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A NEW METHOD OF PORE SPACE SEGMENTATION IN HIGHLY NOISED MICRO-CT 3D DATA APPLIED TO POLISH SHALE GAS DEPOSITS

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Summary: A new method was proposed for pore space segmentation. It was shown that Fourier transform filtering combined with triangle method applied for brightness thresholding gives satisfactory results, even if high resolution X-ray tomography data are highly influenced by noise and measurements artefacts. Moreover, only two parameters have to be adjusted by the user of this method – namely parameters of Fourier bandpass filter.

1. INTRODUCTION

Unconventional oil and gas deposits gain much attention due to industrial importance. Among geophysical parameters, porosity of reservoir rocks plays crucial role in this context thus it has to be thoroughly analysed, taking into account distribution of volume, shape, orientation as well as spatial location. The determined pore space statistics allow the complex evaluation of the reservoir and geomechanical properties, what is important for a proper preparation to the hydraulic fracturing process. High resolution X-ray computed tomography, also referred as micro-CT, emerges as the most appropriate technique applied in order to analyze spatial distribution of pores [1], especially when representative elementary volume scale and non-destructive character of performed measurements are strictly required [2]. However, it has be to emphasized that although micro-CT is powerful method, its successful application strongly depends on appropriate absorption of X-ray radiation by different parts of the sample, since this property is then reflected in voxel intensity contrast. From this point of view, it should be noted that segmentation of pore space is often based on the assumption that brightness histogram is a multimodal function, where each of the modes corresponds to a particular object in the measured volume. Pores, due extremely small electron density thus meaningless absorption of incoming X-ray beam, are usually represented by the lowest brightness values. Hence, an approach consisting of data noise reduction and histogram global thresholding (like Otsu method) is good enough to extract large pores [3, 4]. Unfortunately, the abovementioned approach cannot be used in this study which concerns analysis of nano and micro-pores in Polish shale gas deposits based on micro-CT measurements conducted with Nanotom S General Electric nano-tomograph. The data obtained have unimodal histograms where pores gray level value is not distinctly separated from the surroundings. Moreover, despite high power X-ray tube with max. operating voltage = 180 kV, pore space is highly affected by measurement noise (Fig. 1(a)), mainly originated from weak intensity of detected X-ray beam (this is clear limitation of non-synchrotron radiation used in the laboratory equipment). Another important problem is caused by circular artifacts connected with applied cone-beam X-ray source. Therefore, the main aim of this work is to propose pore space segmentation method which can deal with the described situation.

2. PROCESSING METHOD AND RESULTS

Initial 3D data consisting of 2300x2300x2100 voxels, where each voxel represents 0.8x0.8x0.8 μm^3 in 3D space, were reconstructed using Feldkamp back-projection method. The developed segmentation algorithm consists of following steps: initial processing with median filter, first histogram thresholding, application of Fourier bandpass filter, second histogram thresholding with triangle method and morphological operations combined with median filter. All operations were performed using ImageJ software [5]. Application of Fourier bandpass filter is a fundamental step in the proposed method, as it can be used to reduce noise connected with local brightness

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variations as well as long background gradients. Briefly, structures described by wavelength belonging to an interval defined by two input parameters remain in the filtered image, whereas the rest is removed. Therefore, these two parameters have to be carefully chosen – as shown in Fig. 1(a-d). Also, Fourier transform (FT) is highly sensitive on bright objects which after processing are surrounded with dark shadows. Therefore, first brightness thresholding has to be applied before FT: all voxels with brightness higher than histogram average are assigned a new brightness value equal to the mentioned average. Histogram obtained after bandpass filter: 12 - 400 has shape that can be easily thresholded with triangle method (Fig. 1(e)). As a result, pores can be automatically separated. Finally, 3D morphological operations (erosion and dilation) and median filtering are applied on the binarized data which is necessary due to the fact that FT processing is performed in 2D. The presented methodology has been tested using various shale samples. Example segmentation of pore space in sandstone is presented in Fig. 1(f).

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References

[1] V. Cnudde & M.M. Boone. High-resolution X-ray computed tomography in geosciences: A review of the current technology and applications. *Earth-Science Reviews* 123, 1–17, 2013.

[2] D. Wildenschild & A.B Sheppard. X-ray imaging and analysis techniques for quantifying pore-scale structure and processes in subsurface porous medium systems. *Advances in Water Resources* 51, 217–246, 2013.

[3] Y.-S. Wang & J.-G. Dai. X-ray computed tomography for pore-related characterization and simulation of cement mortar matrix. *NDT&E International* 86, 28–35, 2017.

[4] W. Wang et al. Comparison of image segmentation methods in simulated 2D and 3D microtomographic images of soil aggregates. *Geoderma* 162, 231–241, 2011.

[5] C.A. Schneider, W.S. Rasband & K.W. Eliceiri. NIH Image to ImageJ: 25 years of image analysis. *Nature methods* 9(7), 671–675, 2012.

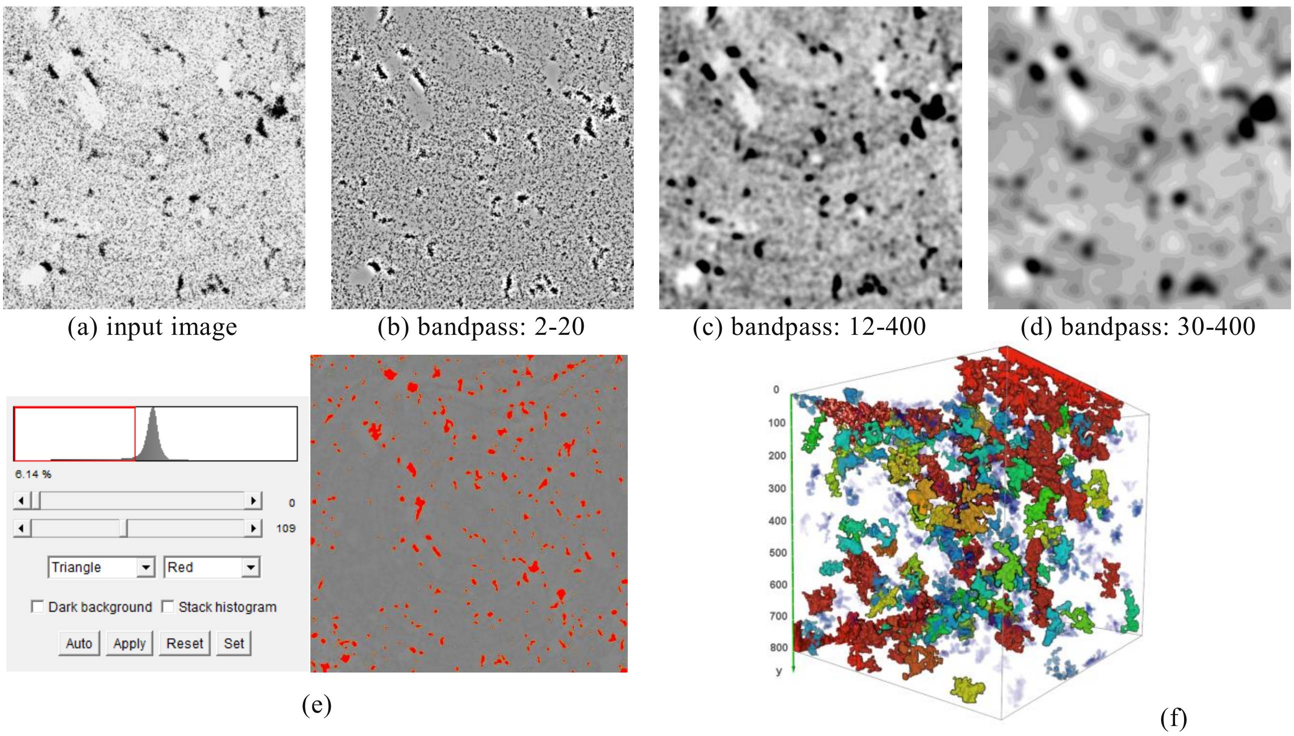

Figure 1: (a-d) Results obtained after application of bandpass filter with parameters: 2-20 (b), 12-400 (c) and 30-400 (d) on input image (a); (e) Triangle thresholding after FT bandpass filtering with parameters 12-400; (f) 3D visualization of the largest pores segmented from sandstone micro-CT data.