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MIPAR™: 2D and 3D Microstructural Characterization Software Designed for Materials Scientists, by Materials Scientists

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Stereology, the science of estimating three-dimensional quantities from two-dimensionally acquired measurements, has historically been the sole technique for microstructural quantification [1]. Over the last decade and a half, 3D characterization has begun to replace stereology with direct-3D quantification. As data acquisition techniques continue to advance, the need for more materials science-orientated analytical 2D and 3D software has become evident.

This led to the development of a comprehensive software suite known as MIPAR™ (Materials Image Processing and Automated Reconstruction) [2]. MIPAR was written and developed within MATLAB™, but is deployable as a standalone cross-platform application. MATLAB's powerful 2D and 3D processing libraries have greatly contributed to and accelerated MIPAR's development. MIPAR is more an application environment than a single program. With a total of five applications, it was designed to handle all post-acquisition stages of 3D characterization: alignment, pre-processing, segmentation, visualization, and quantification, as well as provide a powerful platform for materials science-oriented 2D image analysis. Images of MIPAR's three most commonly used applications are shown in Figure 1.

While direct-3D quantification offers several advantages over stereology such as the absence of sectioning variation and superior quantification of complex shapes, it is not without limitations. With good reason, the representative volume or area element (RVE or RAE) has been an increasingly popular topic of study and discussion [3]. However, a definition of the target quantification precision is often left out of RVE/RAE-related discussions. Therefore, this paper will present the use of MIPAR, together with statistical tools such as random sampling and bootstrapping, to establish quantitative relationships between sampled volume/area size and measurement precision for a variety of microstructural metrics. Two such relationships are shown in Figure 2.

In addition to exploring the influence of sectioning variation on various stereological metrics, direct-3D quantification can either validate or invalidate stereological assumptions. A common stereological metric is the mean linear intercept. Measured from a series of random lines placed within a segmented microstructure, the mean linear intercept has been employed to estimate three-dimensional quantities such as the mean diameter of spheroidal precipitates and mean width of plate-like features [4]. In both cases, the constitutive equations rely of several assumptions regarding the shape and size distribution of the intercepted features. For features in α+β titanium microstructures, MIPAR has been used to explore the validity of these assumptions and determine the sensitivity of stereological quantification to deviations from such assumptions.

The efficacy of these characterization efforts was critically dependent on segmentation. Therefore, a strong focus has been placed on developing a method of objectively quantifying segmentation quality. This method, reliant on the similarity metric of mutual information, has been integrated into MIPAR's Image Processor and examples of its application will be presented.

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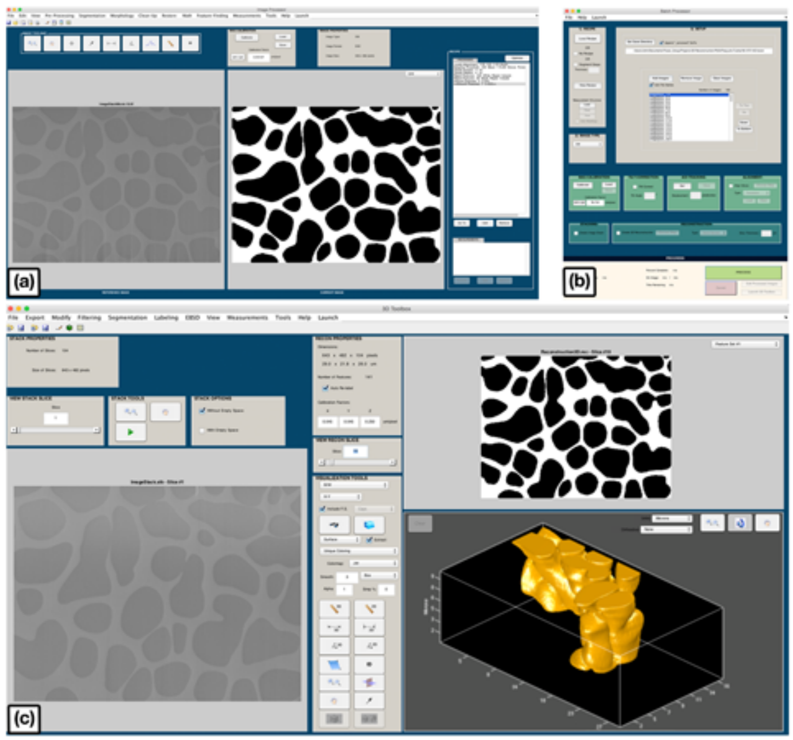

Figure 1. Images of three applications used for 3D characterization in MIPAR™ where (a) reveals the Image Processor, (b) the Batch Processor, and (c) the 3D Toolbox

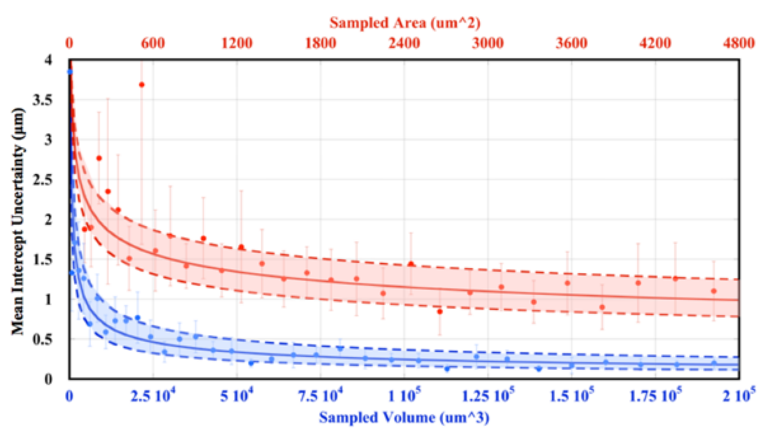

Figure 2. A plot which reveals quantified relationships between mean intercept uncertainty and sampled volume (blue), and between mean intercept uncertainty and sampled area (red). Error bounds for each relationship are shown as dotted lines.

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