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Student Perceptions of Metacognitive Strategies in Hybrid ESL Classrooms: Advancing Self-Regulated Learning for Future-Ready Education

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ABSTRACT

Imaging of flow involving gas bubbles is important for the process industries in order to comprehend the operation and transport aspect of bubble columns which is difficult for conventional flow meters. Traditional methods are not suitable for such purpose as they invade the process. An ultrasonic system based on the tomography concept provides a useful tool for visualizing the internal behavior of such flow. This paper presents an investigation on the use of an ultrasonic tomography system to visualize gas bubbles flow in a vertical pipe. At first mathematical modeling was carried out on the propagation of ultrasound in the system. The image reconstruction was performed based on projections collected by collectors placed at different angles around the object of interest. The system which has sixteen 333 kHz ultrasonic transceivers was tested with five different phantoms resembling gas bubble flow and the results showed that it was capable of accurately detecting the locations of single and multiple bubbles in the flow pipe.

1. Introduction

The process industries process multi-phase flow which involves two or several phases in a pipe. Such flow profiles consist of gas, liquid or solid as well as different immiscible liquids or solids [1]. Such flow regimes are vital phenomenon which is under the condition of a thermodynamic equilibrium. Bubbly flow columns are widely utilized in the chemical industries. Various research on understanding the operation and transport phenomena of bubble columns have improved the comprehension of the hydrodynamic properties, heat and mass transfer mechanisms and flow regime behavior [2,3]. Because of the strict rules on accurate flow control mostly in the case of two-phase fluid flow, it is important to develop a suitable approach as well as utilizing suitable instrumentation. A method for imaging two phase flow regime is termed process tomography such as ultrasonic tomography. Ultrasonic tomography has various advantages in imaging real time data involving bubbles. The tomographic method is more significant and attractable especially in today's

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industrial process [4]. Process tomography (PT) is a unique method for imaging the internal characteristic of process flow. It has been implemented in various industries since it is an effective method for obtaining profiles of a flow with the ability of differentiating between the components of a heterogeneous phase from the continuous one [3]. These images produce important data on a process, which can be applied in monitoring, mathematical model verification and also intelligent control. In process tomography the objective is obtaining important data, such as void fraction and mean velocity [5]. This data which is provided by processing the signals received at several positions assist the researchers to obtain an overall picture of the measured field.

Since the last four decades there have been extensive research to develop the industrial PT techniques. Electrical capacitance tomography (ECT), electrical impedance tomography (EIT), electrical charge tomography (ECHT), optical tomography (OPT), gamma-ray, X-ray, magnetic resonance imaging (MRI) and ultrasonic tomography (UT) are examples of these techniques which are applied in PT based on the internal properties of materials [6]. These techniques can be classified as hard-field and soft-field where in the former case irrespective of the type of material or medium, the direction of travel of the energy waves from the source is constant. Ultrasonic tomography and X-ray are two examples of classified as hard-field tomography. In the soft-field, the electric current flows in the medium being profiled and an electric field profile is obtained according to the physical electrical properties of that material, enabling a profile of resistance, capacitance or impedance profile to be reconstructed by a computer to establish the images. The nature of soft field is complicated than hard field and needs significantly more computer analysis and algorithms to reconstruct the image [7] as soft field is a nonlinear whereas the hard field is linear. The electrical capacitance tomography is an example of soft-field tomography.

Ultrasound can detect fluctuations in acoustic impedance (Z), which is related to the density (ρ) of the media ($Z = \rho c$, where c is the velocity of sound), and as such complements other tomographic imaging technologies such as ECT and EIT [8]. Hence, ultrasonic tomography can be utilized in liquid/gas two-phase flow regime with two-component high-acoustic impedance mixtures e.g. bubbly flow [9]. In addition, it is low in cost compared to radiation-based techniques [10].

UT comprises of hardware and software. Hardware consists of sensors which are installed around the peripheral of a vessel. The electrical circuits include signal conditioning, controllers and a personal computer for data processing and monitoring. After exciting a sensor with an electrical pulse, ultrasonic waves will be transmitted from the ultrasonic sensor towards the medium. The ultrasonic waves be scattered and attenuated inside the pipe when they encountered with the interface of two different materials. Hence, a wave with a weak amplitude can be detected by the receivers installed on the other side of the pipe. After collecting the data from all receivers, the next step is to transmit these data to a PC so as to reconstruct an image which represent the profile of the materials inside the pipe. This is termed the image reconstruction method.

The software contains image reconstruction algorithms which plays an important role in the final step of cross-sectional monitoring of a pipe. Image reconstruction comprises two parts which is the forward problem and inverse problem. The forward problem is concerned with the output of each sensor and the sensing area utilizing the sensitivity maps whereas the aim of the inverse problem is to reconstruct an image to determine the profile of materials such as gas bubbles inside water.

Two main categories in image reconstruction are the analytical and iterative methods [11]. Besides there are some heuristic methods which have been used for image reconstruction including non-linear, artificial neural network [12,13] and fusion methods [14,15], in which a dual mode tomography [16,17] is implemented. Although analytical methods [18-22] have the advantages of being fast and simple, they have disadvantages in that smaller number of sensors are utilized or few view data, which resulted in reduced accuracy. However, iterative methods [23-26] are insensitive to noise and they can reconstruct an optimal image even in the situation where the data is incomplete but they suffered mostly from low computational speed.

2. Ultrasonic System

Modeling mathematically the propagation of ultrasound and its characteristics is not a straightforward matter but in the case of liquid/gas flow regime it can be reduced to some simplified equations [27-30]. A vital parameter in the interaction between an ultrasound wave with a material is the acoustic impedance (Z). The acoustic impedance of a material is the multiplication of the density of that material and the velocity of the ultrasonic wave in the medium as Eq. (1):

$$\mathrm{Z} = \rho\mathrm{c} \tag{1}$$

where ρ is material density and c is the wave velocity inside a material.

The encounter of an ultrasonic wave with the boundary of two distinctive materials caused the wave to be reflected, transmitted or refracted. Reflection and transmission coefficients, R and T are expressed as Eq. (2) and Eq. (3):

$$\mathrm{R} = (\frac{\mathrm{Z_2 - Z_1}}{\mathrm{Z_2 + Z_1}}) \tag{2}$$

$$\mathrm{T} = (\frac{\mathrm{2Z_2}}{\mathrm{Z_2 + Z_1}}) \tag{3}$$

where $\mathrm{Z_1}$ and $\mathrm{Z_2}$ are the external and internal acoustic impedance respectively.

The factors which cause an ultrasonic wave to experience attenuation are absorption, scattering and the distance from the origin. Attenuation is a useful parameter in an ultrasonic measurement system. Attenuation can be modeled based on the Lambert's exponential law of absorption, where the ultrasonic energy intensity of transmitter and receiver are related as Eq. (4)

$$\mathrm{I_R(z) = I_T exp\ (-\mu z)} \tag{4}$$

in which $\mathrm{I_R}$ is the ultrasonic amplitude at distance z from source,$I_T$refers to the ultrasonic initial amplitude at the source, z represents the total pass length and μ is the attenuation coefficient in the medium.

There are three types of ultrasonic various wave propagation namely transmission, reflection and diffraction mode. Theoretically all three modes can be treated as individual solutions (based on different assumptions) of the same inverse problem of a scattered field produced by an object, or group of objects.

If the data measured by the sensors concern on amplitude or transmission time (time of flight) of forward scattering signal, and the reconstruction method is based on straight-line propagation then, the system works as a transmission mode. In the case of reflection-mode technique, the measurement is the same as transmission mode but it is applied to back-scattering signals. In transmission and reflection mode if the reconstruction algorithm is based on the inverse solution of ultrasonic wave equation, it is referred as diffraction mode.

The main scope of this research is focused on image reconstruction technique in the transmission mode and there are two modes of reconstructive ultrasonic tomography based on the transmission mode. The first one is based on attenuation measurements that yields the spatial distribution of the acoustic absorption coefficient within the object examined. The second mode uses time-of-flight measurements that reproduces the acoustic refractive index. Here, the first one is utilized as tool to reach our objectives.

Because of the dynamic characteristic of flow regime in industrial vessels a real time system is needed for monitoring such a process. The propagation of ultrasonic wave inside a medium is relatively slow compared to those electrical or optical tomography systems. For example, for water at 20 ℃, the speed of soundisabout 1500ms^{-1}. For a typical transmission mode system composed of 16 transducers mounted around a pipe full of water and with 110mm diameter, the minimum data acquisition time needed for a frame of image is $\mathrm{T} \approx 8.4\ \mathrm{ms}$. This time include the reverberation delay between each excitation. In addition to this time, data processing and image reconstruction procedure will increase the total time of completing one frame. Therefore, the experimental result would indicate the delay time length. The measured acquisition time in experiment determines the number of image frames in a second.

Another constrain of UT application in flow regime monitoring is the maximum speed of flow. For example, in two-phase flow regime if the depth of acoustic beam along the axis of the flow is 15 mm, the maximum velocity for the discussed system is $v = \frac{15\ mm}{8.4\ msec} = 1.78\ m/sec$.

3. Image Reconstruction

Image reconstruction is a technique in which cross section projections collected by receivers from different angles around the object are used to create a two dimensional or three-dimensional images. An algorithm is used to reconstruct an image using these projections. The image reconstruction process can be reformulated as an inverse problem. In the case of the inverse problem, the exact solution to the reconstruction procedure is often impossible to be found due to data insufficiency and noise disturbances. Therefore, image reconstruction is an ill-posed inverse problem. Radon in 1917 invented a mathematical procedure whereby an object mapped to lower dimensions using projections could be reconstructed to the original. These lower dimensions are also known as Radon space. The solution to this mathematical problem has been applied various applications such as astronomy and optics.

Mathematically, Radon transform corresponds with the integral transform of a function over straight lines. A one-dimensional projection of a cross section of an arbitrary object $f(x, y)$ is given by the following Eq. (5):

$$p_\theta(t) = \int_{-\infty}^{\infty} f(x, y) ds \quad (5)$$

in which $p_\theta(t)$refers to the projections of $f(x, y)$, θ is the rotation angle, t and s are mapped coordinates in Radon space and the integral of $f(x, y)$is along the line s.

The coordinate rotation matrix is Eq. (6):

$$\begin{bmatrix} t \\ s \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \quad (6)$$

The inverse radon transform can be formulated as Eq. (7):

$$f(x, y) = R^{-1}\{p_\theta(t)\} = {}^{1}\!/_{2\pi^2} \int_0^{\pi} \int_{-\infty}^{\infty} \frac{1}{r\cos(\theta - \varphi) - t} \frac{\partial p_\theta(t)}{\partial t} d\theta dt \quad (7)$$

where r and φ are polar coordinates and θ is the rotational angel from 0 to π.

This is a form of radon inversion which is required all measurement data from 0 to π. In practical implementation, there is no infinite number of sensors to satisfy the inverse radon transform. Different sensor geometries and numerous ways of discretization lead to different levels of accuracy.

The simple 1-D radon transform is a collection of parallel projections integrals, for a constant angle θ.These projections cross the region of interest from one side to another side of the region of interest.

Image reconstruction can be divided to two parts: forward problem and inverse problem. In the forward problem a simulation is used to find a sensitivity map which is the discretized line from the transmitter's output to the receiver's input. A sensitivity map is a matrix with all zero elements except the elements which are a part of the line from transmitter to receiver. Accurate forward models help to improve image reconstruction but there is no exact model and usually an estimated method is used.

For finding the sensitivity map in transmission mode tomography, the forward problem discretizes the continuous field ROI and locates the discrete bands spanned by the output of a transmitter and input of a receiver.

Linear Back Projection (LBP) is the simplest reconstruction procedure which estimates the density at a point by summing (integrating) all the projections that pass through it at various angles therefore. The other name for LBP is the summation back projection. An assumption in LBP is that the projections are ideal straight lines and therefore it produces an image with smooth details.

In the fan-beam projection geometry, the LBP method determines the density of objects in each pixel of reconstructed image based on the following Eq. (8):

$$f(x,y) = \int_0^{2\pi} p_\theta(t)d\theta \quad (8)$$

where $f(x,y)$ is the object, $p_\theta(t)$ is the radon space function and θ is the angles between projection and x axis. In parallel beam geometry the equation can be modified as Eq. (9):

$$f(x,y) = \int_0^{\pi} p_\theta(t)d\theta \quad (9)$$

This is because parallel and fan beam projections have different geometries. In fan beam the scan range for sensors is from 0 to 2π covering all region of interest whereas in parallel beam half of angles range is enough.

The flowchart in Figure 1 shows the steps used for the image reconstruction algorithm. As shown in Figure 1 the program begins with initializing the transmitter number Tx, Rx (receiver number) and the image matrix M to 1,1 and 0, respectively. Hence all pixels in the M matrix are set to zero. Then in each loop one projection multiplied by the sensitivity map ($S_{Tx,Rx}$) and the resulted matrix is added to the image matrix (M) using the LBP equation. Finally, the image matrix is displayed by the monitor.

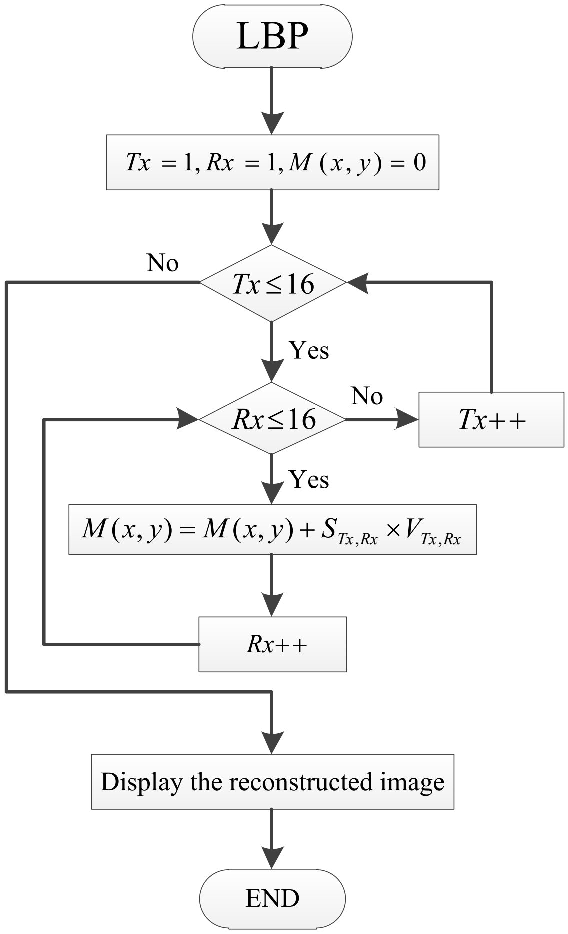


Fig. 1. LBP algorithm flowchart

Various phantoms of bubbly flow regime were used to evaluate the performance of different reconstruction methods. Phantom 1 is a single bubble with a cross-sectional area of 48mm^2 whereas phantom 2 is a single bubble having a cross-sectional area of 192mm^2. Phantom 3 and 5 are multiple bubbles with the same size but at different locations. Phantom 4 consists of a small bubble and a larger bubble of different sizes. The results were obtained in static mode and low voidage bubbly flow was assumed.

The ultrasonic tomography system is illustrated in Figure 2. The pipe consists of an acrylic transparent pipe which enables visual observations to be made and sixteen ultrasonic transceivers which were mounted on a circular array around the pipe. The pipe has an inner diameter of 100 mm and an outer diameter of 110mm. Pphantoms are placed inside the PVC pipe with different diameters of 5mm, 10mm and 20mm. As part of the noise reduction strategy, coaxial cables were utilized to connect sensors to the main board. The main board includes the transmitter unit, the receiver units and the controller unit. The transmitter unit consists of a MOSFET which generates the ultrasonic burst tones. Each receiver unit consists of two amplifiers, a diode for rectifying received signals, a peak detector and sample and hold IC to keep the peak of the received signal. The controller unit was used to send control signals and collect the output of all receivers and send these data to the PC.

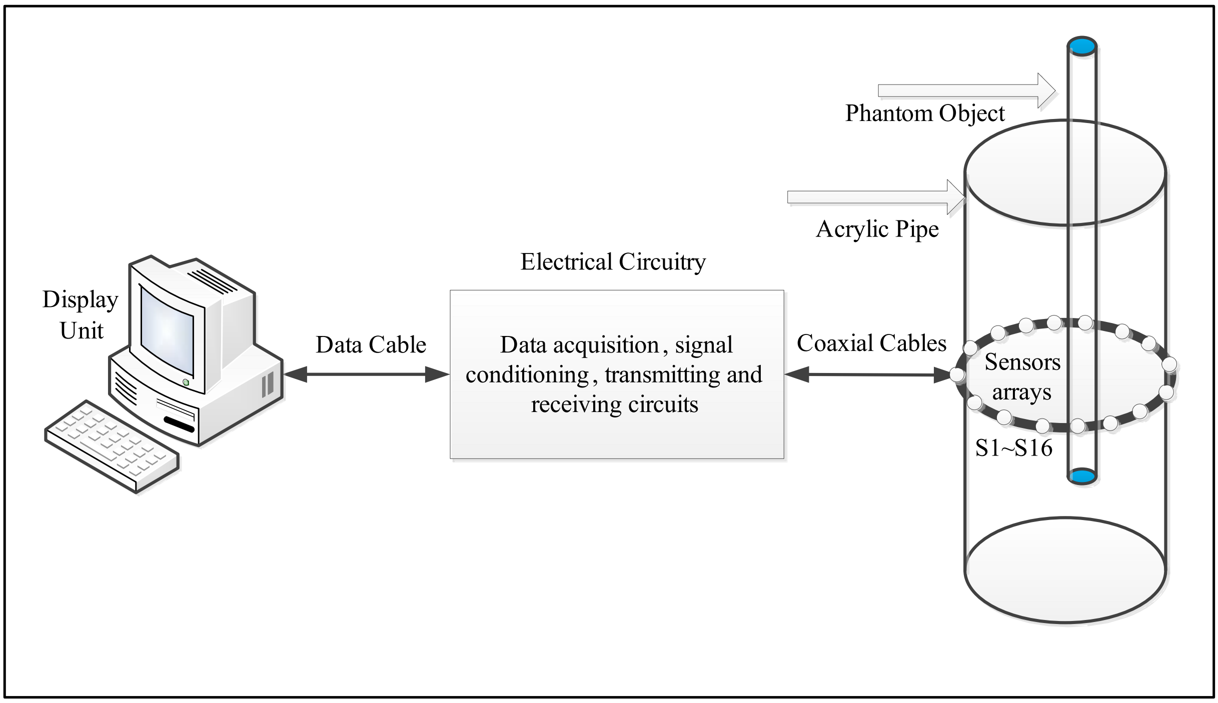


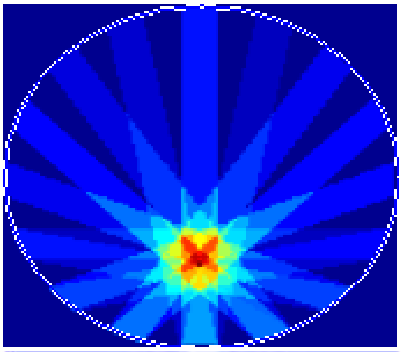
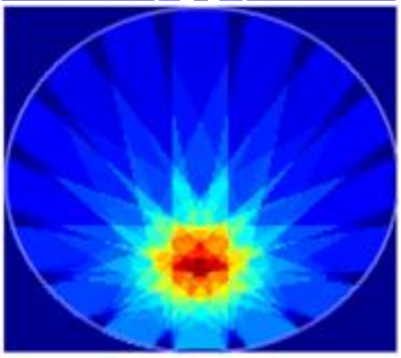
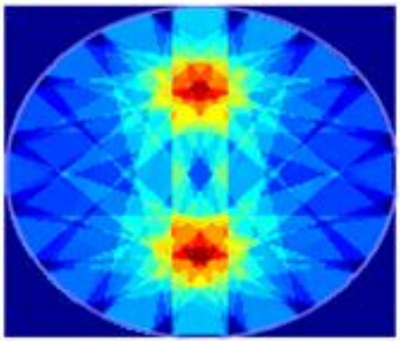
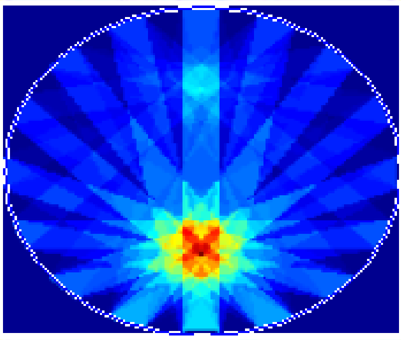
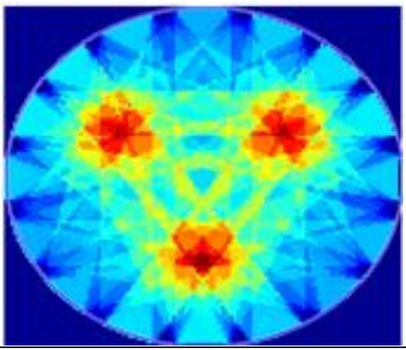
Fig. 2. Ultrasonic tomography measurement setup

4. Results and Discussion

Table 1 illustrates the results of various images reconstructed using the LBP algorithm showing different locations and different sizes of phantoms placed inside a vertical pipe. The phantoms represent static bubbles in a flow pipe. Although noise is present in the images, the system is able to pinpoint accurately the location of bubbles. From the reconstructed images of phantoms in Table 1, the location of the bubbles can be discerned inside the pipe. Phantoms 4 in Table 1 shows the different conditions in which the size of bubbles is not same.

Table 1 represents five different situations in which the phantoms have different sizes and are placed in different locations in a static manner. The results clearly show that the locations of the phantoms can be identified by the ultrasonic tomography system. Table 1 shows the location of phantom 1 and phantom 2 which consists of single bubbles. In addition, Table 1 also shows the results of phantom 3 which shows two equal size bubbles. Besides Table 1 also shows phantom 4 which consists of two bubbles consisting of a small bubble and a large bubble. Phantom 5 is shown in Table 1 which clearly shows the location of three identical size bubbles. LBP has the advantage of being the simplest and the fastest algorithm but the images produced using the LBP algorithm are smeared. All of the results show that the system is capable of detecting the locations of the bubbles.

Table 1
Images of phantoms using the LBP method

Phantom	Normal sensitivity map
Phantom 1	
Phantom 2	
Phantom 3	
Phantom 4	
Phantom 5	

4. Conclusions

The strict rules regarding industryes and the environment have led to various research on industrial process monitoring, control and instrumentation. Flow measurement is extremely important in the field of process instrumentation and has been implemented in the petrochemical, chemical and nuclear power generation industries. However, the characterization of a multi-component flowing mixture, such as oil and gas, is more difficult and conventional flow meters do not usually yield satisfactory measurement results. In this regard, process tomography especially with non-intrusive sensors is gaining considerable significance in industrial measurements since measurement within the pipe might disrupt the flow process. The ultrasonic system developed is useful in investigating the behaviour of bubbles in a pipe. The system is able to indicate the location of bubbles in the pipe whether it is a single bubble or multiple bubbles. As such the system can provide accurate profiles of gas bubbles which cannot be fulfilled by traditional flow meters.

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