Algorithm for High- accuracy particle image position estimation in PIV applications.

P. Padilla-Sosa[*], M.Funes-Gallanzi[b,] L.R.Berriel-Valdos[a], A.Guerrero -Viramontes[b], D.Moreno Hernández[b],

[a]INAOE, México. A.P. 51 y 216. Puebla 72000 México.
[b]C.I.O, A.P.1-948,Leon Gto., [*]Fac. de Física e Inteligencia Artificial, Universidad Veracruzana, A.P. 270, Xalapa, Ver.

ABSTRACT

We proposed a method for the 3D position estimation in particle image velocimetry. The method uses the pattern–matching between theoretical and experimental images by exploiting the scattered energy field and uses genetic algorithm. The simulations and experimental verification of this problem are discussed.

Keywords: Particle image velocimetry, genetic algorithm.

1.- INTRODUCTION

In particle image velocimetry is important to obtain information about the three-component positions. There are several works in order to provide instantaneous three-dimensional position information, such as holographic, stereoscopic and light sheets methods[1-2]. For practical applications, restricted optical access often eliminates stereoscopic approaches. Robustness, experimental facilities, and the need for real-time results make holography an unattractive option. In other hand the scanning light-sheets are difficult to operate with restricted optical access in industrial applications.

Velocimetry particle images show a scattering field that is dependent on their relative 3D position when illuminated in a volume, such as when holographically recorded or imaged using Tunnelling Velocimetry [3]. The Tunnelling Velocimetry technique involves in-line illumination of a volume of interest, achieved through a single instrument using a single optical access point, thus obtaining seeding particle scattering images produced within said volume.

In this work the experimental image was obtained with Tunnelling Velocimetry technique and was interpreted to obtain the 3D information of particle position. So, the diffraction field can be deduced from single CCD camera[4] position for a range of x,y,z particle position , opening the way for using a single camera in practical experiments.

In other hand, the theoretical image was generated by treatment Generalized Lorentz-Mie theory (GLMT)[5]. The particle positioning method using GLMT to create theoretical seeding particle images, and embedding the genetic algorithm search concept, was devised and is described in the present work.

2.- THE 3D POSITIONING ALGORITHM

There are two separate points to be work in assessing the applicability of the 3D positioning method to the case of seeding particles: possessing an accurate scattering theoretical model for spherical particles [5] and a robust positioning algorithm capable of allocating accurate position to estimates arbitrarily particles.

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Genetics algorithms (GA) is a global optimization process based on the laws of natural selection and genetics[6]. They give excellent solves in complex problem with a lot number of parameters. A GA consist of three operations: Selection, Genetic Operations (which include initialization, crossover, and mutation), and Replacement.

In this approach, the variables are represented as genes on a chromosome. The population upon which the GA evolution takes place comprises a group of chromosomes that represent possible solutions of the problem and from which parents for a new generation are selected. By evaluating fitness value for all chromosomes, a particular group of chromosomes is selected from the population as parents to generate offspring (new generation of the problem) . The better is fitness , the greater chance a chromosome stands to be selected as a parent for re-production. Fitness values for offspring are evaluated in the same fashion as for their parents, and then, chromosomes in the current population are replaced by offspring based on certain replacement strategies.

Although GA cannot always guarantee the absolutely correct answer, it is a practical and an efficient optimization method in effect, it has some disadvantages: it has trouble finding the exact global optimum and requires large number of response (fitness) function evaluations. In this work genetic algorithm was implemented for the pattern-matching theoretical to the experimental images. We use a GAOT Matlab software tool that provides an auxiliary function for optimization.

The scattering field image is modelled by GLMT treatment and is called objective image. The experimental image is called estimate image. Each one of the particles of theoretical image and experimental image represents as an input matrix I_o (objective image) and Ie (estimate image). After that, we use the pattern-matching between images. To find the best matching criteria between images the fidelity criteria was applied. The most common used, objective measures are: the root-mean-square error e_{RMS}, the root-mean-square signal-to-noise-ratio SNR_{RMS} and the peak signal-to-noise-ratio PSNR. Here the PSNR criteria is used to provide a error between the original image, objective image pixel value and the estimate image pixel value as

$$PSNR = 20 * \log_{10}\left(\frac{B}{e_{rms}}\right) \tag{1}$$

where B is the number of gray levels (e.g.,for 8 bits B =255) and e_{rms} is the root-mean-square error.

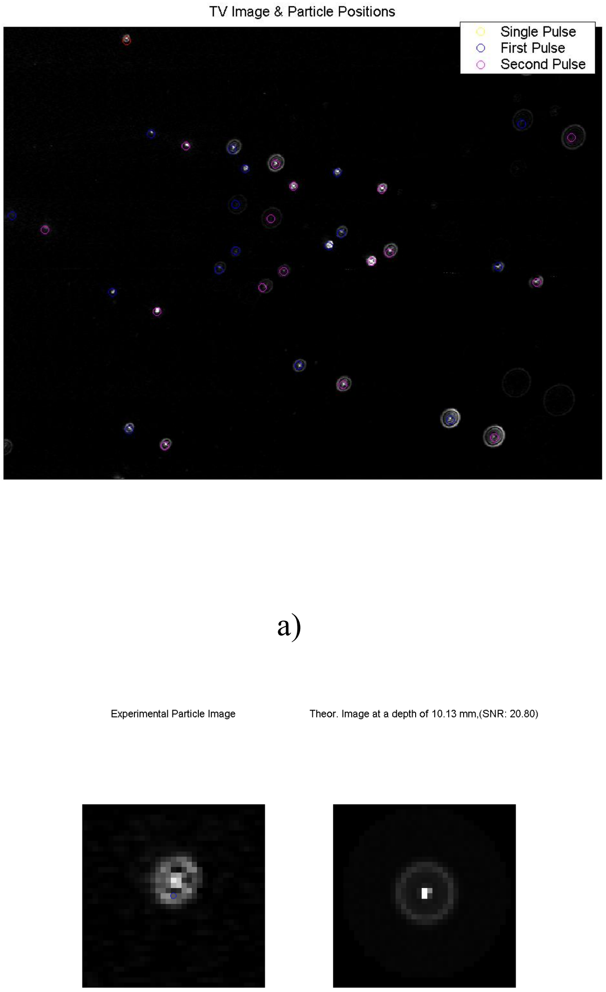
By the process of digitizing at low magnification[7] , we cease to have a recognizable digital representation of the diffraction pattern and simply end up with a matrix does like a diffraction pattern.

3.- NUMERICAL SIMULATIONS AND EXPERIMENT

The 3D positioning algorithm was tested with simulated data and an experimental image was investigated. For the experimental case, a full GLMT formulation of the scattering field was used. The metric error metric used was again to maximize the peak signal-to-noise ration between the experimental image and the estimated image.

The experimental image was obtained by back-scattering tunnelling velocimetry (TV) as described elsewhere et al. [3] , though a holographic image can equally be used. The seeding material was polystyrene with a sized 5 µm of diameter, injected through a nebulizer. Those particles were flowing in a free jet at a speed of 9.5 m/s and an angle of 32 degrees to the image plane. A frequency-double Nd/YAG laser with energy of 100 mJ per pulse and a pulse of 100 µs illuminated the seeding. The resulting image was recorded at magnification of 1.74X, and viewed through a 90 mm SIGMA lens.

The figure 1 shows a schematic a particle image captured by (TV) PIV system, which was used to tested the algorithm. We used manually-assisted particle recognition, just to identify particle and separate particles, in the first and the second pulse. In this manner, the particle centroids were located and separate, and they were taken such as initial centroids.



a)

b)

Figure 1 a) Application to the 3D positioning for experimental image Schematic of sample double–pulse 5 μm polystyrene particle images at a magnification of 1.7X. b) theoretical image generated (GLMT code) and the experimental image.

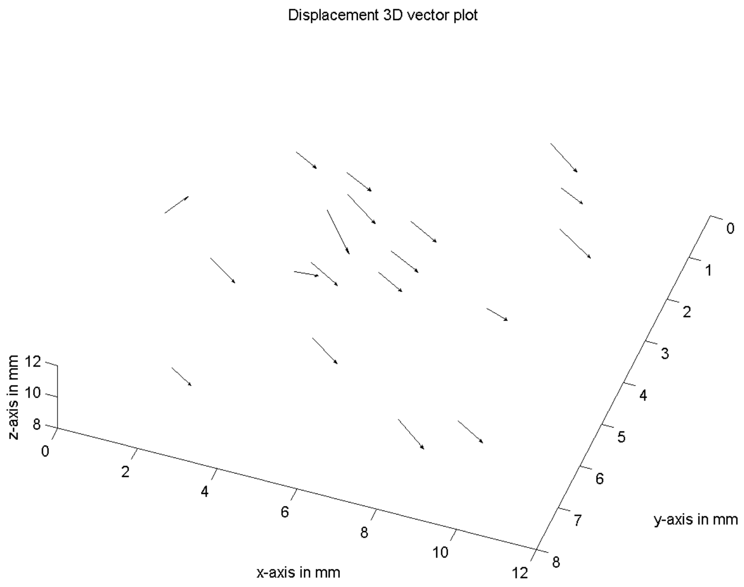


Figure 2 Displacement vector plot of (32° tilted angle nozzle) the analysis data shown in figure

4.- CONCLUSION

Although there are only few particle pairs in this image ,see figure 1,it does serve to illustrate the feasibility of the method. The main measurement velocity was 9.77 m/s, some 3% higher than the actual velocity . This discrepancy led to a further review of velocity vector and the corresponding experimental image.

To be precise, there are some vectors that have a big error. After further investigation it was concluded that the jet contained some water particles that had not yet evaporated, as well as the intended polystyrene seeding. The GLMT code requires knowledge of the complex refractive index and seeding particles size. This two factor generated erroneous positions for those seeding particles that were not made from the same material as the seeding. However, this fact means to isolate contaminant particles in velocimetry images for example in three-state anemometry.

Although the method uses the particle scattering field, it presented a limitation to the applicability for high density velocimetry images. In high-density HPIV case, the overlap of the particle scattering field would led to confusion. However, the method is applicable to the low seeding density, middle density and also, it can be applicable in hostile industrial environments.

5. REFERENCES

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