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Improved 3D image segmentation for X-ray tomographic analysis of packed particle beds

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ABSTRACT

Although High Resolution X-ray Micro Tomography (HRXMT) has been developed in the past years for the 3D analysis of multiphase mineral particles in packed particle beds, image analysis of fine and/or high-density/high atomic number particles has been limited by existing segmentation algorithms. In this regard, a feature-based segmentation algorithm has been developed and demonstrated to provide a more accurate image processing method for the analysis of such multiphase particle populations. Based on this improved segmentation algorithm, image analyses of packed particle bed samples were compared to segmentation by traditional 3D watershed segmentation. Also, calculation of particle number using optical microscopy, together with a digital camera, was accomplished to validate feature-based segmentation. Detailed procedures and results for sample preparation, image analysis and validation are presented and discussed.

1. Introduction

During the past decade High Resolution X-ray Micro Tomography (HRXMT) has been extended to analyze size, shape, texture, exposure and liberation of multiphase mineral particle populations (Dhawan et al., 2012; Miller and Lin, 2004). The application of High Resolution X-ray Micro Tomography for the three-dimensional characterization of individual multiphase particles in a packed particle bed has been demonstrated by Miller et al. (2009), Lin and Miller (2005, 2010). The 3D examination of multiphase systems by HRXMT includes both data acquisition and data analysis.

Data acquisition is accomplished with the HRXMT facility (MicroXCT-400) from Zeiss located at the University of Utah. By rotating the sample (the packed particle bed) located between the source and the detector, a set of projections (usually 1000 projections, each projection consisting of a 1024×1024 pixel array) is collected and then reconstructed in 3D with a spatial resolution (voxel resolution) on the order of 1 μm.

This 3D reconstructed volume is used for subsequent image analysis. The detailed data acquisition process is shown in Fig. 1.

Data analysis of the 3D reconstructed volume is accomplished by a series of steps, such as image preprocessing and denoising, image segmentation of contacted particles, and subsequent compositional analysis. In order to obtain quantitative image information for samples of interest from the digital data, the first and most critical step is segmentation.

Segmentation for the 3D image analysis of packed particle beds has been accomplished using a traditional watershed function that provides a powerful tool and foundation for advances in particle science and technology (Videla et al., 2006). Although the traditional 3D watershed segmentation works well for most mineral particle populations, image analysis of fine and/or high-density particles with elements of high atomic number has been limited by existing segmentation algorithms. For such particles, it is difficult to differentiate and separate contacted particles in packed particle beds.

The object of this research is to describe improved software for 3D image processing, which combines feature-based classification with watershed segmentation and to compare the improved software to the traditional software for the analysis of fine and/or high density/high atomic number particles in a packed particle bed.

2. The 3D watershed segmentation process

Segmentation is known as the process of separation of the image into objects of interest and non-interest. As was mentioned by Beucher and Meyer, the relative techniques dealing with the graytone images segmentation include the techniques based on contour detection and those involving region growing (Beucher and Meyer, 1993). The watershed segmentation, which combines region growing together with edge detection techniques, has been

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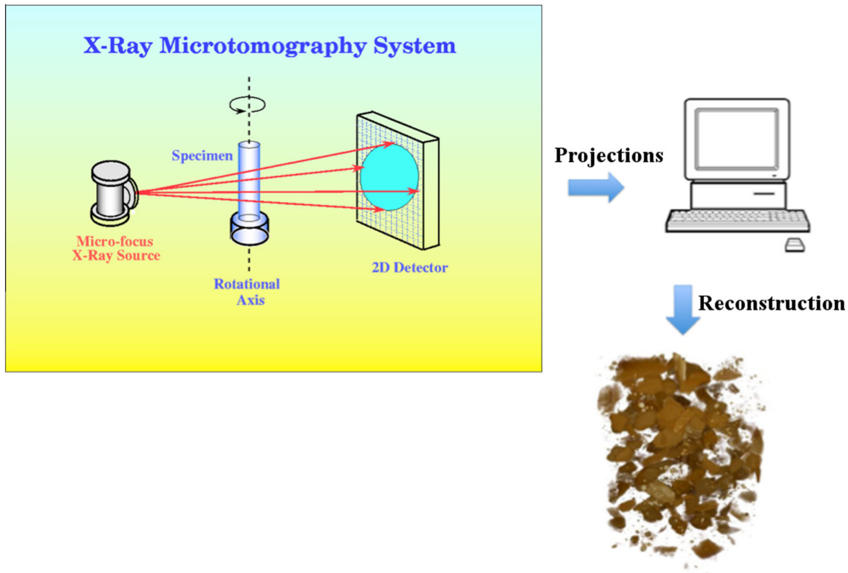

Fig. 1. Data acquisition process.

applied with success in many different situations. However, the direct computation of watershed segmentation always results in over-segmentation. To avoid this problem, marker-controlled segmentation has been developed to transform the input image into the watersheds of the transformed image corresponding to meaningful object boundaries (Beucher and Meyer, 1993; Soille, 1999)

Segmentation is important to our research because it is possible to analyze mineralogical composition after segmentation where the information for each particle in the packed particle bed generates an individual particle histogram, which characterizes just the material belonging to that particle. Considering the irregular shape of the particles and segmentation of the foreground (particle phase), a morphological reconstruction algorithm based on the notion of regional maxima and the use of breadth-first image scannings implanted via a queue of pixels has been introduced (Vincent and Soille, 1993). Based on this algorithm and the semivariogram algorithm developed by Videla et al. (2006), now the watershed segmentation process has been developed in 3D at the University of Utah and successfully applied in many different situations. For example, watershed segmentation has been used in coal washability analysis to improve analysis accuracy (Lin and Miller, 2010). It has also been used in the construction of liberation-limited grade/recovery curves to evaluate flotation separation efficiency (Miller et al., 2009). The 3D air bubble size distribution of porous, brittle solid structures can also be analyzed based on this watershed algorithm (Lin et al., 2010). Fig. 2 gives the complete processing sequence for 3D watershed segmentation. First, noise reduction is applied to the original image using mean, median or non-local mean filters. Second, thresholding is applied to generate a binary image that separates the foreground (solid phase) from the

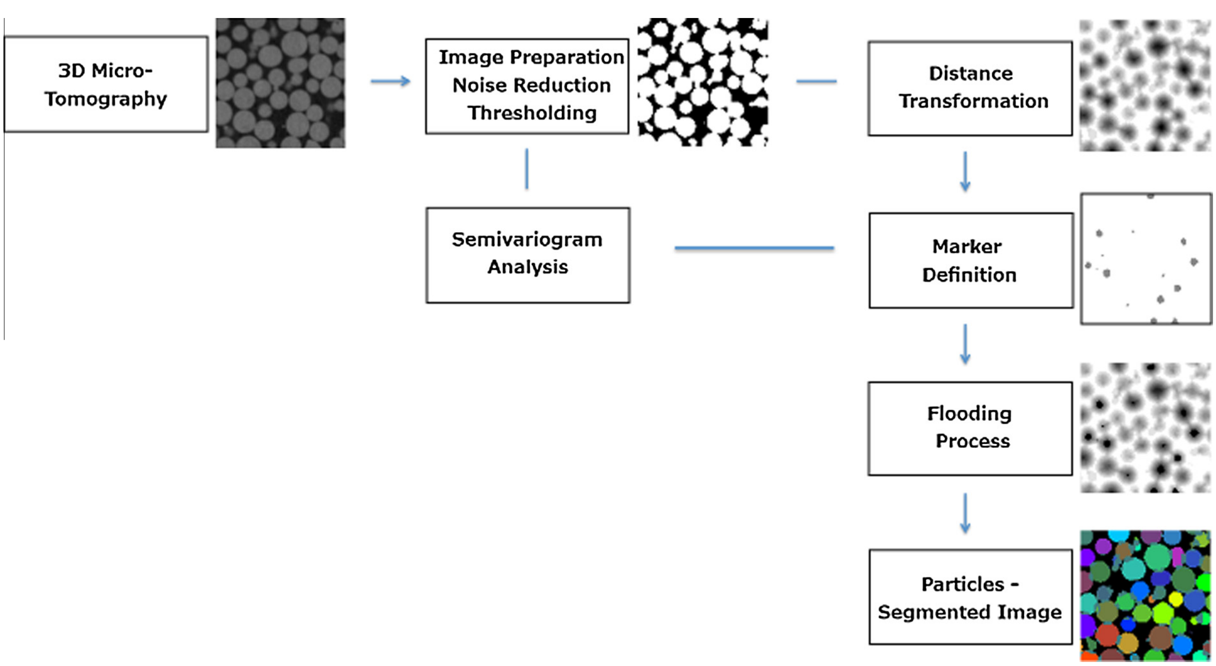

Fig. 2. 3D watershed segmentation process.