Metrology of Tomography for Engineering

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Introduction

Tomography has become one of common methods for visualizing and characterizing process dynamics of multiphase flows in chemical, petroleum, nuclear engineering and many other areas and industrial applications over the past decades. Tomographic imaging, comparing the conventional direct imaging methods such as Optical reflection, PIV and X-ray transmission, has very unique features at “seeing” through the optical opaque medium of a process and “building” up volumetric view of engineering multiphase measurements, e.g. phase concentration and velocity distribution, flowrate and flow regime in a nonintrusive manner. At other aspects, tomograms are indirectly reconstructed with specific algorithm, which may contain a certain level of artificial errors. These images are not conventionally understood. Nevertheless, due to their unique features, nowadays tomography has been widely used for measurements of various multiphase flows, e.g. slurry, two or three phase gas-oil-water flows in mineral or chemical transportations and rectors. This paper will try to address the science and engineering data fusion as two key aspects of the metrological method, typically focusing on electrical resistance tomography (ERT), for measurements of engineering problems.

1. Methods

Tomography is recognized as an indirect imaging method referring the conventional reflection, absorption and transmission imaging. Tomographic images (tomograms) needs be reconstructed from boundary measurements with a specific algorithm. The reconstructed images generally do not report the optical property of the process and are suffered from a level of artificial errors from the inverse solution process. Further data process are normally required in order to derive meaningful engineering data. In the process, errors may be introduced from a number of sources. Typically, error may be generated, e.g. (a) at the measurement stage due to limits on signal-to-noise ratio, (b) at the inverse solution stage due to the linear approximation (for a nonlinear electric field problem) and ill-condition of the inverse problem (therefore the sharp boundary of object image or precise solution not possible) and (c) at the implementation stage due to specific information derivation (e.g. solid concentration distribution from conductivity distribution) and limits of human visual capability (only about 30 shades of grey). Equation 1 demonstrates the potential error source from inverse solution due to the assumption of $\Delta\sigma_k << \sigma_k$ [1]. Typical data fusion methods of the phase fraction conversion using Maxwell relationship, velocity distribution derivation based on pixel-pixel correlation and bubble mapping to enhance the visibility of gas in water two phase flow, are introduced, which are fundamentally different from the metrology of conventional imaging methods in common use. With the bubble mapping approach, a stack of cross-sectional tomograms by electrical tomography is transformed and displayed as individual air bubbles with different size in respecting to the air concentration in a visualization pixel. With further increment of air concentration, large bubbles will be merged from a number of pixels with full air cavity and then all bubbles are computed to 3-dimensional bubbles with an enhanced isosurface algorithm [2].

2. Results

Efficient slurry transportation is vital to many industries. Through the application of SCG ERT algorithm [1], the asymmetric solids concentration distribution in horizontal swirling flows can be quantified and shown in Figure 2 [3]. At a high flow velocity, the mode of particle dispersion along the length of the pipeline appears to take the form of a group of ellipses. The resultant visualization of different flow regimes in a vertical pipe are shown in Figure 3a-c [2]. In each group of images, e.g. Figure 3b, the left shows the photo from camera, the middle is the axial cross section of stacked raw tomograms with color scheme, and the right shows the image produced by the bubble mapping scheme. It is clearly demonstrated that the bubble mapping can greatly enhance the reality of flow regime visualization comparing the raw tomograms.

Equation 1

$$\frac{\Delta V_j}{V_j} \approx -\frac{\sum_{k=1}^{w} \Delta\sigma_k s_{j,k}(\sigma_k)}{\sum_{k=1}^{w} \sigma_k s_{j,k}(\sigma_k)}$$

where *j* is the measurement-projection location and *k* is the pixel number, $s_{j,k}$ denotes the sensitivity coefficient at pixel *k* under the measurement-projection *j*, *P* denotes the maximum number of measurements, *w* denotes the maximum number of pixels, σk and $\Delta\sigma_k$ are the conductivity and conductivity change at pixel *k*, respectively, and V_j and ΔV_j refer to the reference voltage and the voltage change at measurement-projection *j*.

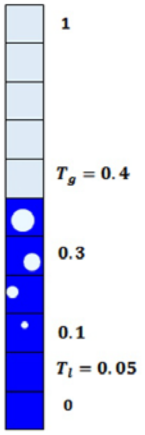

Figure 1. Bubble mapping scheme

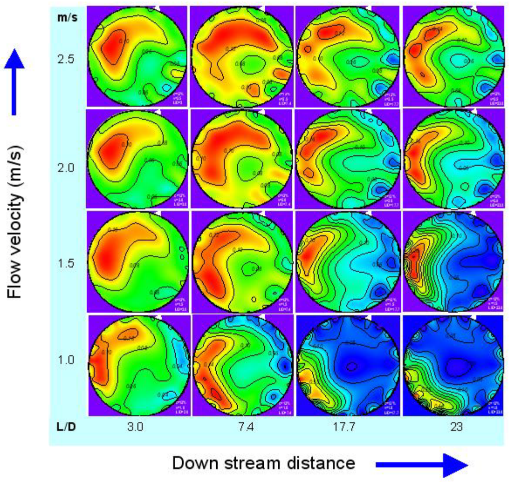

Figure 2. Solids suspension in horizontal pipeline at a fixed particle volumetric concentration of 8.6%.

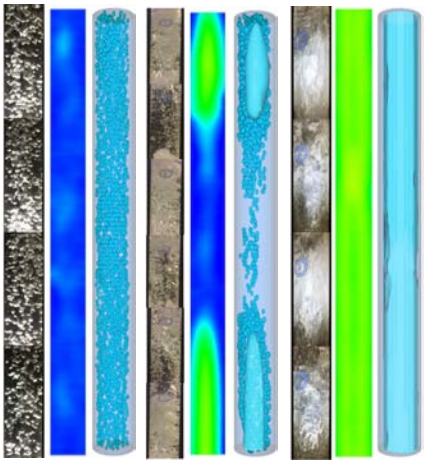
(a) (b) (c)

Figure 3. Visualization of upward gas-liquid flow, (a) bubbly flow; (b) slug flow; and (c) annular flow.

References

[1] [M. Wang. Inverse solutions for electrical impedance tomography based on conjugate gradients methods, *Meas. Sci. & Tech.*, IOP, 13: 101-117, 2002.

[2] Q. Wang, J. Polansky, B. Karki, M. Wang, K. Wei, C. Qiu, A. Kenbar, and D. Millington. Experimental tomographic methods for analysing flow dynamics of gas-oil- water flows in horizontal pipeline. *Journal of Hydrodynamics*, 28(6): 1018-1021, 2016

[3] M. Wang. Impedance mapping of particulate multiphase flows, *Flow Meas. Instru.*, 16(2-3): 183-189, 2005.