Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(5): 520-526

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Digital Electrical Resistance Tomography System and its Experimental Research

Lifeng Zhang*

North China Electric Power University, China

ABSTRACT

Electrical resistance tomography (ERT) is a new technique developed in recent years, which aims to measure multi-phase flow. The conductivity distribution images of cross section can be obtained, and then the gas holdup can be calculated using ERT system. Combining ERT technique and cross correlation measurement method, the velocity can be calculated. In this paper, the dual-plane digital ERT system was designed, and experiments were carried out on a small-scale gas/water two-phase flow experimental set-up. The on-line reconstructed images, gas holdup estimations and correlation velocity can be obtained. Experimental results showed that the reconstructed images with high spatial resolution and real-time performance can be obtained. The software has rich functions and user-friendly interface, which can meet the needs of visualized measurement for two-phase flow in practical application.

Key words: Two-phase flow; Electrical resistance tomography; Gas holdup; Cross correlation

---

INTRODUCTION

Industrial flow processes are complex in nature, which often involve a variety of components in a combination of gas, liquid and solid phases. Measurements of the phase distribution and interfaces in a multiphase flow are very important for the process [1].

Process tomography (PT) technique is a new technique that has developed rapidly in recent years and which has great potential and wide industrial application prospect for direct characteristics analysis for multiphase flows [2]. Electrical resistance tomography (ERT) is one kind of PT technique and has been proved to be a powerful tool for mapping the concentration and velocity distributions in two-phase flow [3, 4].

ERT is used when the continuous phase is conductive in two-phase flows, such as gas-water two-phase flow in vertical pipe, through which the cross-sectional conductivity distribution images can be obtained at two adjacent planes along the pipeline. Then, reconstructed images can be cross-correlated to obtain the velocity profile of the flow. The non-intrusive measurement of velocity profiles within process equipment is a challenging task because few instruments can measure the velocity profile of a multi-phase flow in a pipeline. ERT provides a unique opportunity to do so by cross correlation using a dual-plane ERT sensor [5].

In this paper, the structure of the digital dual-plane ERT system was described. The method for measuring the gas holdup and the velocity based on the gas holdup cross correlation was presented. Experiments were carried on using the designed digital dual-plane ERT system. Experimental results showed that the reconstructed images with high spatial resolution and real-time performance can be obtained.

DIGITALERT SYSTEM

PRINCIPLE OF ERT

A typical ERT system is shown in Fig. 1, which includes the array sensor, the data acquisition system (DAS) and the image reconstruction and display unit. In this paper, there were 16 rectangle stainless steel electrodes with the width of 10 mm and the height of 20 mm for each plane. The voltage signals between adjacent measurement electrodes were measured by DAS. Then, these data were sent to image reconstruction computer. Using image reconstruction algorithm, the reconstructed images can be obtained.

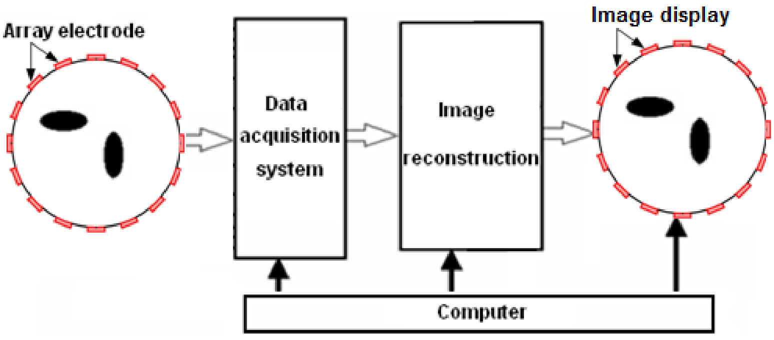


Fig. 1: Structural diagram of ERT

ARCHITECTURE OF DIGITAL ERT SYSTEM

The modular functional design method was adopted for the digital ERT system, implemented as a set of hardware circuit card units and software modules. Data from the dual-plane ERT sensor were integrated by a host PC. An architecture view for the twin-plane ERT system is shown in Fig. 2.

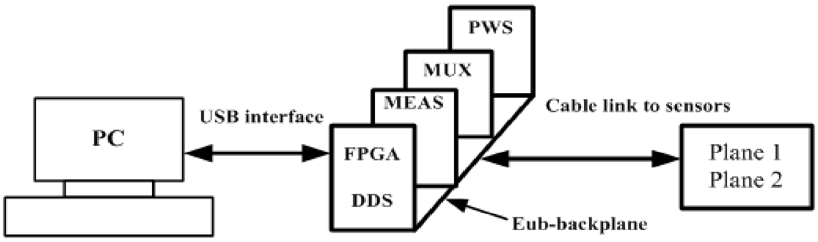


Fig. 2: The ERT system platform

It includes common functions as follows. direct digital synthesizer (DDS) which is realized by Field-Programmable Gate Array (FPGA) and measurement (MEAS), which usually include excitation signal generation and signal condition; multiplexing (MUX), for routing exciting and measurement signals; power supply (PWS), to provide electrical power for the hardware system. The various cards are all organized using a custom-defined backplane. Control signals are provided from a FPGA chip that embraces DAS and communication functions. Data were transferred to the host PC through the Universal Serial Bus (USB) interface.

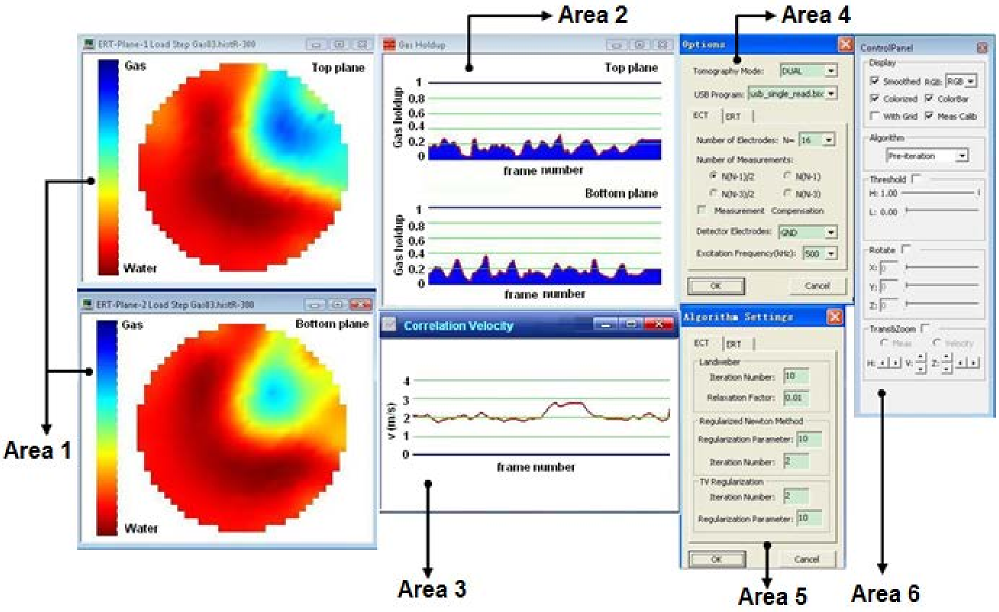
The digital ERT system for dual-plane measurements can be shown in Fig. 3.

Fig. 3: The digital dual-plane ERT system

For the designed digital ERT system, the sinusoidal current (1Hz~1MHz, adjustable) excitation signal is generated by FPGA, which is sent to MEAS card to excite a pair of adjacent electrodes and the resulting potential difference between another pair of adjacent electrodes is measured, which are also called projected data. The current source is fed via the bus to the multiplex to select exciting electrodes. Each measurement card supports up to four electrodes. Eight cards may be used to realize dual-plane 32 electrodes (16 electrodes for each plane). Measurements are routed to a 14 bit, 10 µs, sampling high precision analogue to digital converter. Resulting data are then routed via USB 2.0 interface to the host PC for further processing. The data acquisition rate of each plane is 500 frames/s for digital dual-plane ERT sensor, while the online image reconstruction speed is 120 frames/s for each plane [6].

SOFTWARE OF ERT SYSTEM

Software of ERT system controls the operation and data process, and was developed based on the visual C++ 6.0 software. One typical user interface configuration in Fig. 4 shows an online operation for ERT system.



Options

Tomography Mode: DUAL

USB Program: usb_single_read.bix

Number of Electrodes: N= 16

Number of Measurements:

● N(N-1)/2 ○ N(N-1)

○ N(N-3)/2 ○ N(N-3)

☐ Measurement Compensation

Detector Electrodes: GND

Excitation Frequency(kHz): 500

Algorithm Settings

Landweber

Iteration Number: 10

Relaxation Factor: 0.01

Regularized Newton Method

Regularization Parameter: 10

Iteration Number: 2

TV Regularization

Iteration Number: 2

Regularization Parameter: 10

ControlPanel

Display

☑ Smoothed RGB: RGB

☑ Colorized ☑ ColorBar

☐ With Grid ☑ Meas Calib

Algorithm: Pre-iteration

Threshold ☐

H: 1.00

L: 0.00

Rotate ☐

X: 0

Y: 0

Z: 0

Trans&Zoom ☐

○ Meas ○ Velocity

Fig. 4: The online operation software view

There are six areas in the main GUI (Graphic user interface). Area 1 shows the real-time cross-sectional images of each plane. The online real-time image reconstruction speed is 120 frames/s. Area 2 shows the calculated gas holdup for both planes. Area 3 provides the calculated correlation velocity curve. Area 4 is a main parameter configuration panel for system operation, including exciting frequency, exciting and measuring mode, electrode number and data transfer mode. Area 5 is an algorithm parameter configuration panel, including iteration number, iteration factor and regularization factor. Area 6 is an image display configuration panel, including selection of the image color, grid and smooth effect, filter threshold, 3D rotation, image zoom and translation.

CALCULATION OF GAS HOLDUP AND CORRELATION VELOCITY

The grey values of the reconstructed images are normalized from 0 to 1, which delegate gas and liquid, respectively. The grey value of each pixel corresponds to its phase fraction value [7]. The gas holdup α can be estimated according to (1):

$$\alpha = \sum_{i=1}^{M} g_i \, A_i / A \qquad (1)$$

Where g_i and A_i are the grey value and area of the *i*thpixel, respectively. A is the cross-sectional area of the pipe. *M* is the total pixel number in cross section of the pipe.

The principle of cross-sectional flow velocity measurement along the flow direction is "tagging" signals generated by flow turbulence or suspended moving particles. The principle diagram of flow velocity measurement using cross correlation can be seen in Fig. 5.

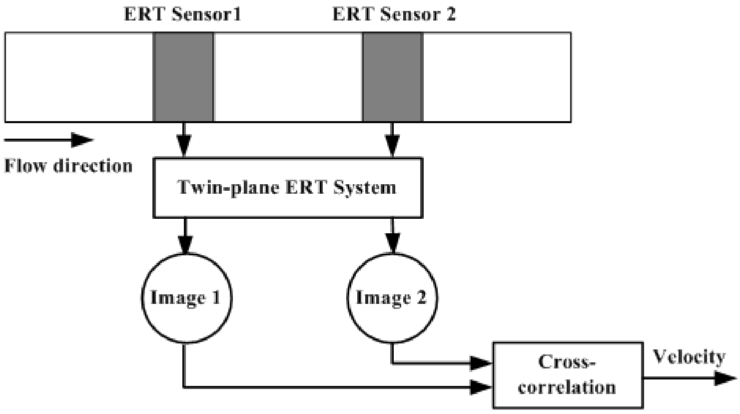


Fig. 5: Flow velocity measurement using cross correlation method

If the flow regime can be considered 'frozen' during transition from plane 1 to plane 2, and the distance between plane 1 and plane 2 is *L*, then the transit time τ_k of the kth pixel of the image from plane 1 to plane 2 can be calculated from the following cross-correlation function [8]

$$R_k(j\Delta) = \frac{1}{N}\sum_{i=1}^{N} x(i\Delta)y(i\Delta + j\Delta) \quad j = 0, 1, 2, \cdots, m \text{ and } m < N, \quad k = 1, 2, \cdots, M \quad (2)$$

Where Δ stands for the sampling interval of each image, *j*Δ is the discrete delay time and *N* is the length of sampling images for cross correlation, *M* is the total number of the pixels in pipe, $x(t)$ and $y(t)$ are the grey values of the *k*th pixels of plane 1 and plane 2, respectively.

When the cross-correlation function reaches the peak value, the transit time τ_k can be obtained.

$$\tau_k = j \cdot \Delta \quad (3)$$

Where *j* corresponds to the peak value of the cross-correlation function. Then, the velocity *v* can be calculated according to (4).

$$v = \frac{L}{\tau_k} \quad (4)$$

It is important to choose a suitable distance *L* for cross correlation [9]. Both the similarity of signals and the dynamic behaviours of the system should be taken into consideration.

The velocity measurement based on pixel-pixel cross-correlation has been adopted by many researchers to obtain velocity profile [10]. But the calculated velocity curve fluctuates very quickly based on this method. In our experiment, the cross-correlation velocity measurement method based on gas holdup of the two planes was presented as follows:

$$R_k(j\Delta) = \frac{1}{N}\sum_{i=1}^{N} \alpha_1(i\Delta)\alpha_2(i\Delta + j\Delta) \quad (5)$$

Where α_1 and α_2 are gas holdups of the plane 1 and plane 2, respectively.

RESULTS

EXPERIMENTAL SETUP

The experimental set-up was showed in Fig. 6. The experiments on the air–water two-phase flow in the vertical pipe were designed to verify the performance of digital ERT system.

The experiment device is movable and contains the following main parts: a Perspex pipe, two planes of 16-electrode sensing arrays, ERT DAS system, an air compressor, four solenoids and valves, the image reconstruction computer, one flow rate meter which is used to measure the water flow and one water pump with an inverter by which the speed of the motor can be regulated in order to control the water flow rate.

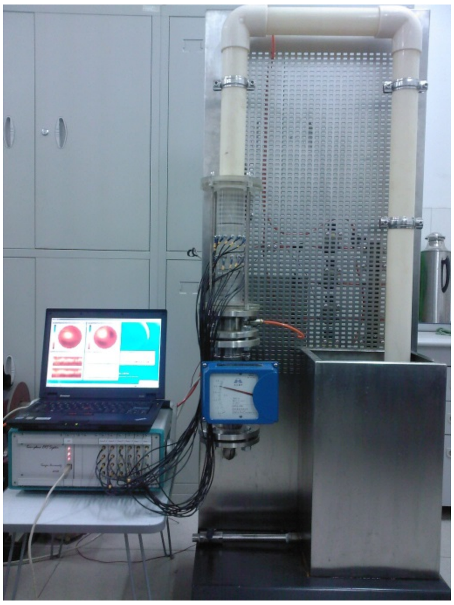
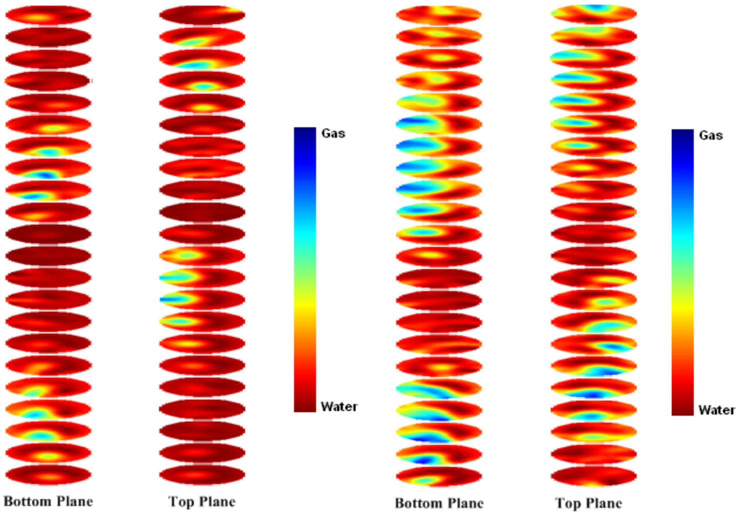


Fig. 6: Experimental set-up

Water is circulated via the motor and the water pump. Water flow rate can be controlled in the range of 0 to 1 m/s. Gas flow rate is controlled through four solenoids and gas valves. The distance between the two sensing planes is 50 mm. Bubble flow, slug flow and churn flow can be obtained using this set-up.

RECONSTRUCTED IMAGES AND GAS HOLDUP

In this experiment, bubble flow and slug flow were tested. Reconstructed images were shown at 20 ms/frame for each plane using pre-iteration algorithm [11]. Fig. 7 showed the images of bubble flow and slug flow over the imaging plane at different time during their pass through the imaging cross-section. It is clearly that the temporal series of the reconstructed images can acceptably reflect the change of the cross-section distribution of the investigated two-phase flow.



(a) (b)

Fig. 7: Reconstructed images: (a) Bubble flow, (b) Slug flow

For bubble flow and slug flow, the motion of bubbles can be clearly seen from the bottom plane to top plane. First, the bubbles can be seen in bottom plane reconstructed images, and then in the top plane reconstructed images. The place of bubbles in cross section changes during their motions. ERT provides a new approach to visualizing the complex motion of the bubbles in gas/water two-phase flow.

The gas holdup curve of each plane is shown in Fig. 8. It gives the real time estimation of gas holdup for each plane. The gas holdup curves of bottom plane and top plane are in good correlation, and they reflect the gas change.

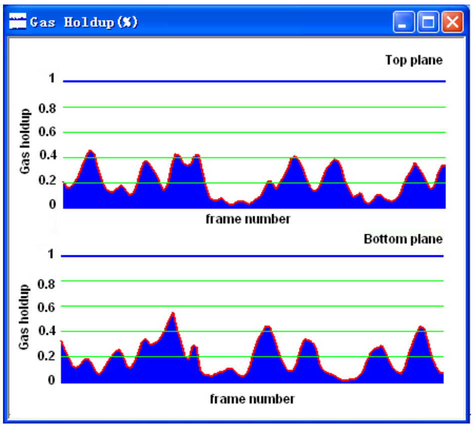


Fig. 8: Curves of gas holdup for dual plane

CORRELATION VELOCITY

The length of sampling images is 100, and the real time correlation velocity curve is shown in Fig. 9. From Fig. 9, it can be seen that the correlation velocity is in consistent with the reconstructed images, which can reflects the velocity of the bubbles.

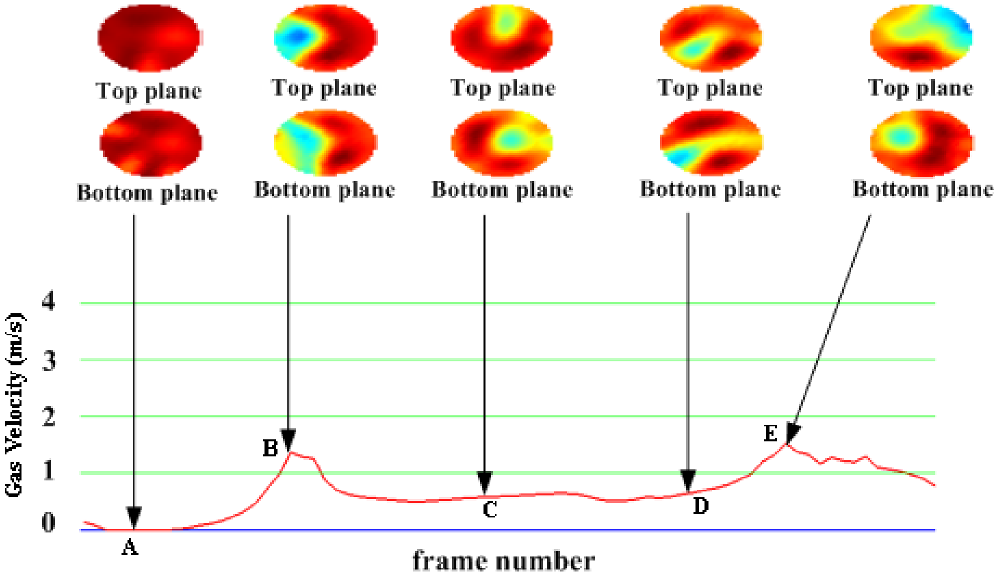


Fig. 9: Curve of correlation velocity

The velocity is very low at point A when there are few bubbles. When the flow regime is slug flow, the velocity reaches a peak value at point B. With the decrease of bubbles, the velocity becomes lower at point C and D. The velocity reaches another peak value at point E, when the flow regime becomes slug flow again. Because this set-up is very small, to obtain more accurate velocity estimate, more calibration work should be done. But from Fig. 9, it is clear that the cross correlation method based on the gas holdup is feasible for correlation velocity estimation.

CONCLUSION

The design of digital dual-plane ERT system and the small experiment set-up were described in this pipe. The ERT system has standard modules and is easy to be expanded. This system has been employed successfully in this small experimental set-up.

Experiment results showed that the reconstructed images can reflect the change of the cross-section distribution of the gas/liquid two-phase flow, the estimation of the gas holdup can be obtained and used in industry control. The presented cross correlation velocity measurement method base on gas holdup was feasible. Further work will focus on improvements of the precision of the estimations of the gas holdup and correlation velocity. Calibration experiments on large-scale experiment set-up will be done.

Acknowledgments
The author wishes to thank the National Natural Science Foundation of China for contract51306058 and the Fundamental Research Funds for the Central Universities for contract2014MS142, under which the present work was possible.

REFERENCES

[1] W Warsito; L-S Fan.*Chem. Eng. Sci.*,**2001**, 56(11), 6455-6462.
[2] MS Beck; RA Williams.*Meas. Sci. Technol.*, **1996**,7(3), 215-224.
[3] H Jiang; M Wang; RA Williams.*Chem. Eng. J.*, **2007**, 130(6), 179-185.
[4] M Wang;ADorward; R Mann.*Chem. Eng. J.*, **2000**, 77(4),93-98.
[5] HX Wang; LF Zhang.*Meas. Sci. Technol.*, **2009**, 20(11), 114007 (8pp).
[6] X Deng; F Dong; LJ Xu; XP Liu; LA Xu.*Meas. Sci. Technol.*, **2009**, 12(8), 1024-1031.
[7] ZY Huang; BL Wang; HQ Li.*IEEE. Trans. Instrum. Meas.*,**2003**, 52(2), 7-12.
[8] S Liu; Q Chen; HG Wang; F Jiang; I Ismail; WQ Yang.*Flow Meas. Instrum.*, **2005**, 16(4-6),135-144.
[9] U Datta; T Dyakowski; S Mylvaganam.*Chem. Eng. J.*, **2003**, 94(8),87-99.
[10] V Mosorov; D Sanlowski; Ł Mazurkewicz; T Dyakowski.*Meas. Sci. Technol.*, **2002**, 13(12), 1810-1814.
[11] HX Wang; C Wang; WL Yin.*IEEE Trans. Instrum. Meas.*, **2004**, 53(4), 1093-1096.