Evaluation of Global and Local Image Thresholding Techniques for Quantitative Analysis of X-Ray CT Images of Geological Materials

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INTRODUCTION

- X-Ray Computed Tomography (CT) is a rapidly evolving technology for visualization and characterization of geometrical and topological pore space attributes of geological materials.
- High-resolution X-Ray CT scanners (Fig.1) yield stacks of grayscale images that are segmented and assembled to obtain a 3-dimensional representation of the porous structure.
- Mathematical morphology and other geometrical procedures are employed to quantify the properties of the reconstructed medium pore space for modeling liquid behavior (e.g. Lattice-Boltzmann simulations).
- The most crucial step that affects all subsequent analysis and modeling efforts is image segmentation to separate pore space from the surrounding matrix.
- In this poster we compare several segmentation approaches and illustrate effects on porosity and pore size distribution of selected materials.

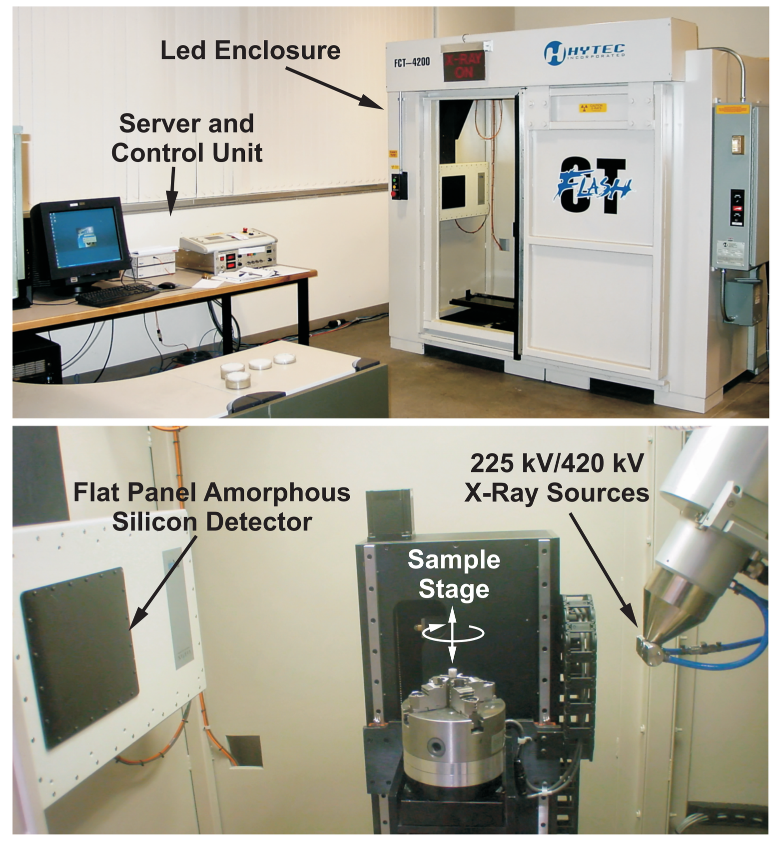

Fig.1: High-Resolution Flash CT X-Ray Computed Tomograph

IMAGE SEGMENTATION

- To distinguish pore space from the surrounding matrix, grayscale images are converted to black and white images (Fig.2). This is achieved by defining a segmentation threshold for the grayscale distribution that assigns each of the image pixels either to the matrix (black) or to the pore space (white).
- There are numerous ways for finding the segmentation threshold. The following methods that are based on the histogram shape (Shape_Zack [6] and Shape_Derivative), clustering analysis (Cluster_Kittler [2] and Cluster_Otsu [4]), entropy of the gray level distribution (Entropy_Kapur [1] and Entropy_Yen [5]), and local statistical pixel parameters (Local_Oh [3]) were compared for this study.

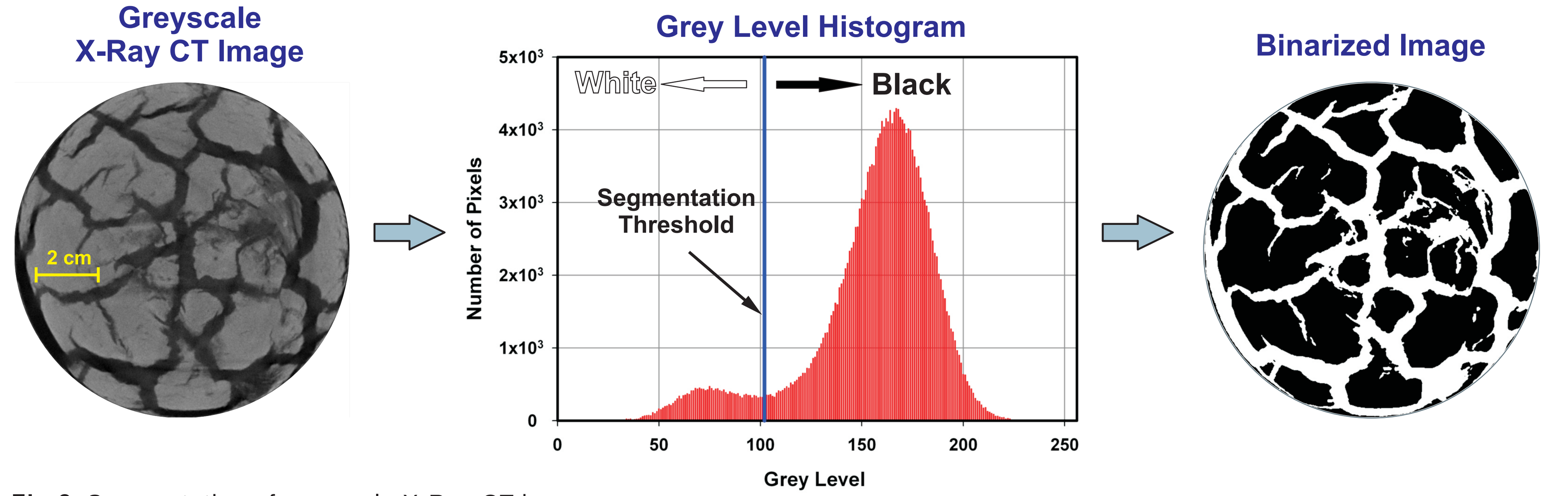

Fig.2: Segmentation of grayscale X-Ray CT images.

RESULTS & DISCUSSION

- For quantifying the impact of image thresholding on medium properties we scanned a range of cylindrical samples composed of uniform glass beads with an industrial X-Ray CT system (Fig.1) at a resolution of 110 microns. Porosities were accurately measured based on bead density and mass and cylinder volume and then compared to porosities obtained from geometrical analysis of reconstructed, binarized image volumes. In addition, we used mathematical morphology operations to construct associated pore-size distributions (Fig.3).
- Preliminary results reveal significant deviations between thresholding methods and measured values. For the sample with 1-mm glass beads (Table 1) all of the tested methods failed to accurately capture the pore space in between glass beads.
- For 3.25-mm beads (Fig.4), the Cluster_Kittler and Entropy_Yen thresholding methods produced results closest to the measured porosity value.
- For 6.35-mm beads, the Entropy_Yen, Entropy_Kapur, and Local_Oh methods came closest to the measured value.

	Sizes of Glass Beads 1.00 mm	3.25 mm	6.35 mm
	Porosities from Binarized Images		
Shape_Zack	0.024	0.418	0.280
Shape_Derivative	0.024	0.549	0.288
Cluster_Kittler	0.006	0.339	0.432
Cluster_Otsu	0.002	0.171	0.269
Entropy_Yen	0.010	0.338	0.339
Entropy_Kapur	0.012	0.271	0.324
Local_Oh	0.012	0.268	0.328
	Directly Measured Porosities		
	0.375	0.370	0.372

Table 1: Comparison of measured porosities of glass bead samples to porosities determined from reconstructed binarized volumes.

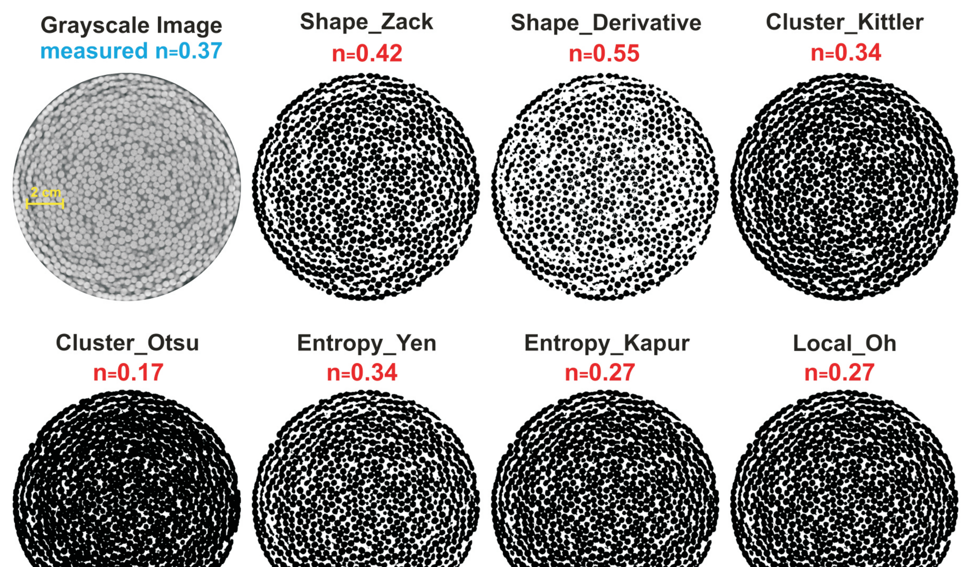

Fig.4: Comparison of segmentation methods for 3.25-mm glass beads.

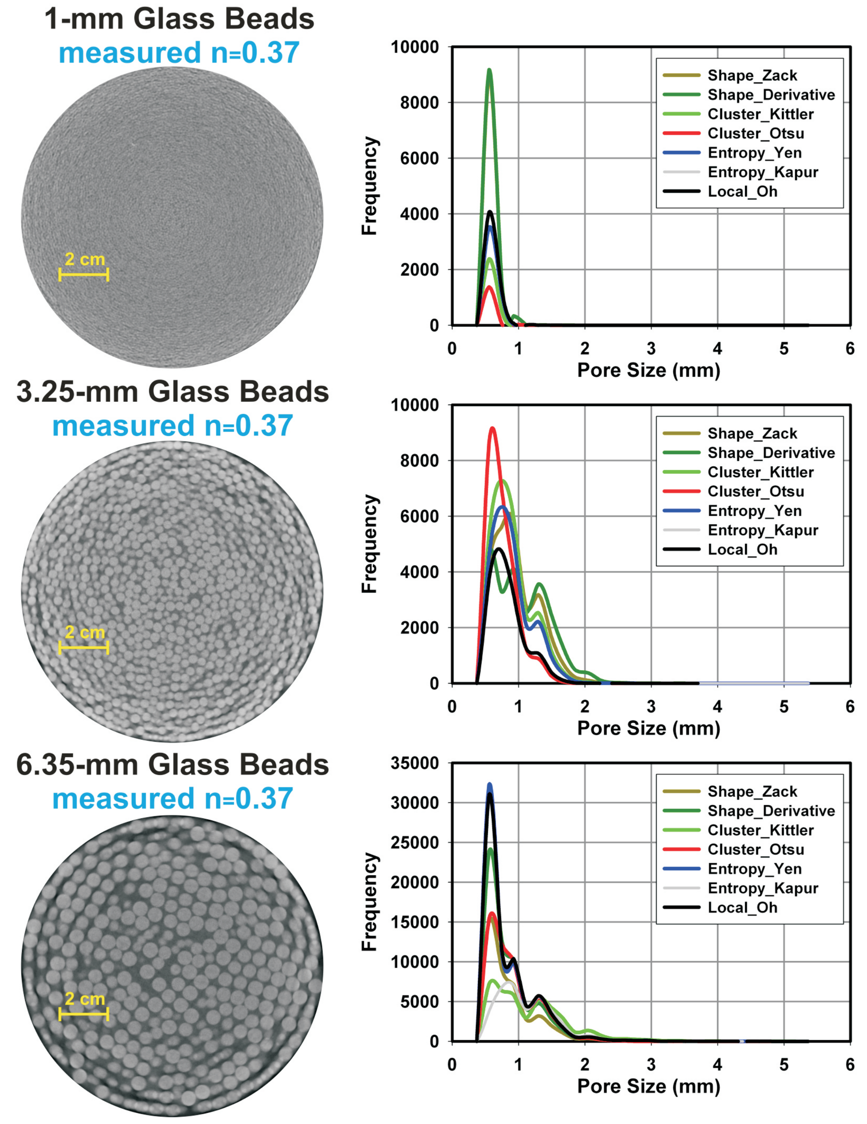

Fig.3: Pore size distributions determined with mathematical morphology operations.

- Based on our preliminary results we cannot make a recommendation regarding a suitable segmentation method for X-Ray CT images of geological materials. It is obvious that all investigated methods have problems with small pores.
- Additional work and fine tuning of methods is required to receive more realistic representations of medium porosity.

MORE RESULTS & ONGOING WORK

- To qualitatively compare segmentation methods for application to macroporous and fractured media, we scanned soil columns with biological macropores (resolution = 110 microns) and bentonite-sand mixtures with dessication cracks (resolution = 165 microns).
- Visual image inspection (Fig.5) reveals that methods based on pixel clustering (Cluster_Kittler and Cluster_Otsu) seem to significantly underestimate macropore space. All other methods seem to reasonably well represent the pore space visible on the grayscale X-Ray CT images.

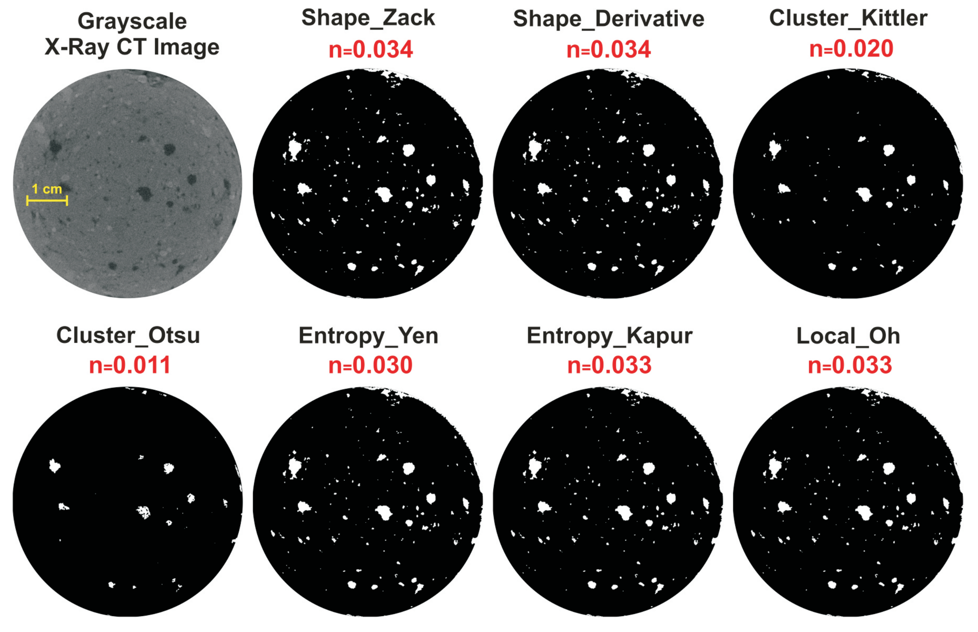

Fig.5: Comparison of segmentation methods for a macroporous soil.

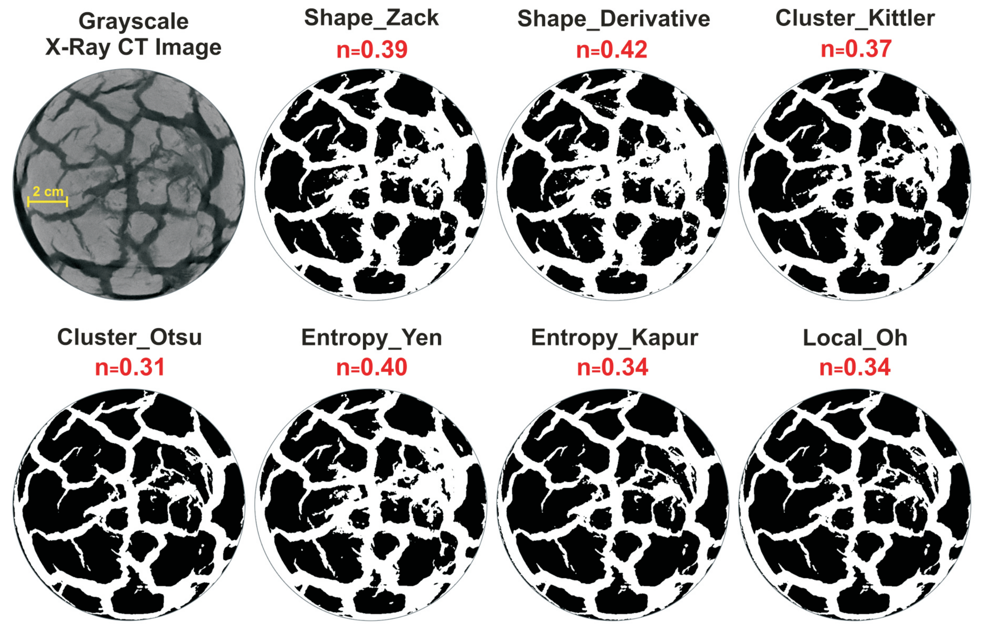

Fig.6: Comparison of segmentation methods for a bentonite-sand sample with dessication cracks.

- For the fractured bentonite-sand sample it seems that the Cluster_Otsu, Entropy_Kapur, and Local_Oh methods best represent the crack network visible on the grayscale images. All other methods seem to overestimate crack space.
- Clearly more work and quantitative analysis is necessary to find the most suitable segmentation method for structured media.
- We are currently testing additional methods and are developing a robust computer code in MATLAB ® that allows side by side comparison of various discussed methods and geometrical analysis of medium pore space (porosity, surface area, pore-size distribution, tortuosity, and pore connectivity).
- All methods are thoroughly tested for all media presented on this poster and for higher resolution (10 microns) Synchrotron Microtomography images. In addition, we are conducting Lattice Boltzmann simulations for the 3-D reconstructed volumes to evaluate how various segmentation methods affect hydrodynamic media properties.

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