Wire-mesh tomography sensors for multiphase flow investigations

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ABSTRACT

Wire-mesh tomography is new to the tomography field. First founded in 1998, the wire-mesh tomography had been used in several sectors as secondary optional sensors. The wire-mesh sensor can be used to gain void fraction distribution in multiphase flow visualization. By using tomography techniques, several measurements like velocity or phase fraction boundaries can be determined and analysed. The sensor basically built perpendicularly as transmitter and receiver layer located above and below respectively. The sensor wires are made of copper and 16 sensors for each layer, those sensors are considered low-cost, easy built and withstand a harsh environment to investigate multiphase flow. Traditional wire-mesh tomography image reconstruction methods only supply the same number of pixels as the measurement number, therefore wire-mesh sensors have a speed benefit but a lower image resolution. The findings from the previous experiments indicate difference in capacitance and other factors on the output.

Keywords: Wire-mesh, multiphase flow, phase fraction, image resolution, sub pixels, linear back projection

1. Introduction

Process tomography is a technique that largely applied in oil and gas industries to investigate and study the multiphase flow of liquid. An intrusive wire-mesh conductive tomography sensor is an alternative technique which was designed by H. M. Prasser in 1998 [1]. That particular sensor helps to identify void fraction distribution in multiphase flow process visualization. To be simple multiphase flow shows two or more physically distinct simultaneous flow mixtures in a process column or vessel and can be the mixture of one or more components of gas, liquid, or solid.

Several measurements, such as velocity or phase fraction boundaries, can be identified using tomography. Multiple tomography sensors were employed to investigate phase flow patterns, phase flow velocity, and phase boundaries. The wire-mesh sensor (WMS) is an alternative approach that is relatively new to tomography systems. A wire-mesh sensor is made up of two layers that are perpendicular to each other and extended over the process column as the transmitter and receiver layers. The wire layers were put in an orthogonal pattern, with no physical contact between them. To detect fluid conductivity, the first wire-mesh type tomography sensor was used.

Wire-mesh sensors allows investigating the flow nature with good degree of details due its good spatial and temporal resolution depends on the grid size of the designed wire-mesh sensor. A collection of papers that discussed the wire-mesh tomography in several fields were reviewed to have a scope on upgrading the sensor.

2. Literature review

When it comes to wire-mesh tomography, the basic construction of wire-mesh sensor is the same. The basic construction is to have 2 layers perpendicularly located where one is transmitter and the other is receiver. The first publication [2] is a review of trickle bed reactors with set bed depths that are used to assess the presence of conductive liquid between them. The sensor's operation is detailed in this section. A multiplexer circuit activates all the wires in the second (receiver) plane one by one as current is delivered to each wire in the transmitter plane. Only one crossing point is measured at a time; the other wires connecting each aircraft to the ground are unaffected. When current is given to all of the transmitter wires, the measuring cycle is complete [5].

The wires are stainless steel, and each layer has 19 wires, resulting in a total of 313 measured crossing sites. In terms of temporal resolution, because the envisioned device only measures one receiver wire at a time, the length of a measurement cycle is determined by the number of cross points to be investigated. It takes 10–15 seconds to do a full scan with all 38 wires.

The wire-mesh technique based on capacitance measurements is used to examine two-phase slug flows in horizontal pipes in the experimental research of horizontal gas-liquid flow using wire mesh sensor [3]. It is feasible to extract some specific metrics of interest from raw data measured.

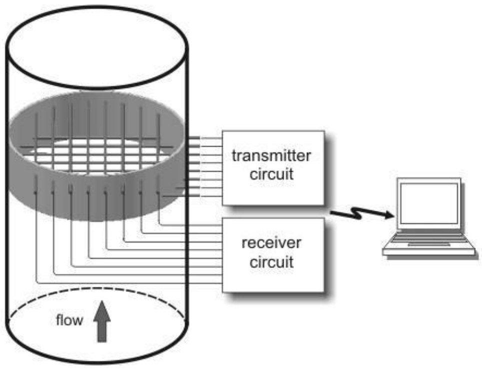


Figure 1. schematic representation of wire mesh sensor

The voltage levels measured by the wire-mesh sensor are stored in a three-dimensional matrix at the computer memory $V(i,j,k)$, with k being the time index and i and j spatial indexes respectively. Wire-mesh sensor electronics produce voltages with a logarithmic response, which is supposed to be understood and corrected to a linear response earlier. As a result, the observed voltages are proportional to each crossing point's electrical permittivity, which is proportional to the void fraction. A calibration process is utilised to convert the observed voltages to permittivity values and then to acquire the phase fraction distributions. First, a matrix VL measurement for a low permittivity substance covering the entire sensor cross-section is done.

The capacitance distribution in a cylindrical pipe was then investigated using a 16 16 wire mesh sensor [4]. To study the distribution of capacitance dispersion occurring within a cylindrical pipe, a tomography system device based on the idea of a wire-mesh sensor has been created. This wire-mesh sensor device is made up of two horizontal layers of wire that may detect the presence of a capacitance fluid between them using local capacitance measurements. The number of cross points between the electrode wires of 256 points of resolution with 16 16 wire design determines the image resolution of the wire-mesh.

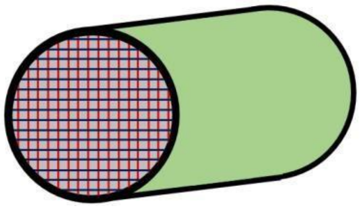


Figure 2. Wire-mesh sensor in a cylindrical pipe

The signal received on the transmitter wire is still a current signal, however in a digital system, the signal must be interpreted as a voltage signal, therefore a current converter circuit that can convert current to voltage signal can be used to change it. A basic feedback circuit consisting of an op-amp, a capacitor, and a resistor may convert current into voltage that is proportional to each other.

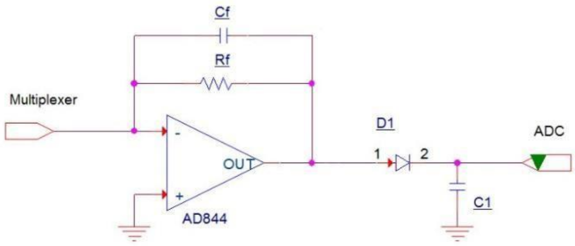


Figure 3. Schematic of a current-converting circuit into a voltage or I-V converter

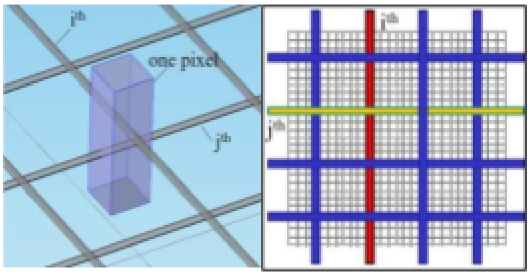
By using equation (1), we can get the capacitance value that occur in cross-section wire-mesh sensor.

$$V_o = -V_i \frac{C_w}{C_f} \qquad (1)$$

The output voltage (Vo) is the op-amp output voltage that will be read by the ADC, while the input voltage (Vi) is the voltage from the receiver wire. The capacitance of the wire-mesh sensor, which fluctuates depending on the flowing substance between the two wire receivers and the transmitter, is represented by capacitor wire (Cw). Because the I-V converter's output signal is still analogue, it must be converted to digital using an ADC by the microcontroller in order to process the picture reconstruction using Equation (1). This equation is placed into the code script of the python 2dimensional image program, making it more than just a image-creation software, However, with wire-mesh sensors, python software also does mathematical calculations to obtain measured capacitance values.

While the other papers reviewed had discussed more on the different setups, variation in construction and number of sensors, some were experimenting on improving the image resolution for wire-mesh sensors. Wire mesh tomography is a type of instantaneous tomography that provides a speed advantage but lower picture resolution because traditional wire mesh tomography image reconstruction methods only supply the same number of pixels as the measurement number. To improve image resolution, a new image reconstruction method based on sensitivity maps is developed, which involves solving the inverse problem using capacitive wire-mesh tomography image reconstruction to provide extra pixels (sub pixels) [9].

Capacitance wire-mesh sensor follows the working principle of ECT sensor, It calculates the capacitance across distinct electrode pairs and reconstructs the sensor cross-section permittivity distribution The goal of picture reconstruction is to obtain a permittivity distribution from capacitance data that has been measured. It's a classic inverse dilemma. Calculating capacitance data from permittivity distribution is the inverse 'forward problem,' which is usually solved using the finite element method (FEM) or actual experiment. Using a much finer pixel mesh grid may help to improve the reconstructed image's resolution. It enables the retrieval of detailed information from a rebuilt wire-mesh tomogram.



(a) (b)

Figure 4. Sub-pixel meshing strategy for wire-mesh tomography image reconstruction. (a) 2D illustration of wire mesh; (b) 3D view of wire-mesh in COMSOL Multiphysics with a pixel marked.

3. Methodology

3.1 Hardware setup

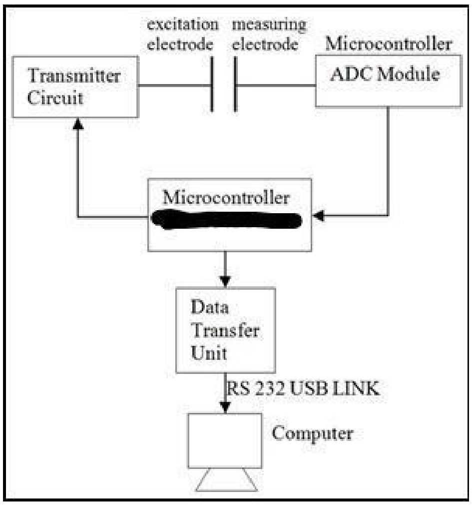


Figure 5. Hardware setup for the experiment

The electrodes were made of tinned copper wire with a diameter of 0.91 mm, and each electrode plane permits 16 parallel wires to reach over to both ends. All of the electrodes were crimped with screw connectors, and the electrodes were made of tinned copper wire with a diameter of 0.91 mm. In the cross-section of the process column, the transmitter and reception planes were spread orthogonally to each other, forming a grid with a pitch of 5.53 mm. The transmitter and reception planes were separated by a distance of 3 mm, h.

The wire-mesh tomography sensor system was used to investigate the liquid/gas interface in a horizontal process column. The experiment before consists of an 80 pin micro-controller, dsPIC30F6014A [6], the transmitter circuit, the electrode pair of wire-mesh sensor, an analogue-to-digital converter, a data transfer unit with RS-232 USB Link and a computer that used for data processing and storage, and for the viewing tomogram result. Similar methodology would be used here but the microcontroller would be changed to Arduino board since it can integrate well with ADC module and better time consumption.

3.2 Limitations

With wire mesh sensor being a low-cost tomography device, it is sure has its own limitations. Other than having lower resolutions in certain circumstances, the characteristics of the construction itself have the limitations. Its intrusive design is a limitation that hard to ignore it [1], [2]. The liquid flow pattern will undoubtedly be affected by two sets of wire planes crossing the column's sectional area. However, because the wires are smaller than the particle diameter and the distance between them is five times that diameter, the effect is minimal. The wires occupy just around 6.5 percent of the reactor cross-section in its current design.

Wire mesh sensor had some problems to quantify liquid velocity. The liquid flow pattern will undoubtedly be affected by two sets of wire planes crossing the column's sectional area. However, because the wires are smaller than the particle diameter and the distance between them is five times that diameter, the effect is minimal. The wires occupy just around 6.5 percent of the reactor cross-section in its current design.

4. Results and Discussions

The previous experiment was conducted with the similar basic construction of wire-mesh sensor as [1] with a much similar goal which is to study multiphase flow of liquid. In [4], the data of the experiment was obtained by a demultiplexer to convert the value of voltage into a digital form so that the digital value used to reconstruct the tomogram image. Free air, distilled water, tap water, and 1 mol of salt solution are among the fluids used in wire-mesh sensors. This variant attempt to assess the sensor's ability to detect fluid changes from non-conductive (air) to highly conductive (salt solution), as well as the capacitance distribution of each fluid.

The current research on wire-mesh studied on the multiphase liquid flow and a simulation had been done to compare the results. A 2D asymmetric model had to be created to investigate the liquid flow for multiphase flow. 2 types of liquid had been tested, first is transformer oil and the second one is water. The figure 3 shows initial value which is nearby 0 in velocity and there was some movement in liquid.

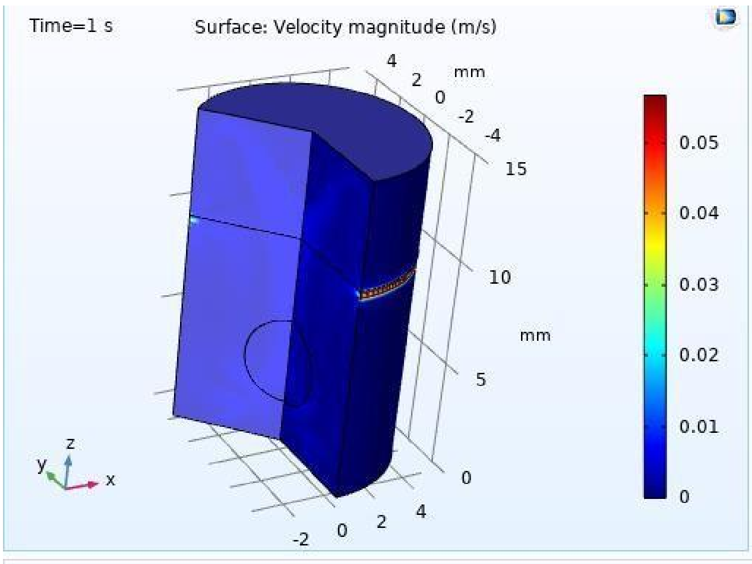


Figure 6: Asymmetric 2D image of velocity

So after the simulation started, the velocity changes when the transformer oil particles flow through the water. Between the height of 5mm to 10mm, higher velocity fluids detected which transformer oil flowed within the viscosity and created a much pressure in the region.

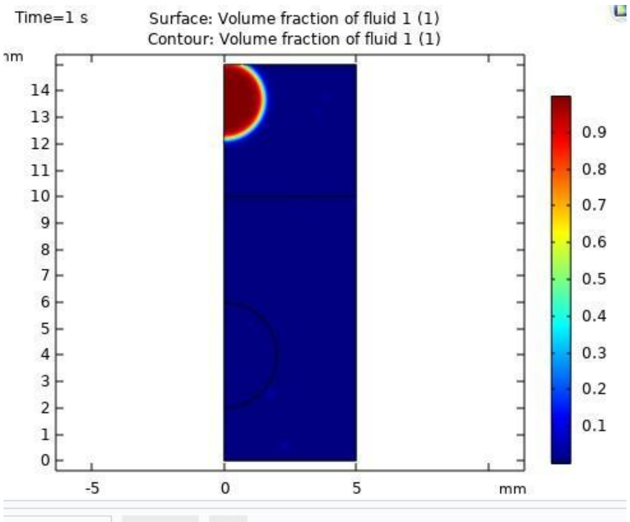


Figure 7. Volume fraction of liquids

So in figure 5, the volume fraction of oil is shown where it flows from 2 mm to 12 mm. The volume fraction consists of velocity and pressure. The velocity was in maximum value as the pressure and the pressure was at maximum before the flow ended.

The result image of the wire-mesh sensor with air media filling the cylinder pipe is shown in Figure 5(a). The approximation of a cylindrical pipe shape is a picture with a white circle and black edges. The shape of this circle is not perfect, and it has a square edge shape. This is because each square represents the cross point of the receiver and transmitter wires, and if all the squares are combined, it becomes a 2-dimensional image of the cylindrical pipe. The image legend on the right shows the value of the capacitance that transformed into colour form, with each colour having its own value, with the colour in the bottom position (white) representing low capacitance and the colour in the top position (red) representing high capacitance (blue) indicates highest value.

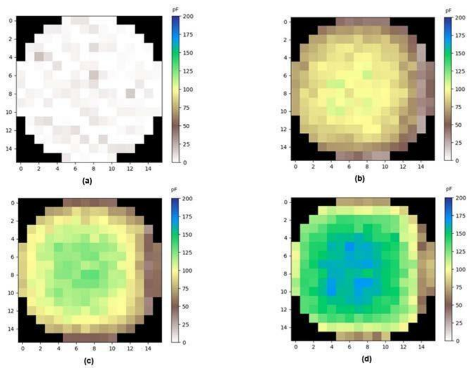


Figure 8. Images generated by wire mesh sensors using (a) free air, (b) distilled water, (c) tap water, (d) salt solution 1 mol

The output picture of a cylinder pipe filled with free air becomes predominantly white (Fig 8(a)), or simply air has zero capacitance. In this scenario, it is unlikely to be zero, although there are some measuring constraints. Because the capacitance of air is too small to be detected, the wire-mesh sensor system had limitations in measuring capacitance on gaseous states, particularly free air. As a result, the system would send the data to the computer as zero, resulting in a white 2-dimensional image. Every measuring point is not zero, so the sensor can measure the air capacitance value at some point, even if it appears to be different color pattern is light brown, this color still can be identified with capacitance value at range 0 to 15 pF.

When distilled water is used as the media, the colour pattern on the output image is considerably more evident, and the pattern has some contrast when compared to photos created with free air. The major hues in the findings image (Figure 8(b)) are brown, yellow, and green. With a total pixel image of less than ten pixels, yellow covers the most area of the image by being in the middle, with brown colour at the perimeter and green colour looking unclear in the centre. The measured capacitance value at the sensor has a quantity of roughly 100 pF in the centre and 50 pF at the edge.

Capacitance rises when tap water is used. The image produced by the device utilising tap water media is shown in Figure 8(c). The number of colour patterns in this image is the same as the number of colour patterns obtained with distilled water. When compared to the previous image, the green colour region is broader; this colour pattern is approximately half of the yellow pattern in the image's central section, indicating that the sensor's capacitance is increasing as a result of tap water pouring down the cylinder pipe.

When the salt solution is poured into the pipe, it generates an altogether new pattern. When the system is used with a salt solution with a molarity of 1 mol, the image produced is shown in Figure 8(d). There are four colour patterns that occupy the image, including brown, yellow, green, and blue, with no white colour. The growth in capacitance value is influenced by the application of additional conductive fluid, as seen by the introduction of a new colour, similar to blue. The green colour is dominating, although the greatest capacitance value, roughly 165pF, is measured in blue. The capacitance pattern distribution in the salt solution remains unchanged from the previous picture pattern, with the maximum conductivity in the picture's centre, shown in blue.

In paper [6], a much simpler but efficient experiment was done to investigate the liquid level visualization using color scaling technique as [3]. But in [3] color scaling used to measure capacitance and reconstruct the image while [6] shows 4 type of liquid level and the tomogram images.

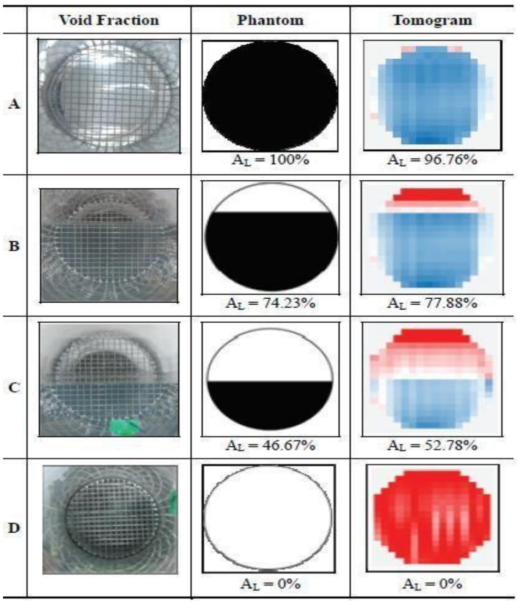


Figure 9 Illustrations of the void fraction, phantom and the tomogram results

Since a phantom picture was employed to clearly describe the experimental scenario and the liquid/gas interface level, the liquid level visualisation can be clearly seen. The results are shown in Figure 6, where AL signifies the liquid area (in percentage). Although the tomogram result image B clearly displays two different regions of the liquid/gas two phase flows in the process column, an analysis of the liquid/gas interface level reveals an overestimation of the level of the liquid/gas region's interface with an estimated error of roughly 3.65%. Meanwhile, the periphery crossing point error in tomogram result image C is the same as in tomogram result image B, but there are a few centre crossing points above the liquid/gas interface is the major of the sensing error. Those crossing points shouldn't be shown as liquid phase, but the sensing values of those crossing points are mostly near to interface value.

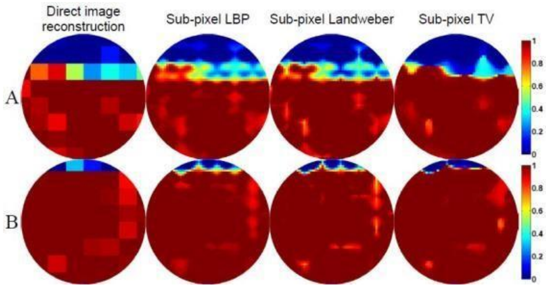


Figure 10. 8*8 sensor reconstruction result of dynamic experiment

Figure 10 is obtained from [9] and this result is based on four different types of flow and the image reconstruction method. This experiment is for sensitivity for the pixels in image reconstruction it has been discovered that different algorithms produce different picture quality, and that the qualities of sensitivity map-based sub-pixel reconstructions are smoother and more detailed than those of direct image reconstruction.

5. Conclusion

The available systems transform the data to reconstruct the image using complex image reconstruction algorithms, which is a time consuming procedure that limits their temporal resolution. The current tomography systems are only capable of imaging gas bubbles with diameters as small as 3mm which is experimentally shown using hollow capillaries of same diameter. Their capability of imaging fast moving bubbles is undetermined.

So studying the limitations, temporal resolution and time consumption are very important and taken into consideration while doing the research. While the preliminary shows color scaling is effective for liquid-level investigation, another paper had proved that wire-mesh sensor indeed can detect particles in different types of liquid within color scaling. The time consumption is indeed quite good but need to be improved. Color scaling is a good method to show liquid level but it need to be experimented if multi-phase flow is involved. One of the example would be best described in drainage systems because multiple objects, different types of liquids and different velocity of liquid were involved. The experiment would be continued in color scaling and for a better 2-D image reconstruction to show the particles through the sensors with the best time consumption as possible.

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