DOI: 10.5604/20830157.1194270

TWO PHASE GAS-LIQUID FLOWS RECOGNITION USING FUZZY INFERENCE

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Abstract*. In this paper the authors shows the new methodology of two phase gas-liquid flows recognition based on the fuzzy inference. At the beginning there is a short description of the experimental set up, later there is a detailed description of the experimental data processing and analysis algorithm and the fuzzy rules building routine, at the end of this paper there are the research results and analysis.*

Keywords: fuzzy logic, electrical capacitance tomography, fuzzy inference, two phase gas-liquid flows recognition

ZASTOSOWANIE WNIOSKOWANIA ROZMYTEGO DO ZADANIA ROZPOZNAWANIA PRZEPŁYWÓW DWUFAZOWYCH GAZ-CIECZ

Streszczenie. *W artykule autorzy zaprezentowali nową metodę rozpoznawania typu przepływu dwufazowego mieszanin gaz-ciecz opartą na wnioskowaniu rozmytym. We wstępie artykułu czytelnik znajdzie informacje na temat instalacji badawczej wykorzystanej w badaniach oraz na temat charakterystyki typów przepływów. W dalszej części autorzy przybliżają szczegóły nowej metody. A więc można odnaleźć opis algorytmu analizy danych pomiarowych, definicje funkcji przynależności oraz reguł wnioskowania. W ostatniej części artykułu autorzy prezentują działanie metody oraz poddają pod dyskusję uzyskane wyniki.*

Słowa kluczowe: logika rozmyta, elektryczna tomografia pojemnościowa, wnioskowanie rozmyte, rozpoznawanie przepływu dwufazowego

Introduction

Recognition of the two phase gas-liquid flows is a big area of research in the field of computer tomography. There are two main approaches to this problem [1]:

- recognition of the reconstructed tomographic images – tomograms,
- recognition of the processed images obtained from high speed camera (CCD),

Both of these approaches are widely described in the word literature and gives real decent results.

In this paper the authors describes new approach to recognition two phase gas-liquid flow regimes using raw electrical capacitance tomography (ECT) data, context information (gas and liquid flow rate) and fuzzy logic based algorithms.

2. Experimental set up

The experimental set up used in the described studies consist of three independent modules:

- Texas Instruments data acquisition system – the task of this module is to obtain context information (such as gas flow rate value, liquid flow rate value, installation supply pressure, installation head and tail pressure) describing current installation state,
- Tomographic data management system – the main task of this module is to manage correctness of the obtained tomographic data and to calibrate the tomography device (the raw data acquisition device [2, 3]),
- Data analysis system – the main task of this module is to analyse all data provided by the other modules, recognition of the two phase gas-liquid flows and control (on demand) the research facility – change investigated pipeline direction and diameter, change the gas and the liquid flow rate values,

Work in such distributed environment required a usage of network calibration algorithms which resulted in possibility of working in none laboratory conditions. The system operators now can work from any place that has internet connection. The same network algorithms were also used in data exchange processes between the system modules.

All described modules works with the semi industrial installation of the two phase gas-liquid flows placed in the Tom Dyakowski Computer Tomography Laboratory of Lodz University of Technology Institute of Applied Computer Science. Detailed information about two first system can be find in [2, 3], in this paper the authors will focus on the recognition system

3. Raw tomographic data – acquiring and controlling

Electrical Capacitance Tomography (ECT) is the measurement technique which has already been successfully applied for monitoring the two-phase industrial flows in which each of the phases differs with the dielectric permittivity [3]. State-of-the-art concerning the application of the tomographic techniques for the two-phase gas-liquid flow visualization can be also found in many of conference proceedings from World Congresses on Industrial Process Tomography held continuously every 2 years, starting in Buxton, England in 1999. Knowing the relationship between the concentration of the material inside the pipe and the dielectric permittivity ε it is possible to determine the liquid and gas phases distribution. This in turn allows the identification of the flow structure and the measurement of the void fraction. This type of measurement technique seems, in fact, to be the most effective in applications for flows mainly because of its speed and non-destructive feature.

The typical ECT system consists of a capacitance sensor, the measurement system and PC computer. The principle of ECT technique is based on measuring changes in electric capacitance between the capacitor planes as a result of changes in the dielectric object located between these planes. The dielectric object in this case is a liquid with gas bubbles. The measurement concept is as follow: once the positive potential on one of the electrodes (excited electrode) is set, while others are grounded. The measured values of capacitances are collected and then further electrodes are excited.

3.1. Construction of tomographic capacitive sensor

The sensors used in the research were constructed on the basis of the technique of multiple winding a synthetic fabric fibre with an epoxy resin laminate. The process of determining the optimal structure of the sensor was conducted by both theoretical and experimentally. The theoretical analysis was applied to the standard rules of determining the capacitance distribution within the capacitors on the basis of the physical phenomena occurring in the electric field. However, the analysis of between electrodes capacitance, collected using Agilent E4980A LCR meter, made it possible to effectively identify the areas of the sensor interior with a lower sensitivity and adopt a strategy for the sensor interior capacitance electrodes structure, characterized by uniform sensitivity measurement throughout the whole scan.

3.2. Structure of the measurement frame

The measurement frame (ECT frame) is a set of measurement data (structured as a vector) collected from the capacitance sensor in one measurement cycle. The measurement cycle is a period of time required for collecting all of the between electrodes capacitance from the sensor by the tomography system and additional time needed to put those measurements into system memory. The measured values are stored in the frame always in the same order. The ECT frame is assembled from measured values and additional header, which stores following information:

- mark of the ECT frame beginning (this is very important information cause in the system memory there could be more than one ECT frame in the same time;
- frame format tag (the most important information provided by this tag is the number of measurement values which are expected in the one ECT frame);

Before any downloaded ECT frame can be processed it has to be translated. ECT frame translation involves header removal and measurement values correctness check.

3.3. Validation of measurement values

Before saving the measured values from the ECT frame it is checked for correctness. First there is a validation of measurement values quantity, the correct quantity values is taken from the second tag of ECT frame header. Second step of the validation is checking if there are no erroneous values such as H "8001" or H "7FFF" which, according to the used in research tomography device specification, should be treated as an overflows. If the validation algorithm determines that the measured values are incorrect or quantity of these values is incorrect - the frame is dropped and not taken into consideration in the classification process.

4. Experimental data processing and analysis

On the recognition system input there are 6 basic information that describes the installation and the flow states during the measurements:

- gas flow rate value,
- liquid flow rate value,
- flow similarity level [2],
- installation supply gas pressure,
- installation head gas pressure,
- installation tail gas pressure.

In this paper there is the description of the fuzzy reasoning process based on the first three parameters, last three information are used to much more precise inference, but the recognition routine is still the same, even with less number of the input parameters.

The liquid and the gas flow rate values are the information about the contribution of each phase in the mixture during the flow analysis. Both parameters are expressed in m^3/h. These information are commonly used in the flow maps determination process. Flow maps gives the information about the specific flow types occurrence in the specific conditions of the gas and the liquid contribution in the mixture. Unfortunately due to the two phase gas-liquid flows phenomena dynamic nature relying only on this two information may lead to problems with imprecise recognition, especially with the recognition of the flow regimes which are placed on the flow map near to the between flow boundary (Fig. 1).

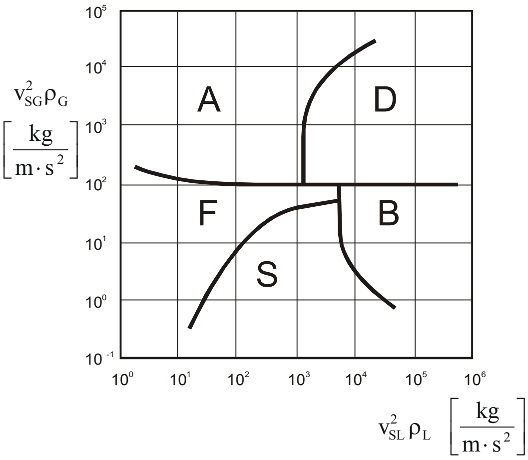

Fig. 1. Example two phase gas-liquid flow map (A – annular, D – dispersed, F - foam, S – slug, B – bubble)

To avoid problems with unambiguous flow identification third input value is taking into the reasoning process, namely flow similarity level (detailed process of flow similarity level determination is described in the authors previous publication [2]), which gives the information about the similarity of the investigated flow to the previous defined pattern flows based on fuzzy classification [4].

All input information are fuzzyficated [2, 4] in order to determine a fuzzy inference usable linguistic variables (transformation the quantitative variables to the qualitative variables). The example of this procedure can be the process of determining the gas range of slug flow occurrence:

- experimental measurements of the gas range of the slug flow occurrence – due to the expert in the research installation that kind of two phase flow occurs in range: 15–30 m^3 of gas per hour,
- dividing the entire obtainable gas range to the linguistic values (by clustering [2])

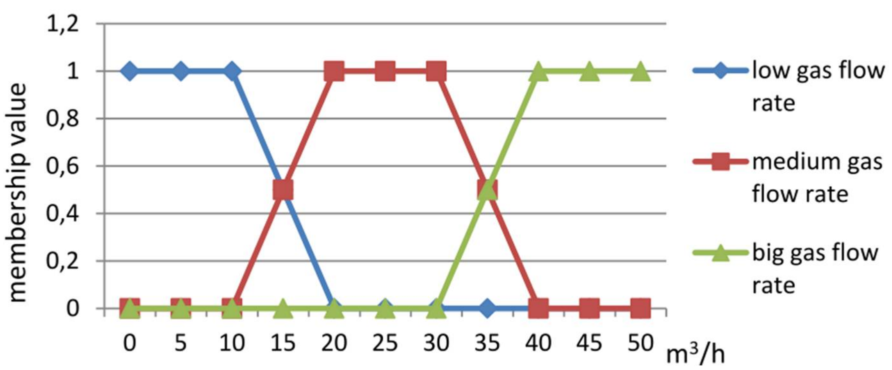

Fig. 2. Example division of the installation gas flow range to the 3 linguistic variables

Having this two information the authors claims that in the used in the studies research installation slug flow occurs in the *average* gas flow area.

5. Fuzzy rules building

The authors during the research used standard [4, 5] fuzzy rules type, namely ***if ... then*** formulas. Having all reasoning system input divided into the linguistic variables the authors can build sample fuzzy rules:

if
gas flow rate value (value corresponding to suitable flow regime)
and liquid flow rate value (value corresponding to suitable flow regime)
and flow similarity level is corresponding to suitable flow regime
then
analysed flow is two phase gas-liquid flow type

Finished fuzzy rule example:

if the gas flow rate is *medium* ***and*** the liquid flow rate is *high* ***and*** the examined flow is similar to the pattern *slug flow* ***then*** examined flow is the *slug flow*.

Off course determined by the authors fuzzy rules includes all linguistic variables corresponding with all possible input parameters. The fuzzy inference results can also be not precise (if needed) such as: highly similar to the slug flow or medium similar to the cast flow (common situation during the recognition process of the cast flow and the laminar flow).

6. Experimental results

The best evaluator of the effectiveness of the described solution is the properly recognition of the "similar" flow regimes (similar due to the expert opinion [2]) for example laminar flow and wavy flow or bubble flow (with big amount of small bubbles) and foam flow.

Proposed solution now gives more than 70% certainty of recognition "similar flows" (it still can be improved in future works by adding more explicit fuzzy rules) and more than 90% certainty of recognition other flow regimes that can be obtained in the horizontal [3] installation pipeline (vertical pipeline fuzzy rules determination is now still in progress).

The time needed to finish the recognition process:

- data acquisition time (observing the flow): 30 sec,
- similarity level determination: <0,5 sec,
- finish fuzzy inference process: <1 sec.

7. Conclusions

Proposed by the authors two phase gas-liquid flows recognition methodology can be very good alternative to the commonly used systems and algorithms. This solution stands out with its effectiveness, low recognition time and full scalability – it can be used in all of that kind installations, only few adjustments need to be done in a membership functions (Fig. 2) that describes range of the input parameters and appropriate to them changes in the fuzzy recognition rules.

Acknowledgement

This work is sponsored by National Science Centre as a part of the research project no 2011/01/D/ST6/07209.

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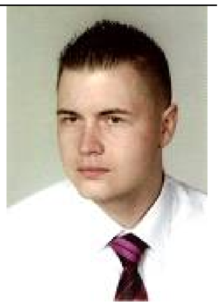

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otrzymano/received: 09.04.2014 *przyjęto do druku/accepted: 29.07.2015*