Available online at www.sciencedirect.com

Journal of Applied Research and Technology

Journal of Applied Research and Technology 13 (2015) 197-204

www.jart.ccadet.unam.mx

Original

An image reconstruction algorithm for electrical capacitance tomography based on simulated annealing particle swarm optimization

P. Wang[a,*], J.S. Lin[b], M. Wang[a]

[a] *School of Electric and Control of Xi'an University of Science and Technology, Xi'an, China*

[b] *Department of Computer Science and Information Engineering at National Chin-Yi University of Technology, Taichung, Taiwan*

Received 19 April 2014; accepted 18 August 2014

Abstract

In this paper, we introduce a novel image reconstruction algorithm with Least Squares Support Vector Machines (LS-SVM) and Simulated Annealing Particle Swarm Optimization (APSO), named SAP. This algorithm introduces simulated annealing ideas into Particle Swarm Optimization (PSO), which adopts cooling process functions to replace the inertia weight function and constructs the time variant inertia weight function featured in annealing mechanism. Meanwhile, it employs the APSO procedure to search for the optimized resolution of Electrical Capacitance Tomography (ECT) for image reconstruction. In order to overcome the soft field characteristics of ECT sensitivity field, some image samples with typical flow patterns are chosen for training with LS-SVM. Under the training procedure, the capacitance error caused by the soft field characteristics is predicted, and then is used to construct the fitness function of the particle swarm optimization on basis of the capacitance error. Experimental results demonstrated that the proposed SAP algorithm has a quick convergence rate. Moreover, the proposed SAP outperforms the classic Landweber algorithm and Newton-Raphson algorithm on image reconstruction.

Keywords: Electrical capacitance tomography; Simulated annealing algorithm; Least squares support vector machines; Particle swarm optimization

1. Introducción

As one of the electrical process tomography imaging technologies, Electrical Capacitance Tomography (ECT) is featured in lower costs, no-irradiative and non-invasive methods, etc., and applicable to the visible measurement of two-phase and multiple-phase flows (York, 2001; Griffiths, 1988). The principle of ECT can be described as: different objects have different permittivities. If the concentration and the composition of the component phase are changed, the permittivity will change to fit the mixture. Variation in permittivity will cause a change of the capacitance measurements and the capacitance measurements reflect the size and distribution of the medium phase concentration of the mixture. On this basis, using a corresponding image reconstruction algorithm can reconstruct the distribution of the test area of the pipeline. Because ECT is non-linearity and the number of capacitances independently measured are much less than the number of pixels for image reconstruction, there is no resolution for the reverse problem. Furthermore, the sensitivity field of ECT is featured in "soft field", i.e. sensitivity is not evenly distributed, the reverse problem equation is in a seriously abnormal state (Yang, 1997). Therefore, image reconstruction algorithm has been the bottleneck for the further development of ECT, and a high precise image reconstruction algorithm is required.

The existing ECT image reconstruction algorithms can be divided into two mainly types: non-iterative algorithm and iterative algorithm. As one of the typical non-iterative algorithms, Linear Back Projection (LBP) is simple and quick, but unsatisfying in imaging precision. So LBP is only used as a qualification method (Peng et al., 2004). Iterative methods include: Tikhonov regularization method (Peng et al., 2007), Landweber algorithm (Yang et al., 1999), Newton-Raphson algorithm (Yang and Peng, 2003) and Conjugate Gradient method, etc. (Wang et al., 2005). Tikhonov method may cause detailed distortion of the reconstructed images due to oversmoothness of regularization functions. As a widely used method in recent years, Landweber returns satisfying results only

* Correponding author.
E-mail address: wangpai2013@xust.edu.cn (P. Wang).

with large number of iterations as to complex flow patterns. Newton-Raphson algorithm is featured in local convergence, but the iterative convergence can't be guaranteed if the initial value is not selected appropriately. Conjugate gradient method is applicable to positive definite matrix and thus it can't obtain better effects when it is applied to complex flow patterns.

In this paper, we introduce an image reconstruction algorithm with LS-SVM and APSO, which is named as SAP. The proposed SAP is described as follows: firstly, we construct LS-SVM and excise the error between the capacitances arising from sensitivity matrix and the actual capacitance measurements; then based on the error, we constructed the fitness function and simulated annealing mechanism for particle swarm optimization; finally, we search for the optimum solution for image reconstruction with APSO.

2. ECT system

As shown in Figure 1, ECT System is mainly consisted with three units: a capacitance sensor unit, a measurement and data collection unit, and an image reconstruction unit. By utilizing capacitive fringe effect, the sensor can produce a corresponding capacitance for a medium with certain permittivity. The combination of all sensing electrodes may provide multiple capacitance measurements, which can be taken as the projection data for image reconstruction. The capacitance measurement and data collection unit primarily functions as rapidly, stably and accurately measuring minor capacitance. It changes in various arrays of electrode couples, and transmits the acquired data to a computer. This unit is mainly comprised of three modules: a capacitance measurement module, a data collection control module, and a communication module. The capacitance measurement module is used to realize switching of capacitance to voltage (CV), to measure minor capacitance and effectively inhibit stray capacitance. Currently, two of the most mature methods to measure capacitance are as follows: capacitance charge-discharge method and AC-based CV switching circuit (Yang, 1996; Yang, 2001) The data collection control module generally takes DSP as the control core and takes ADC for data acquisition. Data communication adopts USB2.0 Technology (Yang et al., 2010). As ECT System has more measurement channels, it is difficult for a single DSP to meet real-time requirements. Therefore, CPLD or FPGA is generally adopted to conduct auxiliary control of DSP (Ma et al., 2006). ECT image reconstruction unit is composed of two parts: hardware and software. Hardware indicates a general-purpose computer, and software indicates image reconstruction algorithm.

3. ECT image reconstruction

ECT image reconstruction process includes forward and reverse questions to be resolved. As the forward question, capacitance values of all electrode pairs on basis of the permittivity distribution and excitation voltages of the known sensitivity field. The mathematic model of forward question of ECT is expressed as follows (Yang & Peng, 2003):

$$C_{i,j} = \iint_{\Gamma} \varepsilon(x,y) \cdot S_{i,j}(x,y)\,dx\,dy \quad (1)$$

where $C_{i,j}$ is the capacitance between the electrode pair of i-j, $\varepsilon(x,y)$ is the permittivity distribution on cross-section of pipes, $S_{i,j}(x,y)$is the sensitivity functions when the capacitance between electrode pair of i-j is distributed on the cross-section of pipe, and Γ is the electrode surface. It can be seen that the sensitivity of the electrode in a point is related to its position, namely the sensitivity is not evenly distributed within the sensitivity field, which is the so-called effects of "soft field".

The capacitance sensor comprising of n electrodes can provide $M = n(n-1)/2$ independent capacitances. With M equations similar with equation (1), such equations shall be linearized and discredited to get:

$$C = S \cdot G \quad (2)$$

where C is a normalization capacitance vector of M dimension, G is N dimension normalized permittivity distribution vector, i.e. the grey level of pixels for visualization, and S is $M \times N$ factor matrix, reflects influence of medium distribution varia-

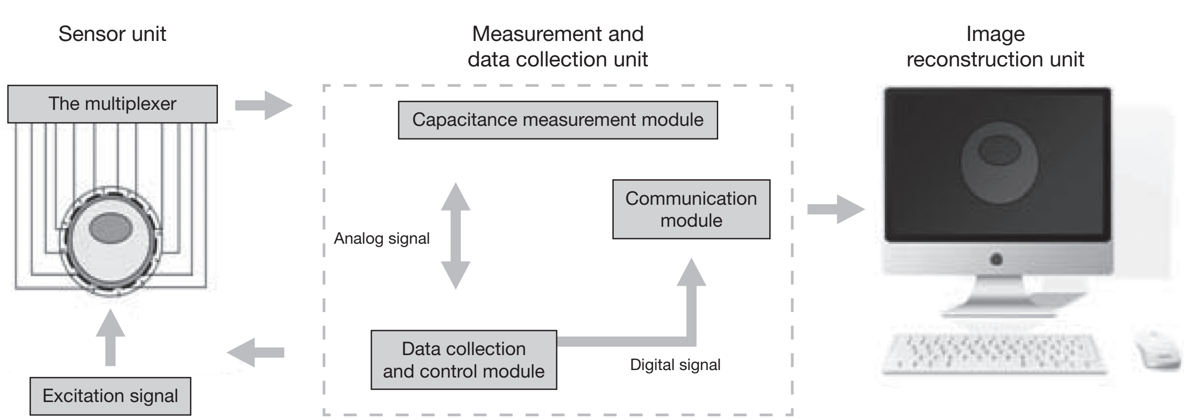

Fig. 1. Constitutes of electrical capacitance tomography system.