http://dx.doi.org/10.5516/NET.02.2013.038

<Technical Note>

ELECTRICAL RESISTANCE IMAGING OF TWO-PHASE FLOW WITH A MESH GROUPING TECHNIQUE BASED ON PARTICLE SWARM OPTIMIZATION

BO AN LEE[1], BONG SEOK KIM[1], MIN SEOK KO[2], KYUNG YOUN KIM[3], and SIN KIM[1,2*]
[1]Institute for Nuclear Science and Technology, Jeju National University, Jeju 690-756, South Korea
[2]Department of Nuclear and Energy Engineering, Jeju National University, Jeju 690-756, South Korea
[3]Department of Electronic Engineering, Jeju National University, Jeju 690-756, South Korea
Corresponding author. E-mail : sinkim@jejunu.ac.kr

Received May 15, 2013
Accepted for Publication September 06, 2013

An electrical resistance tomography (ERT) technique combining the particle swarm optimization (PSO) algorithm with the Gauss-Newton method is applied to the visualization of two-phase flows. In the ERT, the electrical conductivity distribution, namely the conductivity values of pixels (numerical meshes) comprising the domain in the context of a numerical image reconstruction algorithm, is estimated with the known injected currents through the electrodes attached on the domain boundary and the measured potentials on those electrodes. In spite of many favorable characteristics of ERT such as no radiation, low cost, and high temporal resolution compared to other tomography techniques, one of the major drawbacks of ERT is low spatial resolution due to the inherent ill-posedness of conventional image reconstruction algorithms. In fact, the number of known data is much less than that of the unknowns (meshes). Recalling that binary mixtures like two-phase flows consist of only two substances with distinct electrical conductivities, this work adopts the PSO algorithm for mesh grouping to reduce the number of unknowns. In order to verify the enhanced performance of the proposed method, several numerical tests are performed. The comparison between the proposed algorithm and conventional Gauss-Newton method shows significant improvements in the quality of reconstructed images.

KEYWORDS : Electrical Resistance Tomography, Binary Mixture, Two-phase Flow, Mesh Grouping, Particle Swarm Optimization, Gauss-Newton Method

1. INTRODUCTION

Binary mixtures, like two-phase flow, are frequently encountered in various engineering systems. For example, in the chemical, oil, and nuclear industries, binary mixtures of chemical substances, oil-water, oil-air, steam-water are commonly observed in a single component. The information on the distribution of each substance is necessary in the design, the performance analysis, and the monitoring of the system. Especially, two-dimensional information on phase distribution in two-phase flow fields would be more favorable for theoretical model development and verification of CFD (Computational Fluid Dynamics) codes, since the two-phase flow phenomena are essentially multi-dimensional.

Many two-dimensional imaging methods like radiation absorption and scattering method [1], optical method [2], ultra sound method [3] and electrical methods [4] have been developed. Among these, electrical methods such as electrical resistance tomography (ERT) and electrical capacitance tomography (ECT) have favorable advantages, including no ionization radiation, low cost, and high temporal resolution compared to other methods. In this work, the electrical resistance tomography (ERT) technique is considered. The ERT uses the fact that the measured potentials on the electrodes attached on the domain boundary are dependent on the internal electrical conductivity distribution, or the phase distribution, for the given electrical currents through those electrodes. Based on the known injected currents and the measured potentials, the conductivity distribution is reconstructed with the aid of the ERT image reconstruction algorithm.

In the numerical algorithm, the problem domain is discretized into many small meshes (pixels) and each mesh is assumed to have a constant conductivity value. The phase distribution is approximated as the conductivity values of many meshes. The image reconstruction algorithm estimates the conductivity value in each mesh. The image reconstruction algorithm, so called the inverse algorithm, searches the optimal distribution of the conductivity values, minimizing the objective functional, that is the difference between the measured potentials and the calculated potentials, by solving the governing equation with the assumed conductivity distribution and the boundary condition. In this, the potential distribution is computed numerically using usually the finite element method (FEM).

As the inverse algorithm to minimize the objective functional, the Gauss-Newton (GN) method is widely accepted [5]. However, the number of unknowns or meshes is much more than the number of current-potential data sets. Hence, the ERT image reconstruction is an inherently ill-posed problem. These characteristics result in low spatial resolution, which is the major drawback of the ERT.

For binary mixtures like two-phase flows in which there are only two distinct conductivity values, the number of unknowns can be reduced significantly and two approaches have been proposed. One is the mesh grouping approach and the other is the boundary estimation approach. The boundary estimation approach estimates the interface between the background and the secondary substances directly, not the conductivity distribution [6-11]. In this, the interfacial boundary should be properly parameterized with a few numbers of unknowns. Also, the mesh structure should be updated after each iteration step. In the mesh grouping approach, on the other hand, a number of meshes, which can be categorized into one of the substances, are grouped and each group is assumed to have a same conductivity value [4, 12-15]. As a result, the number of unknowns can be reduced significantly. Glidewell and Ng [12] proposed a two-step approach in electrical impedance imaging for medical tomography. In the first step, the anatomical information was obtained through the magnetic resonance imaging (MRI) data, and in the second step with this prior information, the internal configuration was preset and the meshes were grouped. Cho et al. [13] firstly introduced an adaptive mesh grouping algorithm to the ERT, in which the grouping criteria were determined by using the genetic algorithm and fuzzy set theory. Later, M.C. Kim et al. [14] employed the genetic algorithm only to determine the grouping criteria. K.Y. Kim et al. [15] suggested utilizing the predetermined threshold among the groups based on the best homogeneous resistivity value, and compared its performance with the grouping method based on the genetic algorithm. Recently, B.S. Kim et al. [16] applied the Otsu's method to select the optimal threshold.

This work proposes a new adaptive mesh grouping algorithm combining the particle swarm optimization (PSO) algorithm with the GN method for the improvement of spatial resolution. In this technique, the meshes are categorized into two groups: the background and the remnant groups. The PSO algorithm is used for the determination of the threshold between the groups and the representative conductivity value of the background group. Compared to the previous grouping algorithms like genetic algorithm and fuzzy set theory, the PSO, which is a recently developed evolutionary optimization algorithm, is easy to understand its concept and much simpler to implement, even with comparable optimization performance.

This paper consists of four parts. After the introduction, the 2nd section, the FEM formulation and the mathematical statement for the GN method are introduced. In the 3rd section, a mathematical demonstration for a proposed element grouping technique is described. In the 4th section, several numerical simulation results for the verification of the proposed algorithm are provided.

2. MATHEMATICAL MODEL

In general, the ERT is composed of the forward and the inverse problems. The process to obtain the potential distribution by solving the governing equation, subject to the given electrical conductivity values and boundary conditions, is called the forward problem, and the inverse problem is described as the process to estimate the internal conductivity distribution based on the measured voltages and the injected currents on the electrodes. A schematic flowchart is given in Fig. 1.

2.1 Forward Problem

When electrical currents I_ℓ are injected into the problem domain $\Omega \subset \Re^2$ through the ℓth electrode e_ℓ attached on the

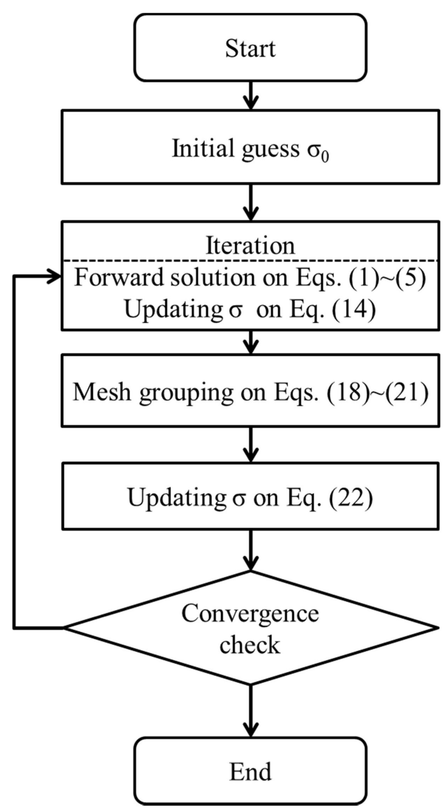

Fig. 1. Flowchart of Proposed Algorithm.