A virtual particle images generation system for 3D-PTV verification

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Abstract

The paper describes a virtual particle images generation system for 3D-PTV (Particle Tracking Velocimetry) verification. It's used for evaluating the accuracy of PTV algorithms and simulating the real experimental setup. At the first time, mass of virtual particles are generated in the world coordinate system and placed in the virtual flow field. After the camera system conversion from world coordinate to pixel coordinate is applied, the virtual particle images are produced. And the movement of virtual particles can be specified by researchers or given by the flow simulation results in FLUENT. The numbers of cameras and all the parameters of cameras both can be modified in this system. Even more, the illumination model of visual particles, geometry shape variation of visual particles, and defocus blur of visual particles are carefully considered here. Therefore, the virtual particle images generation system can fairly simulate real PTV setup and generate the virtual particle image sequences. It would be helpful to optimize the placement of cameras and the images quality of a real PTV. In addition, a well-known open-source PTV software is used to test the virtual particle images. The result shows that the virtual particles and its tracks can be calculated out as the images from real PTV cameras. As expected, the mismatching of particles in the results can easily be found through the comparison to the specified particles motion.

Keywords: virtual particles; PTV; verification; matching algorithms; flow visualization;

1. Introduction

In many fluid measurement ways, there is a special interest for non-contact 3D measurement techniques. Most of these methods base on seeding particles that can be recorded by an imaging system visualize the flow and visualize the flow [1]. As a typical quantitative flow visualization method [2], PTV is widely used in flow measurements. PTV allows the velocity of a fluid to be simultaneously measured throughout the entire flow field [3]. Image
sequences from several synchronized cameras can measure the three-dimensional displacement or trajectories of a
mass of small tracer particles suspended in a fluid [4]. Although relatively often used for flow measurement,
however, Particle Tracking Velocimetry (PTV) is still considered as a product of imperfect [5].

Lots of PTV algorithms have been developed and applied to various flow fields, including the cross-correlation
method, genetic algorithm and so on [6]. And none of those algorithms can be applied to all kinds of flow field. The
developers analysed the effectiveness of their PTV techniques using their own evaluation procedures. PTV system is
usually much more complex than the PIV system. Indeed, there are some standard ways for PIV which has the
functions of evaluating PIV techniques [7]. Unfortunately, the accurate way of evaluating PTV algorithms is rarely
seen.

The paper proposes a virtual particle images generation system, which is used for evaluating the effectiveness of
PTV algorithms and simulating the real experimental setup. In this system, lots of image sequences of virtual
particles whose trajectories known in the world coordinate system can be generated. The effectiveness of particles
pairing calculated from matching algorithms is obtained by comparing with the actual positions of virtual particles in
those images. And this system can contribute to develop the matching algorithms. Furthermore, the real
experimental setup can be simulated accurately by this system. Firstly, mass of virtual particles are generated in the
world coordinate system and placed in the virtual flow field just like the tracer particles in real flow field. Then the
virtual particle images are generated after the camera system coordinate conversion. The motion of virtual particles
can be provided by developers. In order to simulate actual flow, the movement is given by the flow simulation
results in FLUENT. The number of particles, the position of particles, and all the parameters of camera can be
adjusted in this system. Not only that, geometry shape of visual particles, the illumination effects of virtual particles,
and defocus blur of visual particles are carefully considered here. Obviously, the virtual particle images generation
system also can fairly simulate the real PTV experiment. And the development cost of algorithms can be reduced
greatly. In addition, the best location and the best angle of cameras can be determined by simulating before the
installation of PTV experiment equipment. In PTV setup, the number of particles in view might be different if
camera in different position or angle, and the position where the number of particles largest is greatest.

2. Methods

2.1. The generation of virtual particle image

This system is implemented in MATLAB. Using this system, almost real PTV images can be generated. Firstly,
mass of visual particles are produced randomly in the world coordinate system and placed in the virtual flow field.
The number of particles is determined according to the size of flow field and the density of particles. Four
coordinate systems are involved in order to generate those images.

The Euler angles and the rotation matrix are applied to the transformation from the world coordinate system to
the camera coordinate system.

| Nomenclature | Description |
|--------------|-------------|
| α, β, γ      | one of Euler angles, α ∈ [0, 2π], β ∈ [0, π], γ ∈ [0, 2π]. |
| Rz(α), Rz(β), Rz(γ) | the rotation matrix of Euler angle. |
| (x1, y1, z1) | coordinate in the world coordinate system. |
| (x, y, z)    | coordinate in the camera coordinate system after translation. |
| (u', v')     | coordinate in the pixel coordinate system. |
| T            | a translation matrix. |
| f            | focal length |
| u0, v1       | half the size of the particles image. |
| dx, dy       | the size of the particles of pixels |
The ruler of Euler angles is z-x-z. At first, both coordinate systems are in the same position, and the Euler angles transformation is done. \((x_1, y_1, z_1)\) is the location of \(O'\) (a virtual particle) in the world coordinate system. In order to simulate the real PTV camera which observe flow field, the camera coordinate system must be able to move to any location and angle. After change the position and angle, \(O'(x, y, z)\) is expressed as follow,

\[
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix} = R_z(\gamma) \ast R_z(\beta) \ast R_z(\alpha) \ast 
\begin{bmatrix}
x_1 \\
y_1 \\
z_1
\end{bmatrix} + T
\]

(1)

The \(T\) can be solved by plugging some special values into the above formula. Next is the conversion that from the camera coordinate system to the pixel coordinate system implemented by the following formula,

\[
\begin{bmatrix}
u \\
v
\end{bmatrix} = \begin{bmatrix}
1 / dx & 0 & u_l \\
0 & 1 / dx & v_l \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
x / z \\
y / z \\
1
\end{bmatrix}
\]

(2)

The final position \((u, v)\) in the pixel coordinate system can be generated by the integral form of above results. Then the virtual particle images are generated after the transformations. The resolution of particle images can be modified just like researchers select cameras in PTV experiments. Not only that, all the parameters, the angle, and the position of cameras can be specified by users. And the image sequences from multiple cameras can be produced by cell structure in MATLAB.

In order to generate the visual particle images, lots of important parameters are considered carefully. Especially the illumination model, the novel model is adopted although there is a known feasible model [7]. This novelty is extracted from the actual images taken from the PTV experiment. Figure 1 show the illumination model extracted from actual images, in the Fig. 1. (c), the blue line is the grayscale curves of row that include centroids of connected domains, the red line in the left is the mean grayscale curves of row, and the right red line is the mean grayscale curves of columns.

Firstly, particle images are transformed to binary images in MATLAB. These are many connective regions in a binary image. Then the grey distribution of those regions is extracted and the most suitable distribution can be selected. By the way, the illumination model is obtained.

2.2. The movement of virtual particles

The particles are considered as following the fluid flow in the particle velocity measuring technique. In this system, the motion of visual particles can be specified by researchers or given by the flow simulation results in FLUENT. Some flow fields of PTV experiment can be simulated well by those flow models. Then the image sequences of virtual particles from several cameras can be generated.
3. Results

To evaluate the effectiveness of the system, those virtual particle images are tested by PTVlab that is a MATLAB software featuring state of the art mathematical algorithms and a Graphical User Interface (GUI) adapted from the open source project PIVlab [8].

After setting the necessary parameters of system, the images are generated. Those parameters are given typical value in order to simplify the process of testing. The particles number is 20, the resolution of images is 400*400, the radius of visual particles are random values in a certain range, the illumination model is extracted from actual PTV images, the position of cameras is reasonable, the time step is 100ms.

To test the images, those particles are given the motion of simple vortex. The core of vortex is (0, 0) in the pixel coordinate system. All particles are rotating round the core, the angle-velocity of all particles is 0.5rad/s, and the direction is counter clockwise. Two images time-adjacent are selected to verify the effectiveness of images. Figure 2 show the example of the image sequences of virtual particles. And those images are close to the actual images largely.

![Fig.2. Example of the image sequences.](image1)

The motion vectors of particles can be provided after the two images are processed by the PTVlab. Figure 3 show the motion vectors of particles. All the particles can be identified, and most of the vectors of particles can be measured. Obviously, the effectiveness of the particle identification is great. Furthermore, those vectors of particles are very close to the actual vectors.

![Fig.3. (a) The motion vectors of the virtual particles; (b) the velocity of particles.](image2)

Figure 4 show the rainbow of velocity magnitude provided by PTVlab. The velocity is increased along the radial direction. The velocity magnitude also can satisfy the real velocity of simple vortex given. Figure 5 show the scatter plot u & v, the plot of Fig.5(a) is provided by PTVlab. Figure 5 (b) show the scatter plot u & v of the real value. By comparing with the real velocity, the velocity provided by PTVlab is almost equivalent to the real velocity.

![Fig.4. The rainbow of velocity magnitude.](image3)
Through the above test, the effectiveness of virtual particle images generated by this system proved to be reliable. Those results suggest that the images of virtual particles can substitute for the actual images. In view of the reliable result, the system can still perform well when the density of particles is changed.

4. Conclusions

A virtual particle images generation system is proposed with the aim of evaluating the effectiveness of PTV algorithms. The virtual images have been developed based on the flow model provided by flow simulation results and they almost involved in all of the parameters of PTV images. A large number of PTV experiments can be simulated effectively by setting these parameters appropriately.

The Euler angles, the rotation matrix and the conversions of coordinate systems are used in order to generate the particle images. To close to the actual particle images, the illumination model of virtual particles and the radius distribution of visual particles are extracted from the actual PTV images. To demonstrate the effectiveness of the system, a simple vortex is constructed, and two time-adjacent images of image sequences are evaluated in PTVlab. The results include velocity field and vector field indicate the effectiveness of visual particle images.

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