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The effectiveness of global thresholding techniques in segmenting two-phase porous media

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HIGHLIGHTS

- Various image segmentation techniques are highlighted.
- Effectiveness of thresholding, in image segmentation, was examined.
- No single thresholding technique was found to be effective across a wide range of geomaterials.

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ABSTRACT

The effectiveness of five global thresholding techniques, to accurately segment different geomaterials, was evaluated in this work. X-ray CT images-taken from two-phase pervious concrete, glass bead, and silica sand specimens-were analyzed for evaluating five chosen methods. The core algorithms for these methods were coded using a Matlab programming language and packaged into a standalone application software. Three hundred and thirty-five image slices were provided for the pervious concrete specimen and the cropped size of this specimen was approximately 68 mm in diameter. The method proposed by Kapur et al. (1985) yielded the best results qualitatively and quantitatively (e = 0.28) to the laboratory and Image-Pro measured void ratios of 0.26 and 0.30, respectively. Eleven image slices were analyzed for a 10 mm in diameter glass bead specimen. Once again, the method proposed by Kapur et al. (1985) gave the best results with a void ratio of 0.91, as compared to the Image-Pro void ratio of 0.89. Ten image slices, with a cropped diameter of 4.48 mm, were used for the analysis of the silica sand specimen and the Otsu (1979) method was the most successful image segmentation technique, yielding a void ratio of 0.85 (Image-Pro e = 0.77). From the results, it can be said that, no single image segmentation technique performs well over a wide range of material and that the performance of each image segmentation technique varies depending on the type and state of the analyzed media.

1. Introduction

Some of the most utilized segmentation techniques use the concept of thresholding. Thresholding techniques could be either bi-level or multi-level [1]. For bi-level thresholding, an image is segmented into two different regions. Pixels with gray values greater than a threshold value are classified as foreground (object) pixels and pixels with gray values less than a threshold value are classified as background pixels. On the other hand, in multi-level thresholding, a gray-level image is segmented into several distinct regions. Multi-level thresholding results in more than one threshold value for the image [2]. The field of image thresholding has been well researched, yielding many different models that can be used to achieve the same result of effectively segmenting an image.

Thresholding techniques can be categorized as global or local. Global thresholding is used when a chosen threshold value depends only on gray-level values and relates to the characteristics of pixels. There are numerous global thresholding techniques such as Otsu's method [3] that will be discussed further in this paper. The biggest issue that global thresholding methods face when utilizing an image's gray-level histogram is that not all features of interest form prominent peaks, in the image histogram, due to noise [1]. In the presented work, to ensure that the efficiency of the global thresholding techniques is not compromised, the images analyzed will be freed from any noise that could significantly affect the quality of the thresholding results.

Local thresholding techniques are applied when a threshold value depends on both the gray-level value and local property of

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a pixel. In other words, a different threshold value is determined for each pixel based on the grayscale information (e.g., range and variance) for the neighboring pixels [4]. This approach divides an image into several subregions and chooses a threshold for each of these subregions. After such thresholds are applied, a gray-level filtering technique is used to eliminate discontinuous gray-levels among the subregions.

Global thresholding techniques, in segmenting two-phase porous media, have been discussed in the literature [3,5–9]. From the vast range of global thresholding techniques, the Otsu (1979), Pun (1980), Kapur et al. (1985), Johannsen and Bille (1982), and Kittler and Illingworth (1986) methods are selected, based on their prior applicability success over a wide range of image types, and tested for their effectiveness in accurately segmenting geomaterials. Ensuing sections provide further details on these techniques, including the mathematical algorithms and theoretical concepts behind the selected methods.

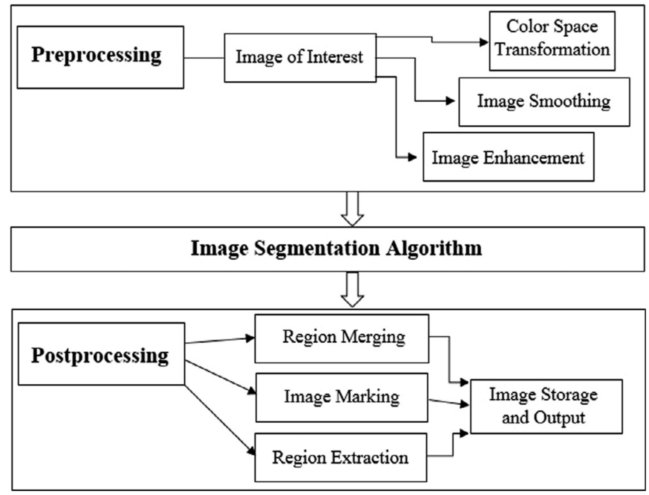

Fig. 2. Image segmentation system structure (Yang and Kang 2009).

2. Image acquisition and processing

2.1. Image acquisition

There are various types of images, such as magnetic resonance images (MRI), thermal images, and light intensity (visual) images. Light intensity images are the most commonly encountered type of images. As indicated in the name, light intensity images represent the variation of light intensity on the scene [2]. All images, regardless of type, can be viewed as digital images. A digital image is represented by a two-dimensional discrete function, f(x,y), which is digitized in both spatial coordinates and magnitude of feature value (e.g., light intensity, depth, and temperature intensity) [2]. The values of x and y in a discrete function represent row and column indices, respectively. A point marked by these indices is known as a pixel. The pixel equivalent in three-dimensional space is referred to as a voxel [10].

Images can be obtained through X-ray computed tomography (CT), which is an advanced imaging technique that allows for non-destructive and noninvasive imaging of specimens to depict cross-sectional and three-dimensional internal structures [11]. Such a system is especially useful for highly porous materials [12]. There are numerous X-ray CT systems in the market today ranging from benchtop synchrotron microtomography scanners to industrial X-ray image acquisition systems. Fig. 1 provides a general scheme for specimen installation in an X-ray CT chamber. X-ray beam, originating from an X-ray source, passes through a specimen and hits a detector where data that is useful in projecting the internal structural details of the scanned media is created. The specimen is rotated about an axis perpendicular to the beam and a detector processes attenuation coefficients of the X-rays as they emerge from the specimen. Each image slice represents a portion of the specimen and combining all of the slices together yields the virtual three-dimensional representation of the imaged specimen [13].

2.2. Image Segmentation

Image processing deals with utilizing algorithmic programs to identify and extract information from images. Almost all image processing tools convert an 8-bit or 16-bit image into its binary format after segmentation is performed. Binary images take smaller storage space, are easier to manipulate, and can be processed faster when a thresholding algorithm is applied. This binarization is what is commonly referred to as image segmentation and it represents the foundation for computer vision and object recognition. In image segmentation, the overall histogram of an image is partitioned into two regions, with the goal of separating objects of interest (i.e., the foreground) from the background [14]. The quality of the segmented image is controlled by how well the threshold that separates the foreground from the background is estimated.

Advancements in image acquisition and processing technologies, over the last few decades, have allowed for tremendous growth in both the theory and application of image segmentation techniques. These techniques are very popular in many fields, such as medical [15], forensic [16,17], and agricultural [18]. Scanned documents, including text, line drawings, or other graphics may

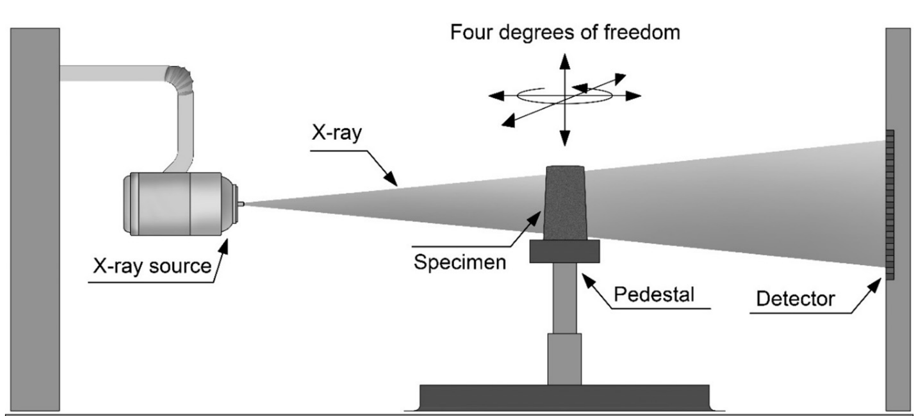

Fig. 1. Schematic of specimen installation in X-ray CT chamber.