11

APPLICATION OF FUZZY LOGIC METHOD IN ELECTRIC CHARGE TOMOGRAPHY AS A FLOW REGIME IDENTIFIER

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11.1 INTRODUCTION

Transportation of bulk solid materials over long distance from one station to another is gradually becoming routine in industrial trade. The conveying of bulk solids is commonly carried out all the way through a closed conduit with water or air as the conveying medium. Material handling by pneumatic conveying can be found in wide applications particularly industries dealing with power generation, food processing, steel making, pharmaceuticals, solid waste treatment, chemical and many others. The advantages coupled with this method of solid transportation include relatively high level of safety, low operational cost, ease of automation and installation. Consequently, flow measurement of particulate solids in a pneumatic pipeline has been subjects of interest for many researchers in view of the fact that huge numbers of publications in this area are seen within past few decades [1]-[3].

The promising techniques for measurement flow of solid materials in pneumatic conveying have been discussed elaborately by many researchers like Yan [4] and Ostrowski et al [5]. Electrical Capacitance Tomography [6], optical tomography [7], and electrodynamic tomography [8]-[9] have been utilized to visualize the particles distribution across a given cross section of pneumatic conveyor and with the assistance of computer the images can be analyzed and information can be extracted to achieve better control of the plant.

In this paper, electric charge tomography or also known as electrodynamic tomography is presented in turn to investigate the concentration profile of plastic beads conveyed in pneumatic pipeline. Apart from that through this work various flow regimes are introduced such as full flow, three quarter flow, half flow and quarter flow regimes. Therefore, fuzzy logic technique has been employed to recognize the pattern of different flow regimes. An idea to solve the problem of identification in fuzzy logic manner was the main motivation of this work.

11.2 SENSOR DESIGN AND MEASUREMENT SYSTEM

The transducer system consists of two basic elements which are a small electrode and associate electronic circuit. These two components act as sensing device and signal conditioning respectively. The sensor is called an electrodynamic sensor. The electrode detects charge on the flowing particles. The electronic circuit consign of amplifier and filter which converts the identify charge to voltage signal and made it available in three forms of output. The first output is an ac signal which can be used to obtain velocity of flow. The second output is a rectified signal which can be used for spatial filtering test. The third output is an averaged voltage signal which can be used for concentration profile. In this work, the interest is on the third output which is the average signal and it is used to produce tomographic image of concentration profile. Figure 11.1 shows an electrodynamic sensor.

Figure 11.1 The constructed electrodynamic sensor

The electrodynamic sensor is passive, it needs no excitation circuit and the electrodynamic sensor's signal is generated by the electrical charge of the particle [10]. Solid particles in pneumatic pipeline carried some amount of electrostatic charge due to abrasion between particles and air pour, collision amongst the particles, and contact between particles and pipe wall. The 16 electrodynamic sensors were mounted around circumference of pneumatic pipeline which will detect the existent of these electrical charges whilst showing the distribution of particles inside the pipe. Figure 11.2 shows an array of sensors escalated around pneumatic pipe wall.

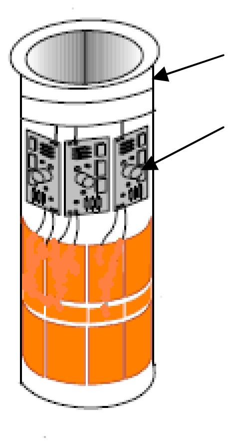

Figure 11.2 Structure of sensors around pipe wall.

The particles used in this experiment are plastic beads with mean size of 3mm. These plastic beads accelerated by the force of gravity hence the theoretical velocity can be calculated using equation 11.1.

$$V = \sqrt{u^2 + 2gs} \qquad (11.1)$$

where:
u is the initial velocity, in this case is 0
g is gravitational acceleration, $9.8ms^{-1}$
s is the distance between the feeder and the sensors, which is 1.4m.

As a result, by substituting the above values into equation 1 the velocity of particles while pass through the sensors is $5.24ms^{-1}$.

The signals received from an array of 16 sensors are stored for image reconstruction process by high speed data acquisition card Keithley KUSB-3116 which performs as an interface between the sensors and the computer. Figure11. 3 show the measurement system of electric charge tomography.

Figure 11.3 Measurement system of electric charge tomography

11.3 IMAGE RECONSTRUCTION

Image reconstruction is the key issue in any tomography systems. There are two most commonly method used in this work named Linear Back Projection (LBP) and Filter Back Projection (FBP).

The forward problem must be solved in order to obtain concentration profile. By solving the forward problem the theoretical output of each sensor can be determined. Firstly, assume that charges of σ coulombs per square meter are evenly distributed on sensing area [8]. The cross sectional area of the pipe is mapped onto an 11 x 11 rectangular array consisting of 121 pixels as shown in Figure 11.4.

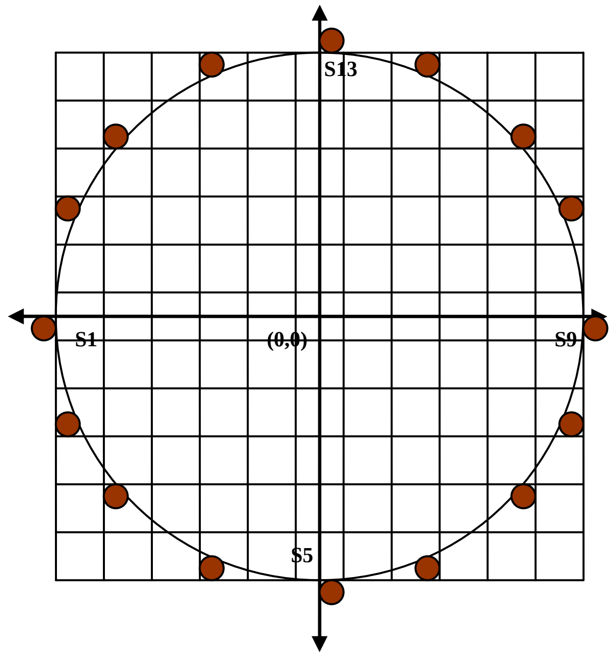

Figure 11.4 The 11x11 rectangular array maps on pipe

The diameter of pipe is 100mm, the centre of pipe has a rectangular coordinate (0,0) and the dimension of each pixel is 9.091mm x 9.091mm. The corresponding sensitivity map of each sensor is generated by calculating the charge which chosen pixel will induce into sensor using equation 11.2.

$$S = \iint \frac{C}{r^2} dA = \int_x dx \int_y \frac{C}{x^2 + (50.5 - y)^2} dy \qquad (11.2)$$

where:

r is the distance of charge to sensor.

A is pipe cross sectional area.

(x,y) are the co-ordinate of the part of the pixel contributing to the sensor output.

The total charge induced on each sensor when assumed C is equal to 1 Cm^2 is calculated via equation 11.3.

$$S = \int_{-50.5}^{50.5} dx \int_{-\sqrt{50.5^2 - y^2}}^{\sqrt{50.5^2 - y^2}} \frac{1}{x^2 + (50.5 - y)^2} dy \qquad (11.3)$$

The back projection algorithm can be obtained by multiplying sensor reading with sensitivity map. Multiplication of each sensor reading with its sensitivity map was made to obtain the 11x11 matrices. Each sensor corresponds to one sensitivity matrix, result of individual element from 16 matrices are summed to obtain concentration matrix.

However, linear back projection algorithm is not suitable for electrodynamic system due to non linear sensing mechanism which has low estimation of solids at the center of pipeline [11] hence to overcome this problem filter back projection algorithm is introduced. A filter mask is calculated by taking the maximum pixel's value of concentration profile based on linear back projection algorithm which is afterward divided by each pixel value within the pipe mapping. However this filter mask is only suitable for full flow condition, different filter mask should be calculated for different type of flow regime. Prior to applying filter mask, knowledge of flow regimes is required [12]. Fuzzy logic technique is applied to identify different type of flow regime such full flow, three quarter flow, half flow and quarter flow.

11.4 FUZZY LOGIC SYSTEM FOR FLOW REGIME IDENTIFICATION

Nowadays, fuzzy logic technique is one of the good tools used to describe the system's behaviour. Fuzzy logic method solves the identification or classification problem by using rules to handle its behaviour, membership functions, and inference process, which may result in improved performance, and simpler implementation. Moreover, from the implementation point of view, fuzzy logic is inherently uncomplicated since it does not required to be too precise, reduces complexity of the system itself.

Application of fuzzy logic to solve identification problem requires the design of a FUZZY controller. Matlab's Fuzzy Logic Toolbox was used in solving this system identification.

In this work several steps are followed to develop fuzzy system in identifying different types of flow regimes.

- Specify the problem and identify input and output variables.
- Determine fuzzy sets.
- Extract and construct fuzzy rules.
- Encode the fuzzy sets, fuzzy rules and procedures to perform fuzzy inference into the fuzzy system.
- Evaluate the system.

The first step in designing fuzzy system is to identify the input and output variables. Therefore, the flow regime was chosen as an output variable while the outputs of 16 sensors were chosen as the set of inputs variables for fuzzy system. Membership function used for the inputs are trapezoid. Membership functions for the output are trapezoid and triangle. The overall structure of the proposed FUZZY controller is shown in Figure 11.5.

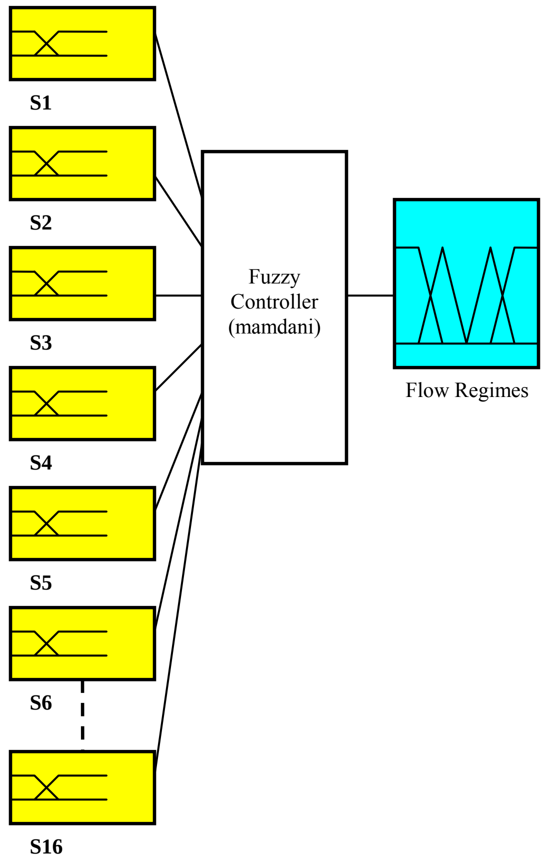

Figure 11.5 Structure of the FUZZY controller

Once the design variable have been identified, a suitable control strategy solving the identification of flow regimes problem needs to be recognized by carrying out a knowledge acquisition process that codifies the knowledge of an expert into a set of fuzzy rules.

In developing this activity, it is possible to take advantage of linguistic information, that summarise a reasoning process as a set of fuzzy if then rules with correct membership function, and numerical information, that could derive from data recorded during experimental operation. Using linguistic directives makes it easy to obtain a set of fuzzy rules. The proposed rules have following structure.

IF (s1 is high) and (s2 is high) and (s3 is high) and (s4 is high) and (s5 is high) and (s6 is high) and (s7 is high) and (s8 is high) and (s9 is high) and (s10 is high) and (s11 is high) and (s12 is high) and (s13 is high) and (s14 is high) and (s15 is high) and (s16 is high) THEN (FlowRegime is Full)

IF (s1 is high) and (s2 is high) and (s3 is high) and (s4 is high) and (s5 is high) and (s6 is high) and (s7 is high) and (s8 is high) and (s9 is high) and (s10 is high) and (s11 is high) and (s12 is low) and (s13 is low) and (s14 is low) and (s15 is high) and (s16 is high) THEN (FlowRegime is 3Quarter)

IF (s1 is low) and (s2 is high) and (s3 is high) and (s4 is high) and (s5 is high) and (s6 is high) and (s7 is high) and (s8 is high) and (s9 is low) and (s10 is low) and (s11 is low) and (s12 is low) *and (s13 is low) and (s14 is low) and (s15 is low) and (s16 is low) THEN (FlowRegime is Half)*

IF (s1 is low) and (s2 is low) and (s3 is high) and (s4 is high) and (s5 is high) and (s6 is high) and (s7 is high) and (s8 is low) and (s9 is low) and (s10 is low) and (s11 is low) and (s12 is low) and (s13 is low) and (s14 is low) and (s15 is low) and (s16 is low) THEN (FlowRegime is Quarter)

The entire set of linguistic and numerical information identified above represents the foundation of the knowledge base which needs to be codified in the fuzzy controller. The next step in designing fuzzy logic controller concerns the identification of the appropriate control architecture. The fuzzy logic controller for classifier is based on Mamdani fuzzy classifier with following parameters:

- AND method: MIN;
- OR method: MAX
- IMPLICATION method: MIN
- AGGREGATION method: MAX
- DEFUZZYFICATION method: CENTROID

In order to evaluate the effectiveness of the proposed fuzzy controller, simulation was developed with used of Simulink so that the performance of controller can be justified.

11.5 RESULTS AND DISCUSSIONS

The concentration profiles for both linear back projection algorithm and filter back projection algorithm are generated using Matlab. The constructed concentration for linear back projection and filter back projection are presented for different flow regimes such full flow, three quarter flow, half flow and quarter flow at rate of 500g/s.

11.5.1 Full flow

In this case, the plastic beads flow naturally without inserting a baffle into pipe. Therefore, in theory the distributions of plastic beads are fairly distributed through the pipe cross section.

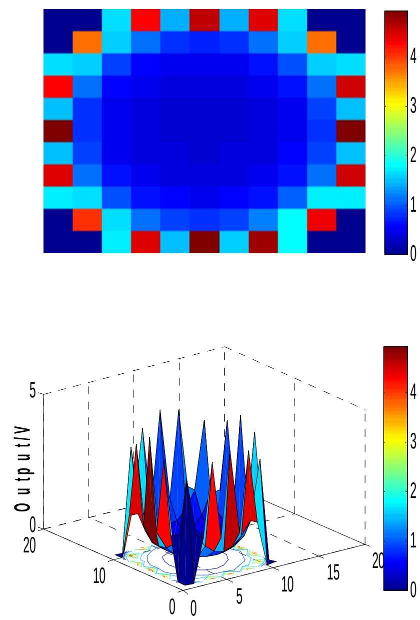

Figure 11.6 Concentration profile for full flow obtained at flow rate 500g/s based on LBP

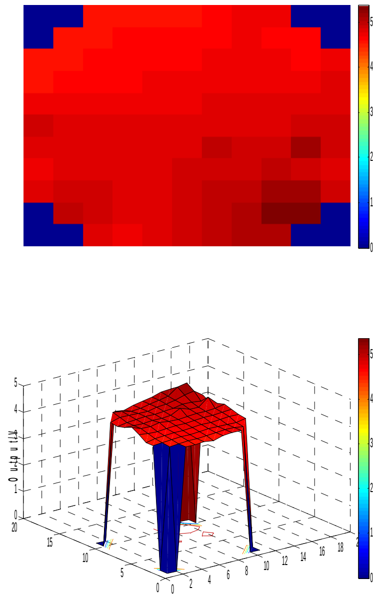

Figure 11.7 Concentration profile for full flow at flow rate 500g/s based on FBP

It is clearly shown from the tomographic images of Figure11.6 and 11.7 that images plotted using filter back projection (FBP) algorithm illustrates more realistic of concentration profile compare with the result using linear back projection (LBP) algorithm. There is no lower concentration exist at the center of image which is similar with the actual at pipeline for full flow condition.

11.5.2. Three quarter flow

Three quarter flow is created by inserting baffle a quarter of diameter into pipe which means blocking quarter of pipe and cause the remaining three quarter of pipe for the plastic beads to flow. Theoretically, there is no charges detected for quarter size of pipe which covered by baffle.

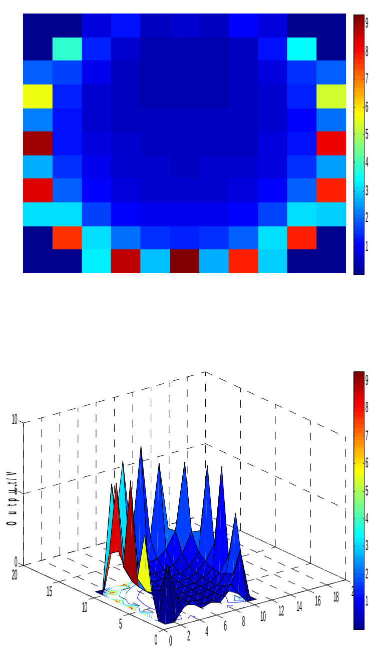

Figure 11.8 Concentration profile for three quarter flow at flow rate 500g/s based on LBP

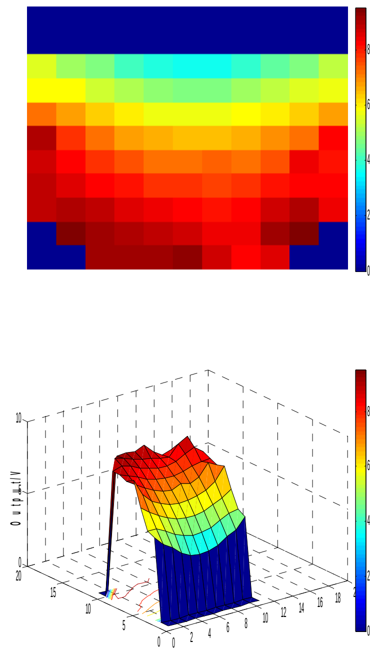

Figure 11.9 Concentration profile for three quarter flow at flow rate 500g/s based on FBP

By looking at Figure 11.8 and 11.9 the images result show an excellent agreement with the actual position where no charge detected at the area of pipe blocked by baffle. But for Figure 11.8 which images plotted using linear back projection algorithm a low estimation of solids concentration for those far form the sensors, on the other hand for image plotted using filter back projection algorithm the concentration of plastic beads are more practical.

11.5.3. Half flow

In this case, baffle is inserted to block half of the pipe and allow another half for material to flow. The predicted image must have half of the cross section emptied while the other half filled.

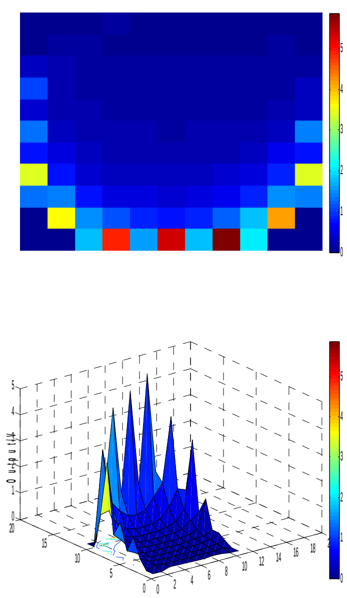

Figure 11.10 Concentration profile for half flow at flow rate 500g/s based on LBP

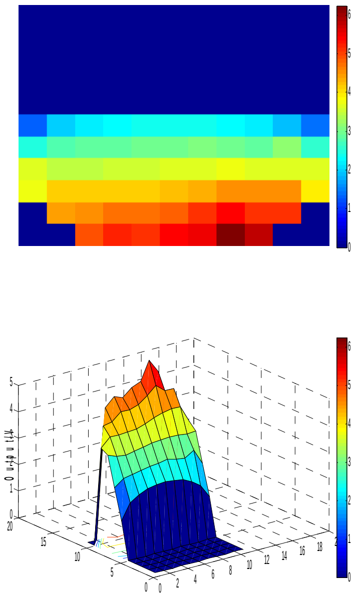

Figure 11.11 Concentration profile for half flow at flow rate 500g/s based on FBP

Figure 11.10 and 11.11 reveal that half of the cross section area of pipe is occupied with image concentration of particles while another half is emptied. For Figure 11.11 image plotted is more accurate because filter back projection (FBP) algorithm reduce the limitation of linear back projection (LBP) algorithm.

11.5.4. Quarter flow

For quarter flow, baffle inserted on three quarter size of pipe and leaving only quarter part of pipe in letting plastic beads to flow.

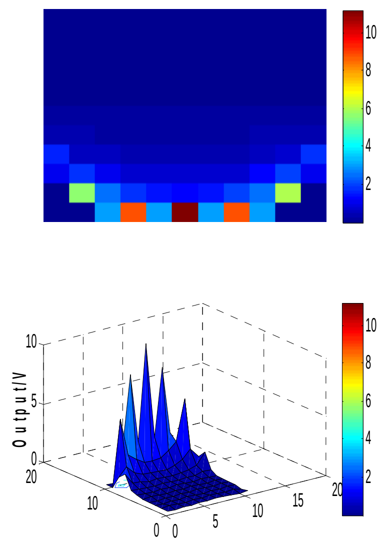

Figure 11.12 Concentration profile for quarter flow at flow rate 500g/s based on LBP

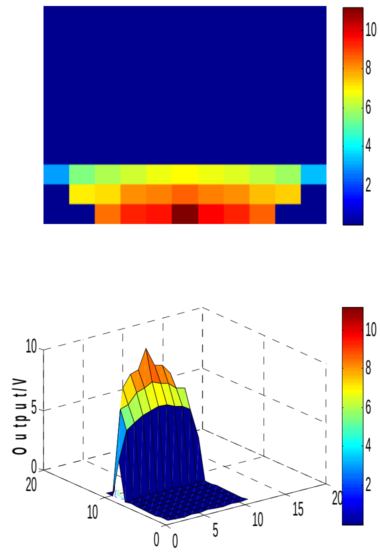

Figure 11.13 Concentration profile for quarter flow at flow rate 500g/s based on FBP

Figures 11.12 and 11.13 show tomographic images of concentration profile for full flow at rate 500g/s based on Linear back projection and filter back projection algorithm respectively. Only quarter cross section area of pipe sensed the present of charge. Same as the previous cases the results illustrate that filter back projection algorithm would give more weight to image concentration located further away from the sensor so that the concentration profile would be equally distributed.

11.6 CONCLUSIONS

By looking at the experimental results, the following conclusions can be drawn.

- Electrodynamic sensor suitable to measure concentration profile of plastic beads conveyed in pneumatic pipeline where the sensor sensitively detects the present of charge near its sensing zone.
- The successful used of fuzzy logic technique to identify the different type of flow regime proved that fuzzy logic is one of the precise tool for identification problems.
- Filter back projection algorithm reduces the limitation of linear back projection algorithm to measure concentration profile of solids particles in pneumatic conveyor which limitation occurred due to non linear sensing mechanism.

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