharpness of different fusion methods (a-e) Input LC-SEM images (note various sections of the input images are blurred due to the narrow DOF), (f) Fusion by TVT (g) Fusion using MSD based fusion [3] (h) color coded partitions from our partitioning scheme where each colored region represents areas for one focal plane, and (i) multifocus fused image using our method.*



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