Measurement on non-pulsating and pulsating jets with Fuzzy PTV

Liping Shen, Ohki Suhara, Yuichi Murai, Fujio Yamamoto
Department of Mechanical Engineering, Fukui University
Bunkyo 3-9-1, Fukui, Japan, 910-8507

Abstract
In this paper, a non-pulsating jet and a pulsating jet are researched experimentally and the experiment data are analyzed with a PTV (Particle Tracking Velocimetry) method. The velocity fields are measured accurately and efficiently with a PTV method based on fuzzy logic although the strong shear and turbulence appear in the jets. Based on the measured velocity fields, the distributions of mean velocity, mean vorticity, shear strain rate and kinetic energy are compared between non-pulsating and pulsating jets in order to analyze the different flow features between the two kinds of flow fields.

Keywords: Jet, PTV, Fuzzy logic

Experimental apparatus
The main parts of experimental apparatus are shown in Figure 1. The test section of the experiment is illuminated by an Ar-Ion Laser light sheet. The movement of tracking particles is captured by a CCD camera, and the signal is recorded by a high speed video system (Photron: FARSTRCAM-Net 500C/MAX), then the data are treated by a personal computer. The circular jet is generated in a cylinder with diameter of 200mm and height of 400mm. To decrease the refraction effect, a water jacket is installed to outside of the cylinder.

The pulsation for generating pulsating jet is provided by a pulsating device, and its structure is shown in Figure 2. A butterfly valve is driven by a motor. By adjusting the rotating speed of the motor, the different pulsating frequency can be generated. The pulsating device is set up under the nozzle (Suhara, 1999).

Fuzzy PTV
In Fuzzy PTV, both the extraction and pairing of particles are based on fuzzy logic, which was introduced by Prof. Lotfi A. Zadeh in 1965 as a mean to model the vagueness and ambiguity in complex systems. The theory of fuzzy logic provides a mathematical strength to capture the uncertainties associated with human cognitive and judgement process, such as thinking and reasoning (Fuller, 1995; Kaufman, 1985). In this paper, fuzzy logic is used to set up a method of particle tracking velocimetry, because in order to measure the jet flows, a PTV method, which is very robust to the noise in PTV images and very effective to the strong shear is needed.

Extraction of the particle information
Extracting particles in an image is a good candidate of fuzzy logic. The questions, such as whether a pixel should belong to a particle image and where is the boundary between two particle images, are examples that a fuzzy approach can be the more suitable way to manage. Therefore, a method base on fuzzy logic should be a good choice for it. A typical particle image is shown in Fig. 3, which is extracted from a real PIV
image. In this image every small block represents a pixel and the number is the gray level of this pixel. From this image we can find out that a particle image should have the following characteristics:

- A particle image should have a local maximum of gray levels.
- All pixels in a particle image should have a gray level that is higher than a preset threshold.
- The gray levels of all pixels in a particle image should have a degressive distribution; in other word gray levels drop continuously from the center to outside of a particle image.

This description can be implemented very efficiently with fuzzy logic and be performed satisfactorily (Shen, 1999).

According to the description of a particle image, a MISO (multi-input-single-output) fuzzy system can be established for the particle recognition, and its organization is shown in Figure 4. Three inputs are selected for the fuzzy system of particle recognition: the highest gray level of a particle image (Max), the gray level of a pixel (Gray) and the gradient of gray level between two neighboring pixels (Grad). The definition of the gradient of gray is expressed by the following equation.

\[
Grad = \frac{Gray_P - Gray_R}{Gray_R}
\]  

(1)

Here, \(Gray_P\) is the gray level of a target pixel, and \(Gray_R\) is the gray level of a reference pixel, which is the neighboring pixel of the target pixel and nearer to the center of the particle image than the target pixel.

The output of the fuzzy system is a fuzzy set, which represents the confidence of a pixel belonging to a particle image, ranging from 0 (low confidence) to 1 (high confidence). A pixel is regarded as belonging to a particle image if its confidence is higher than a preset threshold.

![Figure 4. Fuzzy system for particle extraction](image)

Particle tracking

Particle Tracking Velocimetry (PTV) is a quantitative velocity measurement technique, which can measure the velocities of particles from the visualized digital images of various types flows. The essential role of PTV is to identify the same particles correctly from one image frame to the next.

The fuzzy PTV is based on the following assumptions in this paper:

- If two particles in the first image are close enough, then the pair of vectors that looks the most similar must be the correct pair of displacement vectors for these two particles.

- For a correct vector, the size of particle in the first frame is very similar to that in the second frame.

- For a correct vector, the gray levels of two particles are similar to each other.

The first feature can be found from any vector maps obtained from PTV and it is also a very reasonable assumption from the continuity of a flow field (Wernet, 1993). In other words, if the difference between two very close vectors is very large, we can be sure that at least one of them is a spurious vector. The second and the third assumptions are more obvious and can be understood more easily. The process of particle pairing is shown in Fig. 5. Particles A and B are two very near particles selected from the first frame, and the other particles denoted by a letter with a prime are particles in the second frame. The dashed circles are the search regions of particles in the first frame. The sizes and the gray-levels of particles are also shown in the figure at same time. The arrows from particles A and B stand for the all possible particle pairs in this
situation of particle distribution (Shen, 1998).

For particles A and B, we can find that the vector pair AB' and BC' will agree with the above assumption best among all vector pairs. By now, a fuzzy system for particle pairing can be constructed with a method similar to that of particle extraction introduced above. Four inputs are selected for each vector pair, i.e. the difference of two vectors ($\delta V$), the angle between two vectors ($\delta \theta$), the difference of particles’ size ($\delta A$) and the difference of the gray level of particles ($\delta G$). The first and second inputs, when combined, act as the similarity of two vectors. The rest two inputs describe the similarity of the paired particles.

\[
\begin{align*}
\delta V &= 2.0 \cdot |V_1 - V_2|/|V_1 + V_2| \\
\delta \theta &= \arg \left( \frac{\vec{V}_1}{\vec{V}_2} \right) \\
\delta A &= |A_1 - A_2|/(A_1 + A_2) \\
\delta G &= |G_1 - G_2|/(G_1 + G_2)
\end{align*}
\]

Output of the fuzzy system is the confidence of a vector pair. Only the pairs with confidence levels above the preset threshold level are considered to be valid.

**Results and discussions**

In the experiment, the sampling frequency is 250Hz, i.e., the time interval between two frames is 1/250 second. The resolution of images is 640X480 (pixels). Figure 6 shows two consecutive examples of the images taken in the experiment. Due to the strong shear and unsteady of jet flow, its PTV measurement is very difficult. With the fuzzy PTV method, both the pulsating jet and the non-pulsating jet are measured very well. Their results are introduced as follows.

<table>
<thead>
<tr>
<th>Average</th>
<th>Non-pulsating</th>
<th>Pulsating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle number</td>
<td>516</td>
<td>693</td>
</tr>
<tr>
<td>Vector number</td>
<td>357</td>
<td>377</td>
</tr>
</tbody>
</table>

Table 1. Statistical results of Fuzzy PTV
Comparing the average velocity distributions and vorticity distributions of pulsating jet and non-pulsating jet, the differences between them are very remarkable. After the pulsation was added to the steady circle jet, the influence region of the jet is enlarged greatly. Furthermore, because the forced pulsation is periodic, the flow field of pulsating jet appears a kind of periodic flow feature. This is shown very clearly in the distribution of vorticity.

Reference


