

# Problems of Objects Identification in Three-dimensional X-ray Tomography

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**Abstract.** X-ray computed tomography is a unique non-destructive technique which is suitable for dimensional measurements and quality testing. X-ray tomography is applied widely not only in the traditional medical area, but in natural science and engineering fields. The result of tomography is a volumetric map of attenuation coefficients which has, in fact, a limited practical sense. Usually, segmentation that converts the map into binary objects by means of threshold value is applied. In this paper we discuss the some key features of segmentation applied to a test object which is gravel composed of unconsolidated rock fragments. Gravel appeared to be a challenging object for segmentation and image recognition. One of effective approach for image processing of tomographic data, among many possible ones, is presented in this paper.

## 1. Introduction

X-ray XCT is a non-destructive technique for imaging the internal structure of solid objects. XCT is useful for a wide range of materials, such as rocks, bones, ceramic, metals and soft tissues.

The interaction of X-rays with matter is a base of XCT technique. X-rays are attenuated due to Beer's law for complex materials after they pass through an object and this attenuated radiation is registered by the detector. In XCT, a set of shadow projections of the object are obtained from different angles. The set of projections is then reconstructed and a volumetric map of attenuation coefficients is obtained. For tomographic reconstruction different mathematical algorithms and software based on them are used. The purpose of dedicated software is not only reconstruction, but also reduction of artifacts and basic imaging operations, that are required for further processing such as segmentation and quantification [1, 2]. A map of attenuation coefficients has a limited practical sense. Usually, reconstructed volume is processed by segmentation. This operation converts the map into binary objects by means of threshold value chosen manually or by some algorithm. On this first step, one can encounter unavoidable difficulties which are inherited from nonlinearity and complexity of X-ray and matter interaction. After segmentation, the most common procedure is quantitative analysis that deals with separate binary objects produced by segmentation.



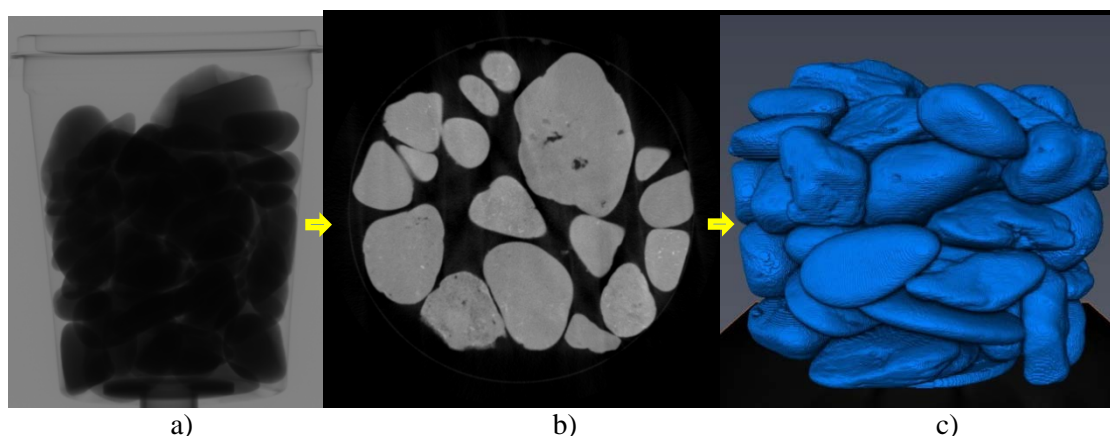
## 2. Materials and methods

The high energy computed tomography scanner was assembled at Institute of Nondestructive Testing, at Tomsk Polytechnic University. The research group developed the present setup reported recently their first successful results in field of XCT scanners assembling and evaluating [3, 4].

The main components of the system are a scintillator based X-ray detector, an X-ray tube and a rotary stage. The setup uses the MXR-451HP X-ray tube (produced by Comet, Switzerland) as an X-ray source. The voltage of the tube is in 20–450 kV range and the focal spot has two modes and can be 0.4 or 1 mm in size. The X-ray detector is XRD 1622 flat panel (produced by Perkin Elmer, USA) with 2048×2048 pixels array based on TFT technology. The pitch of pixels is 200  $\mu\text{m}$ . Scintillator is made of CsI crystals. Rotary stage provides smooth rotation by step down to 0.01 degree and linear translation of the specimen between the detector and the tube to adjust required magnification and, thus, voxel size.

We used gravel mixture as a test object to demonstrate segmentation and image processing as well as some possibilities of quantitative analysis. Scanning parameters were: accelerating voltage of 100 kV, anode current of 3 mA, angular step of 0.5 degree, frame exposure of 1 s and voxel size of 101  $\mu\text{m}$ . It required approximately 45 minutes to acquire the data set of shadow projections with total number of 720. In addition, we used copper filter 0.2 mm in thickness to reduce beam hardening artifacts.

Usually, XCT consist of the three main steps: data acquisition, reconstruction and segmentation [5]. The results obtained on each step are shown on figure 1.

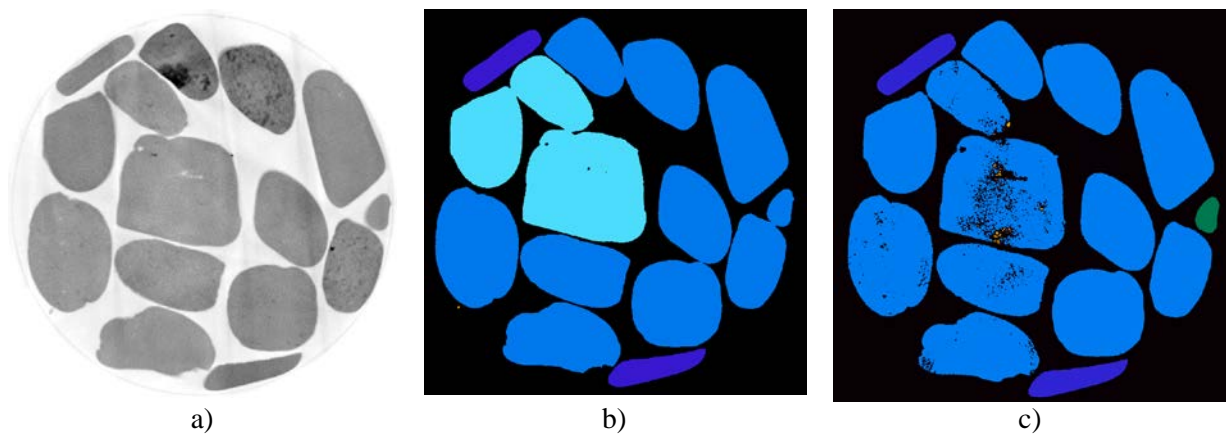


**Figure 1.** The three main step of XCT: acquisition results in shadow projections (a); reconstruction results in tomographic slice (b); segmentation results in binary objects, seen separately within the volume of interest (c).

The internal structure of the investigated rock fragments was reconstructed by means of the Nrecon software for cone-beam scanning geometry developed by Bruker microCT [6]. To enhance the image quality of slices a few correction options were used, namely, beam hardening correction and ring artifact reduction [7]. In result, a set of 8-bit grayscale slices was obtained.

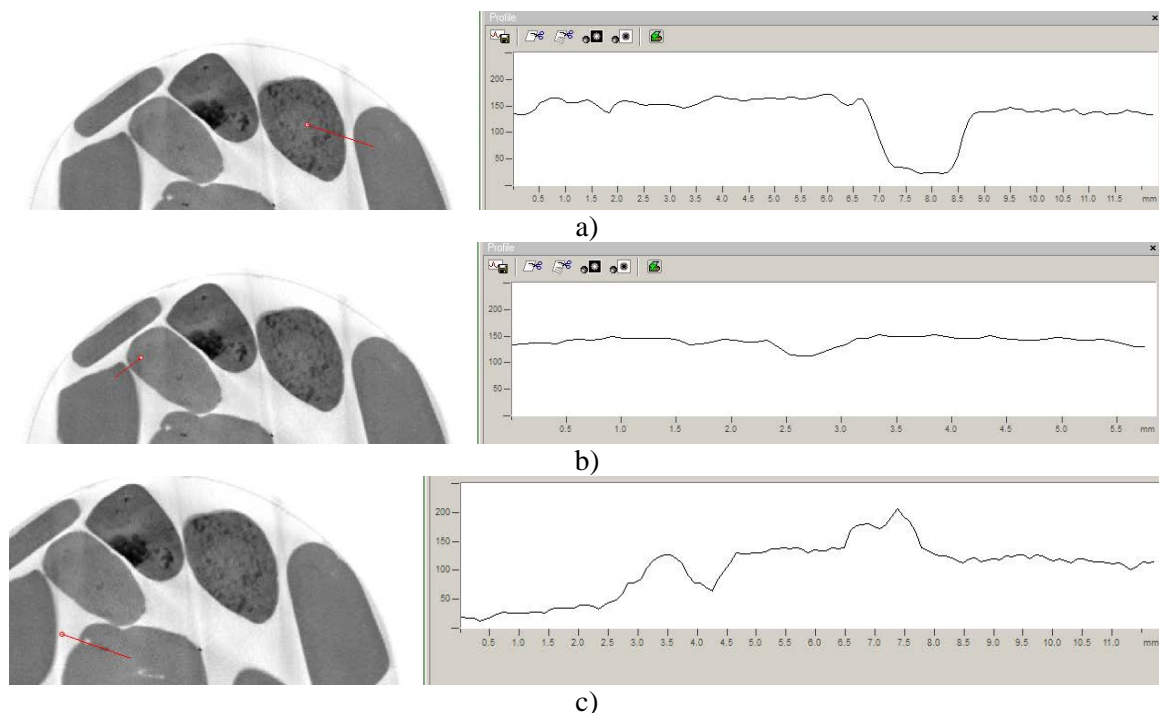
## 3. Results

Segmentation is an operation applied to a grayscale image to convert it into a binary image by using some segmentation algorithm and some threshold level. The gravel mixture appeared to be a challenging object for segmentation procedure. As seen on figure 2, there are 15 rock fragments on the slice. However, a simple segmentation by Otsu algorithm with threshold value is equal 71 reveals only 11 fragments, because the gap between some of them is not pronounced enough. We can change the threshold value, for example, to 117. In this case, we are getting a proper number of fragments, but distorted picture of objects within the slice.



**Figure 2.** The slice in grayscale shows 15 fragments (a); segmented image with threshold on 71 shows 11 fragments (b); segmented image with threshold on 117 shows 15 distorted fragments (c).

The reason for this is illustrated on figure 3. Any tomographic image suffers from partial volume effect [6], which means a border between an object and the outer media is a slope, not a sharp edge. In some regions gaps between objects are pronounced enough to separate them, in others they are not. In addition, internal structure of rock fragments is inhomogeneous. Resuming, one-step simple segmentation is not enough to identify rock fragments in the mixture. It requires much more complex approach.



**Figure 3.** The gap between fragments is pronounced (a); the gap is hardly detected (b); the density, i.e. gray value, within a fragment is inhomogeneous.

The image segmentation and visualization was performed by the VSG Avizo Fire 9 software [8]. We used several morphological operations for image processing, namely, despeckle, thresholding, dilation, separation, and additional operation: labeling, label analysis and volume rendering. Despeckle tool was used to remove “bad” (or “died”) pixels and the noise from the image. The size of

removed pixels was 300  $\mu\text{m}$ . Global threshold was used to produce binary images. Thresholded images were dilated which uses structuring element for probing and expanding the shapes contained in the input images. Finally, dilated images were separated by watershed segmentation. The combination of these morphological operations made it possible to further quantitative image analysis. The complete scheme of image processing is shown on figure 4.



**Figure 4.** The scheme of image processing applied to gravel mixture from despeckle step to quantitative analysis.

Figure 5 shows the difference between filtered image (the second step on the scheme on figure 4) and segmented image in XY plane (the next to last step on the scheme).

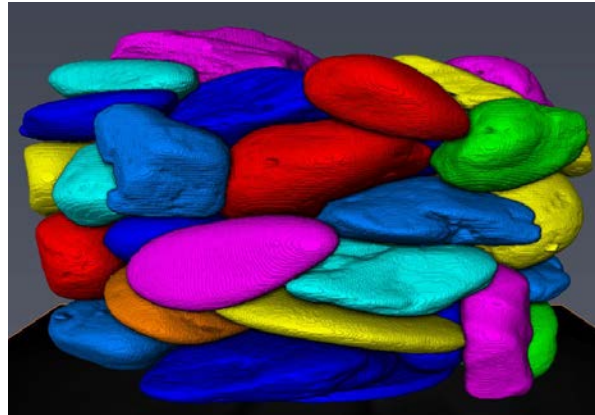


**Figure 5.** Image processing: a filtered image (left) and the same image after segmentation and labeling (right).

As seen on figure 5, on the filtered image borders between rock fragments are absent; consequently, the number of fragments is far from the true value. On the contrary, segmented image shows a realistic result. Segmented image was labeled to visualize the shape of each fragment.



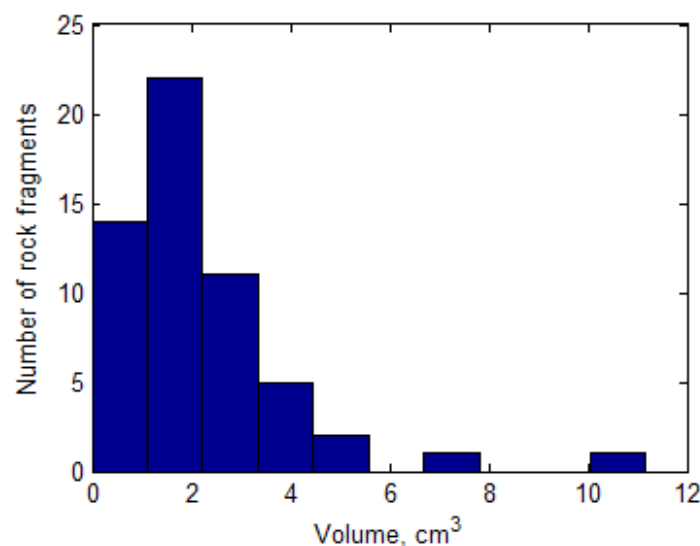
Labeling algorithm was implemented to the segmented binary images. Then the rock fragments were separated according to their volume and visualized using different colors as shown on figure 6.



**Figure 6.** Different rock fragments labeled by different colors.

After visualization of a 3D object from 2D slice images, the quantitative analysis and volume distribution was performed. For this purpose number of rock fragments was calculated from the 3D data set, and then they were organized into 10 groups according to their volumes (see figure 7). The number of rock fragments counted automatically was equal to their number in reality.

Besides volume distribution, one can estimate the volume of objects as a percentage to the volume of interest, which can be defined, for example as the space within the container. In addition, spatial orientation of rock fragments is a possible option. Resuming, relevant segmentation opens as many ways to quantitative analysis as one would need.



**Figure 7.** Rock fragments' volume distribution.

#### 4. Conclusion

XCT is a powerful technique for investigation the internal structure of objects. In this paper, we presented the image processing and image analysis with using gravel as a test object. The main steps of XCT are demonstrated. Data was acquired by means of high energy computed tomography set-up. The reconstruction slices from shadow projections was enhanced by applying beam hardening and

ring artifact corrections. Reconstructed data set was segmented to obtain binary objects. The number of rock fragments was correctly counted and their volume distribution was calculated. The described method can be applied for investigation of porous and non-uniform materials to perform quantitative analysis.

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