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Multiphase flow imaging using an adaptive multi-threshold technique in electrical resistance tomography ☆

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ABSTRACT

Electrical resistance tomography has been employed as an alternative technique to visualize multiphase flows, because it has the high temporal resolution for monitoring fast transient processes. However, the non-linearity and ill-posedness of the inverse problem cause the poor spatial resolution of the reconstructed images. In this paper, the inverse problem is solved with an adaptive multi-thresholding method (multi-Otsu's method) to improve the reconstruction accuracy and decrease the ill-possedness. A multi-threshold technique is employed to separate the background from the target regions in the resistivity profile estimated on each iteration. The iterative Gauss–Newton method with an adaptive multi-threshold method is applied to the multiphase flow imaging. Numerical simulations and experiments have been carried out to illustrate the reconstruction performance of the proposed method.

1. Introduction

Multiphase flows are of great interest in various engineering applications as well as in many other scientific fields, such as chemical and nuclear engineering, biology, meteorology, and physics [1,2]. The understanding of the flow configuration of the multiphase mixtures is important in the design and safe operation of mechanical systems. For the monitoring of multiphase flows, various non-invasive techniques have developed, for instance, X-ray tomography [3], Terahertz tomography [4], electrical capacitance tomography [5], and so on. Electrical resistance tomography (ERT) has been employed as an alternative technique to visualize two-phase and multiphase flows, because it is relatively inexpensive and non-destructive. Especially, it has the high temporal resolution characteristics for monitoring fast transient processes. Despite a strong potential for monitoring multiphase flow fields, there is still a need for improving the spatial resolution of the reconstructed images due to its non-linearity and ill-posedness.

Several researchers have proposed different methods to improve the spatial resolution of the ERT reconstruction images. In this perspective, Kim et al. [6] proposed an adaptive mesh grouping scheme with predefined threshold values for two-phase flows. In Kim et al. [7], an adaptive threshold method is applied to the iterative Gauss–Newton method to overcome the poor spatial resolution in the two-phase flow study. Martin et al. [8] applied the simulated annealing method to the multiphase flow image reconstruction from the electrical capacitance tomographic measurements. However, their method requires lots of forward problem computations.

This paper is an extended version of the work of Kim et al. [7] for multi-target and multiphase flows, so the basic concept of this paper is similar to that of their work. In this paper, to enhance the reconstruction accuracy, an adaptive multi-threshold method adopted from image processing techniques is applied to the ERT inverse problem. The resistivity distribution can be considered as the intensity or the gray level of an image in the image reconstruction problem [7]. Usually lots of threshold techniques in image processing are used to separate the objects from the background [9]. On the other hand, this paper employs a multi-threshold technique to determine classification criteria that are for roughly extracting the background elements from a given domain. Optimal threshold values for the classification criteria are automatically computed by multi-Otsu's method [10,11] from the resistivity image profile estimated on each iteration. After finding the threshold values they are combined with the iterative Gauss–Newton (GN) method. The main feature of the proposed method is to reduce the condition number of the inverse term of the GN method and mitigate the ill-posedness in the inverse problem and, thus improve the accuracy in the image reconstruction. Numerical simulations and phantom experiments have been carried out to evaluate the reconstruction performance of the proposed method.

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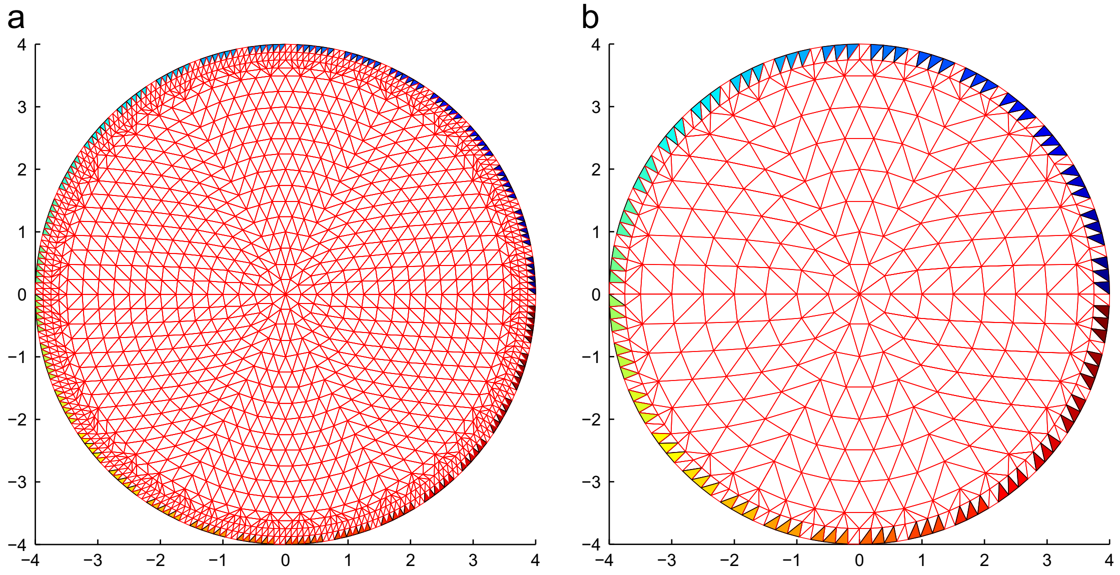

Fig. 1. The finite element meshes: (a) forward fine mesh and (b) inverse coarse mesh. The colored regions in the boundary represent 32 electrodes.

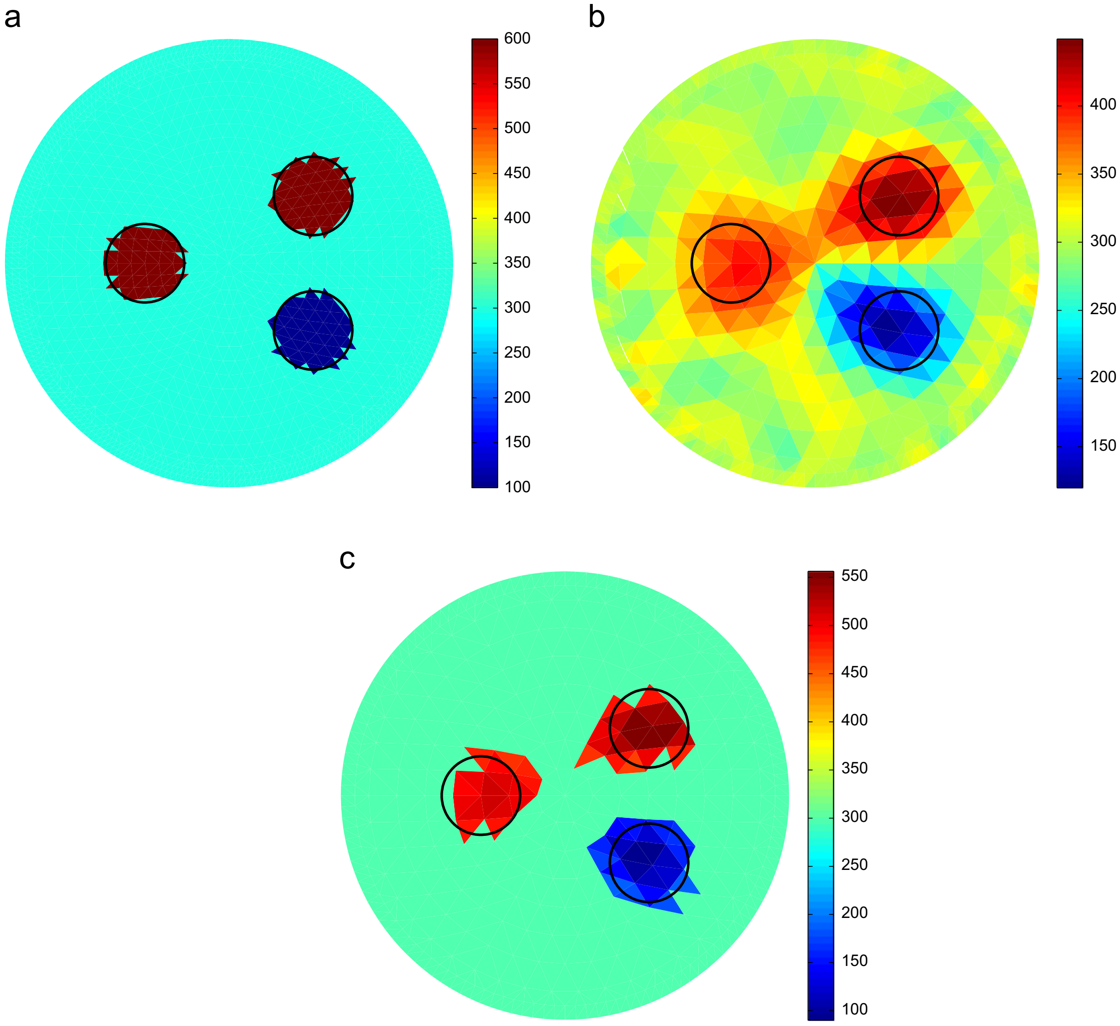

Fig. 2. Reconstructed images for case 1: (a) true image, (b) image by GN, and (c) image by GNAM. The black circles in the images represent the true position of three targets.

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