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Image Reconstruction Enhancement Using Convolution Back Projection Method for Electrical Tomography Application

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Abstract: This paper presents an image enhancement technique using convolution back-projection (CBP) technique to overcome the blurry issue caused by linear back-projection (LBP) technique on tomographic images. The CBP technique is discussed and employed on four different types of stratified flow test profiles. The obtained image results are compared between LBP and CBP and further assessed using mutual structural similarity index (MSSIM). The enhancement technique has successfully scored MSSIM rating above 0.9 for all four test profiles whereby the rating is ranging from 0 (poor quality) to 1 (best quality).

Keywords: linear back projection, tomography, electrical capacitance, convolution back projection

1. Introduction

Electrical tomography or soft-field tomography (SFT) such as electrical capacitance tomography (ECT), electrical resistance tomography (ERT), electrical impedance tomography (EIT) and electromagnetic tomography (EMT) are commonly applied in process industry. These tomography techniques are capable of visualizing the cross-sectional image of an internal activity within a sensing region. Unlike the conventional hard-field tomography (HFT) such as X-ray, electrical tomography exhibits its advantages of being non-radioactive, non-intrusive and non-invasive.

The SFT and HFT methods has different behavior and measurement parameters as they have different sensitivity based on the wave propagation characteristic respectively. The sensitivity of such system is independent of the parameter distribution in the sensing zone while soft-field sensors are sensitive to the distribution inside the cross-sectional field depending on the parameter distribution which often generates inhomogeneous field [13]. Hard-field tomography propagates its signal wave in straight line in an obstacle free path. On the other hand, soft-field tomography has its electric field line exist between the electrode sensors in curved line due to the soft-field effect. SFT methods has the common problem of low sensitivity in the center of the region of interest. As consequence, the reconstructed image result often suffers image distortion, artifact and blurry edges which could not precisely visualize a stratified multiphase flow regime [14].

1.1 Electrical Capacitance Tomography

Electrical capacitance tomography (ECT) is well established for multiphase (liquid-gas-solid) flow imaging. Basically, ECT measures the variations or changes of capacitance between the electrode pairs thus visualizes the permittivity distribution of the materials within the sensing region. Visualizing the cross-sectional images are usually carried out by an image reconstruction method. In ECT, the changes of inter-electrode capacitance due to the changes of permittivity distribution of dielectric materials are measurement. By using the charge measurements, the inter-electrode capacitance can be calculated as follows [1].

$$\mathrm{C}_{ij} = \frac{Q_{ij}}{\Delta \mathrm{V}_{ij}} \tag{1}$$

Where C_{ij}= inter-electrode capacitance, $\Delta\mathrm{V}_{ij}$ = electric potential difference between excitation electrode i and detection electrode j, Q_{ij} = charge induced by the

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potential difference of ΔV_{ij} , $\varepsilon(r)$ = permittivity distribution and $\varphi(r)$ = potential distribution. Further understanding on the fundamental of ECT is explained in [2-4].

The basic buildup of an ECT system will consist of a sensory system, signal processing circuitry and software interfacing where image reconstruction work take place. The process flow of ECT is depicted in Fig. 1 follows [2, 5].

2. Image Reconstruction

Image reconstruction for ECT is a mathematical process that generates tomographic images from the capacitance sensitivity distribution. These images can be obtained from a set of projection acquired from different angles around the pipe peripheral. The sensitivity model is needed for all the sensor projections which is further discussed in [6-8]

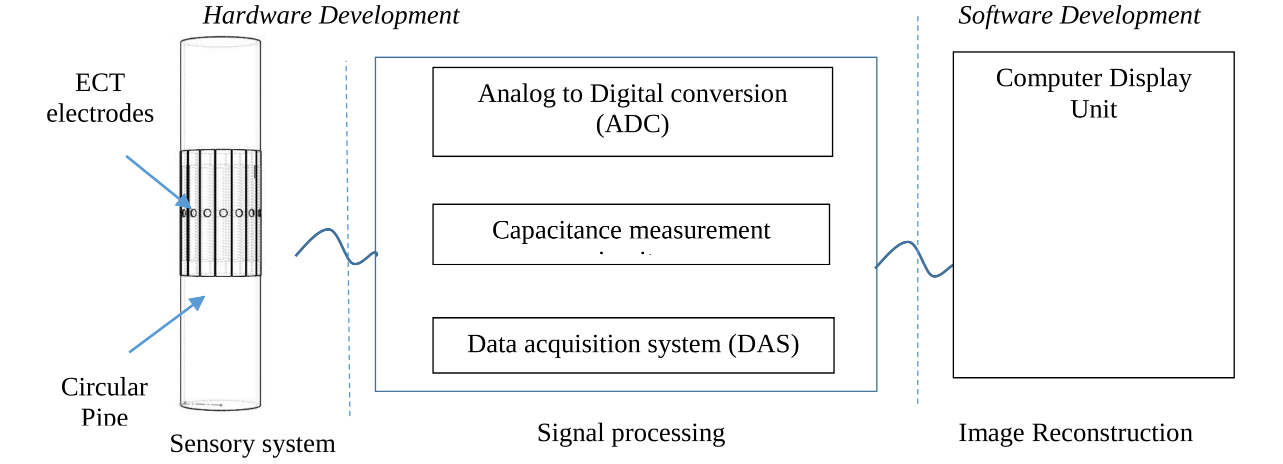

Fig. 1. Electrical capacitance tomography basic block diagram

2.1 Linear Back Projection

There are several technique to reconstruct tomographic images which can be categorized into two; iterative method and real-time reconstruction method. Linear back projection (LBP) technique is the real-time reconstruction of process image with its fast computational speed. Its simplicity makes up as the most preferable technique used especially in process tomography [4]. However, due to its simplicity, several draw back such as blurry image issues and inaccuracy has been observed [7]. Therefore, a convolution back projection technique is applied to further enhance the LBP reconstructed images.

2.2 Convolution Back-projection

Convolution back-projection (CBP) is a mathematical operation in combining two functions to form a new function. It sums up the two function *f(x,y)* and *g(x,y)* and measures the amount of overlap as a new function *h(x,y)*. A *3 x 3* kernel matrix is used to shift over the other as in Fig. 2. The convolution at a specific point or pixel is the product of the two functions as follows [9, 10].

$$h(x,y) = f(x,y) * g(x,y) = \sum_{i=-k}^{k} \sum_{j=-k}^{k} f(i,j) g(x-i, y-j) \quad (2)$$

Where $f(x,y)$ is the input image, $g(x,y)$ is the kernel matrix and $h(x,y)$ is the filtered LBP image after CBP. The impulse response $g(x,y)$ is referred as kernel matrix. CBP is performed by convoluting the 3 x 3 kernel matrix over the LBP acquired image starting from top left corner of the matrice as in Fig. 2.

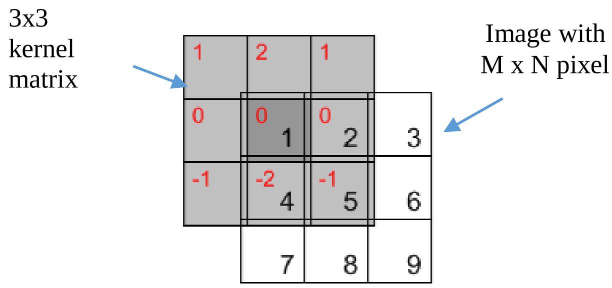

Fig. 2. Convolution process using 3x3 kernel matrix on an image.

The CBP algorithm is employed on the LBP reconstructed tomographic images to reduce the problem with blurry edges and inaccurate size or shape of the subject of measurement. As to evaluate the reconstructed image quality, MSSI is employed to assess the image quality. MSSIM measures the similarity between two images by modelling the distorted image or reconstructed images comparing to the ground truth image which represent the ideal condition of the flow state. The mathematical equation is given as follows.

$$MSSIM\ (A,B) = \frac{1}{M}\sum_{j=1}^{M} SSIM(x_j, y_j) \quad (3)$$

$$SSIM(x,y) = [l(x,y)]^{\alpha}[c(x,y)]^{\beta}[s(x,y)]^{\gamma} \quad (4)$$

where A is the reference image or undistorted image. B is the distorted image or reconstructed image *x* and *y* are the image content at j^{th} local window. M is the number of local window of the image. $l(x,y)$ is the luminance comparison function. $c(x,y)$ is the contrast comparison function. $s(x,y)$ is the structure comparison function α, β and γ are the parameters to adjust the relative importance of the three components which is further explained in [12].

3. Results and Discussion

The tomographic images of four sets two-phase flow regime are reconstructed using LBP and CBP method as depicted in Fig. 3 follows.

To further validate the performance of CBP on the LBP tomographic images, an image quality assessment method using mean structural similarity index (MSSIM) [11] is measured and tabulated in Table 1. The CBP images are compared to the ground truth images for both visual inspection and to identify the MSSI index.

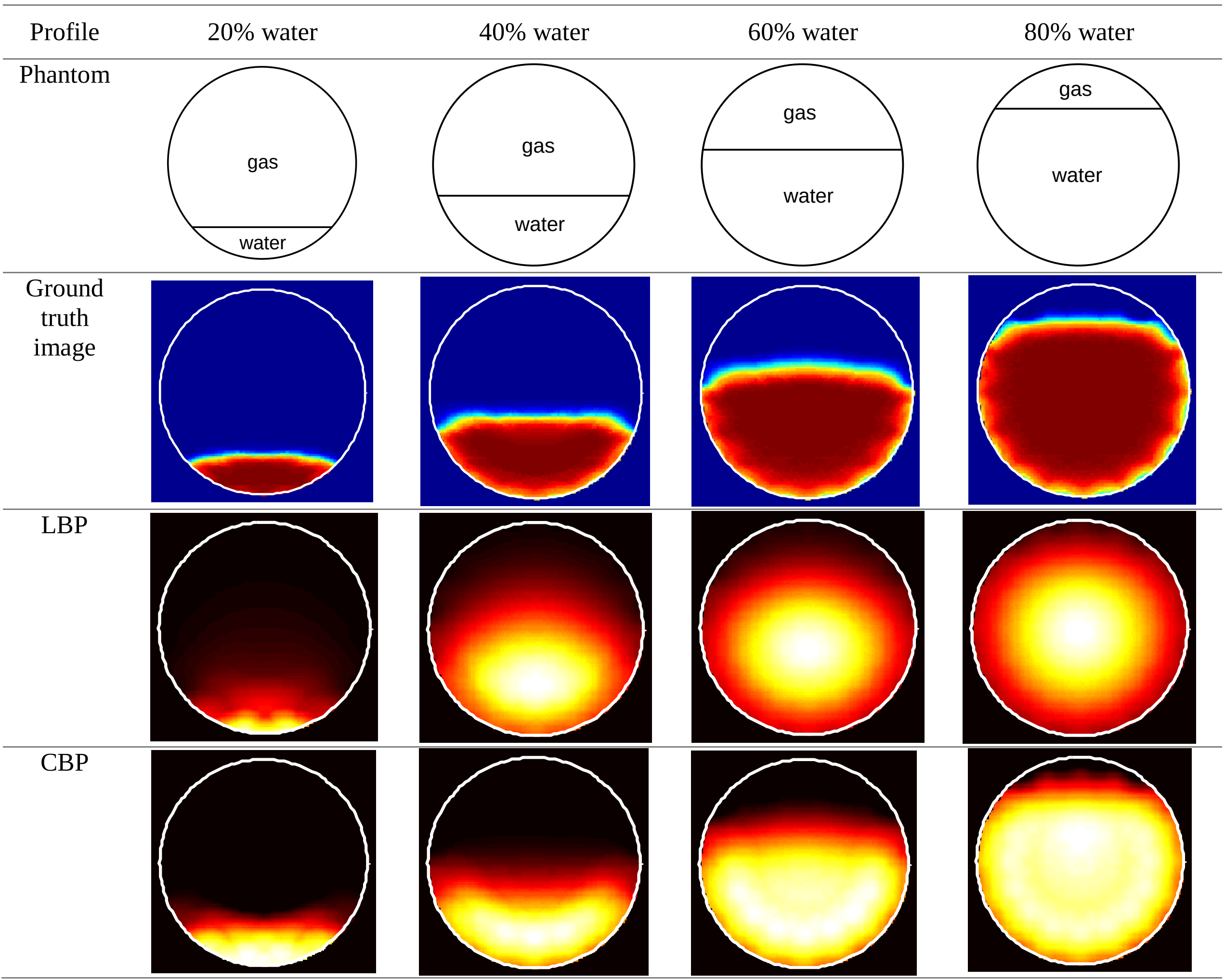

Fig. 3. LBP and CBP tomographic comparison for two-phase water-gas multiphase flow

Table 1. MSSIM score for stratified flow test profiles

Profile	20%	40%	60%	80%
MSSIM	0.9712	0.9633	0.9575	0.9558

From Fig. 3, it is obvious that the LBP tomographic image regime could not precisely present the multiphase stratified flow condition especially as the amount of water increased from 20% to 80%. LBP images has suffered excessive distortion which can be visually observed. In contrast, CBP has successfully improvised these images by using convolution technique. The blurry edges noticeable in LBP tomographics has been reduced significantly. The MSSIM rating from 0 (poor) to 1 (best) proven that the CBP technique manage to score at above 0.9 for all four test profiles. These index results show that the reconstructed CBP images has higher similarity structure to the ground truth images with better visual flow regime.

4. Conclusion

This paper presented a tomographic image reconstruction technique using convolution back-projection (CBP). This is an enhancement step using a 3 x 3 kernel matrix to convolute on the linear back-projection (LBP) reconstructed images to smoothen the edges of an image. The developed technique is essentially useful for image reconstruction work in process tomography. The CBP technique is tested out on four different test profiles; 20%, 40%, 60% and 80% water-gas stratified flow. Comparing to LBP images, the CBP obtained image results have significantly enhanced the tomographic images with a MSSIM score above 0.90. The developed CBP technique can be applied in many related tomography applications which involves image reconstruction work.

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