Recurrence quantification and time-frequency analysis of two-phase flow patterns *

Keying Ren, Xiaoyan Chen, Meng Du

College of Electronic Information and Automation,

Tianjin University of Science and Technology, China;

E-mail: renkeying@mail.tust.edu.cn
www.tust.edu.cn

Abstract

Two phase flow often occurs in industrial production. If it is not detected in real time, it will do great harm to industrial production. In this paper, a method combining recurrence quantitative analysis and time-frequency representation is proposed to identify the flow patterns of the Gas-liquid flow. From the construction of the experimental device to the collection of conductance fluctuation signal of two-phase flow, the recurrence plot and WVD distribution map are drawn by MATLAB which are used in the final flow pattern analysis of two-phase flow. Experimental results show that our method can accurately identify the flow pattern of two-phase flow.

Keywords: Two−phase, Recurrence quantification, time-frequency, flow-pattern

1. Introduction

Two-phase flow is a complex nonlinear system, when the two-phase flow is affected by the relative movement between the two phases caused by the difference in flow velocity between the two phases, and the fluid turbulence in the pipeline, the phase flow presents a high degree of uncertainty, irregularity and activity. In recent years, great progress has been made in the nonlinear analysis of two-phase flow patterns in China. Nonlinear characteristic analysis is applied to the signal processing of two-phase flow measurement, which provides strong support for the highly complex and uncertain flow pattern transformation mechanism of two-phase flow.

The concept of recursive graph was first proposed by JP Eckmann et al. in 1987[1]. After in-depth studies by Eckman, Casdagli, Marwan, Yan et al., recursive graph has been applied to the accurate identification of nonlinear dynamical system. And gradually transformed to the correlation analysis of oil-water flow, through the study found that the flow pattern of two-phase flow can be well reflected by recursive graph analysis method. The characteristics of fluid dynamics and the internal state of the kinematic system can be intuitively reflected through the recursive graph. But recursive graphs are difficult to measure dynamic systems. For this reason, Zbliut and Webber[2] proposed recursive quantitative analysis, which is mainly used to analyze the characteristics of recursive graphs.

In 1807, Fourier first talked about the method of understanding the intrinsic properties of the signal, but this method can only process a large section of the signal, and cannot process the local part of this section of the signal. In 1946, the short-time Fourier transform was proposed. In 1981, Y. Meyer and J. Morlet first studied the wavelet transform method[3]. After continuous development, it finally became the most effective method of time-frequency feature analysis. In 1932, Wigner proposed a method of analyzing unstable signals, which is Wigner's analysis method. However, this method will have cross terms when processing unstable signals, which will interfere with the experimental results. By analyzing this shortcoming, in 1966, Cohen further analyzed this method, which weakened the interference of the Wigner distribution cross term on the experimental results. This method is the Cohen-like time-frequency distribution analysis method. The time-frequency distribution of Cohen class is defined as follows:

$$P(t,f)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} z(u+\frac{1}{2}\tau)z^*(u-\frac{1}{2}\tau)\phi(\tau,v)e^{-j2\pi(vt+f\tau-vu)}dudvd\tau \qquad (1)$$

Many efficient time-frequency analysis methods have been obtained. There are still many shortcomings in the field of time-frequency analysis. The research on the analysis method of unstable signal is still a big problem that we need to overcome.

2. Hardware Design

In order to observe the flow pattern of the two-phase flow and the evolution of the flow pattern in the fluid flow process, a dynamic experimental device for the two-phase flow is designed to achieve uniform fusion of the gas and water in the pipeline, peristaltic metering pumps and gas flowmeter are installed below the water tank and air bottle to achieve real-time measurement of the two parameters.

1. Water tank and air compressor: These two containers mainly store water and air.

2. Peristaltic pump and gas flowmeter: The peristaltic pump can steadily transfer water from the tank to the experimental measurement pipe, which can detect the flow and speed of the liquid. Gas flowmeter is mainly used to detect the flow rate gas.
3. Experimental measurement pipeline: Through the experimental pipeline, we can fully mix the two substance, and can better allow the measurement device to measure the two-phase flow with real data.
4. Measuring device and sensor: The measuring device can measure the state of the two-phase flow in the experimental measurement pipeline in real time, and record the flow pattern of the two-phase flow and the evolution process of the flow pattern in time.

After the experiment began, the peristaltic pump and gas meter transported water and air stably to the experimental measurement pipe, forming gas and liquid two-phase flow. Real-time experimental data were recorded by measuring devices and sensors to provide basis for subsequent experimental analysis.

3. Data analysis

3.1 *Time-frequency characteristic analysis*

The dynamic experiment of two-phase flow at low flow rate was carried out through the above-mentioned experimental device, and a large number of conductance fluctuation signals that can reflect the characteristics of Gas-liquid flow were obtained. Next, we will pass the signal obtained under the above experiment through Wigner-Vill. The Wigner-Vill transform method performs time-frequency characteristic analysis. After a large number of experimental verifications, we have summarized some flow pattern characteristics in each stage of the Gas-liquid flow: When the fluctuation frequency of the conductance fluctuation signal is low and the signal energy is relatively concentrated, the energy of a certain part is not very low, its Wigner-Vill transform map has the characteristic of slug flow. When the fluctuation frequency of the conductance fluctuation signal becomes higher and its energy is scattered and the local energy is small, its Wigner-Vill transform map has the characteristic of bubbly flow. In the Gas-liquid flow dynamic experiment, we can know that when the speed of water in the Gas-liquid flow becomes larger and larger, the energy of the conductance fluctuation signal becomes concentrated. When the flow rate of the water becomes faster, the conductance fluctuation signal becomes dispersed. Some experimental results are shown as Fig. 1.

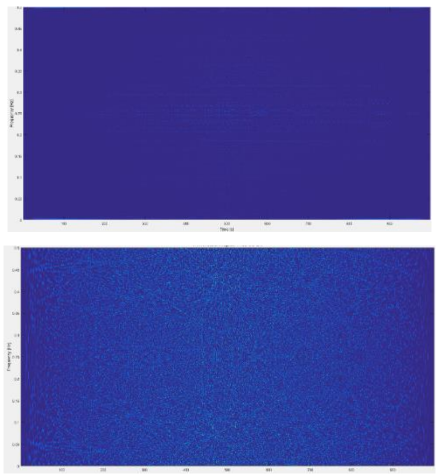


Fig.1.Time-frequency distribution atlas under different flow patterns

Through experiments, we can observe the different characteristics of the Gas-liquid flow under different flow patterns, however, the flow pattern of Gas-liquid flow cannot be accurately distinguished, so we also need to perform quantitative analysis of time-frequency data. Through quantitative analysis of time-frequency characteristics, we can accurately distinguish the flow pattern of Gas-liquid flow. We analyze these signals by summing the energy of each signal point. some experimental data are shown as Fig. 2.

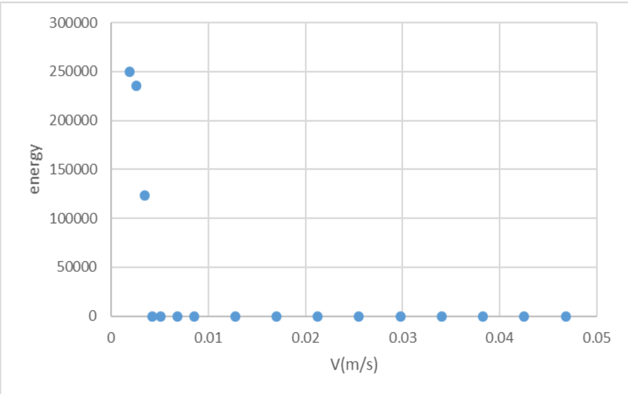


Fig. 2. Under different water content, the signal energy changes with the flow rate.

3. 2 *Recursive graph analysis of oil-water flow*

In the above experiment, we have obtained a large number of conductivity signals of gas-liquid flow, and now we make a series of recursive processing on these conductivity signals. After observing the signal graph and recursive graph, we can observe the recursive characteristics of different flow patterns. Some experimental results are shown as Fig. 3

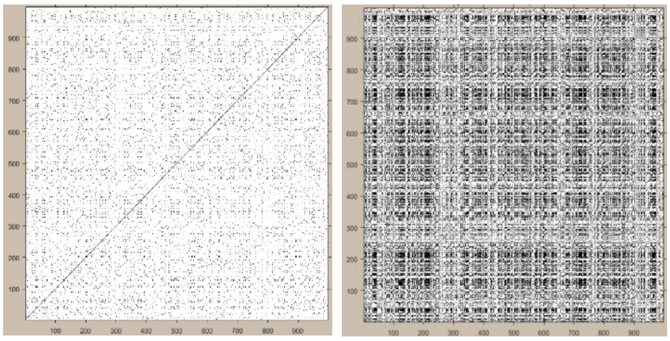


Fig. 3. Recursion diagrams for different flow patterns.

3. 3 *Quantitative analysis of recursive graph of oil-water flow*

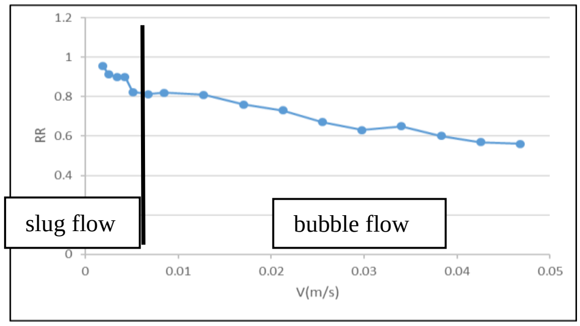
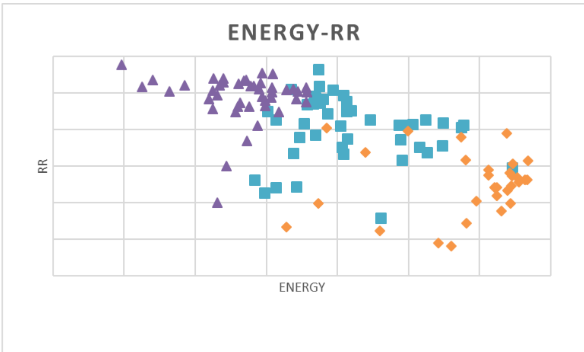


Fig. 4. Recursive rate of different flow.

By observing the above chart, we can know that when the gas flow velocity is fixed, the RR of the two-phase flow, namely the recursive rate, will decrease with the increase of the liquid flow velocity. experimental results are shown as Fig. 4.

3. 4 *Recurrence quantification and time-frequency analysis of two-phase flow patterns*

We have obtained some important conclusions from the recursive quantitative features and time-frequency features. We conduct a joint analysis of the flow pattern dynamics of two-phase flow based on recursive



quantification and time-frequency.

Fig. 5. Energy-recursive rate plot. In the figure, the purple point represents the Fine vesicular flow, the blue square represents the bubble flow, and the orange square represents the slug flow.

We can get the flow pattern of the two-phase flow through the above analysis and the position of the signal point in the figure. Recursive quantitative analysis and time-frequency characteristic analysis are combined to identify the flow pattern of two-phase flow. This method can distinguish flow patterns more efficiently and accurately.

4. Discussion

Through the above conclusions, we can know that recurrence quantification analysis and joint analysis of time-frequency characteristics can accurately identify flow patterns. As the requirements for industrial production and pipeline transportation are gradually increasing, This accelerates the research on the signal processing technology of two-phase flow. It is hoped that more efficient measuring instruments can be developed through this subject, so that industrial production becomes safer, more efficient and reliable.

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Authors Introduction

Keying Ren

He is an Master of Control Science and Engineering, Tianjin University of Science and Technolog. The research topic is target detection and tracking based on deep learning.

Prof. Dr. Xiaoyan Chen

She is professor of Tianjin University of Science and Technology, graduated from Tianjin University with PH.D (2009), worked as a Post-doctor at Tianjin University (2009.5-2015.5). She had been in RPI, USA with Dr. Johnathon from Sep.2009 to Feb.2010 and in Kent, UK with Yong Yan from Sep-Dec.2012. She has researched electrical impedance tomography technology in monitoring lung ventilation for many years. She is in charge of the TUST-EIT lab and guides young researchers and graduate students to improve the electrical data acquisition hardware platform, to study the traditional and novel reconstruction algorithms with the prior structural information. Recently, her research team is focus on the novel methods through deep learning network models.

Dr. Meng Du

He received the Ph.D. degree in control science and engineering from Tianjin University, China, in 2013. He is currently with the College of Electronic Information and Automation, Tianjin University of Science and Technology. His current interests include multi-phase flow parameter measurement, flow pattern identification, time series analysis, and machine learning.