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Particle Pairing Using Genetic Algorithms for PIV

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***Abstract*:** This paper presents a new particle pairing algorithm using "Genetic Algorithms" for DPIV (Digital Particle Image Velocimetry), which are searching algorithms for obtaining an optimal solution based on the mechanism of evolution. The particle pairing between two tracer images with a constant time interval is needed to obtain a velocity vector field. Since the algorithm adopts a fitness function which totally evaluates the similarity between respective small particle patterns in the two tracer images over the field, it promises to give a more correct velocity vector distribution than the conventional PTV (Particle Tracking Velocimetry) which identifies each particle based on its local information. In addition, a particle pattern matching for the similarity is performed after correcting fluid rotation. It therefore is robust against a high particle density and an increase in the time interval. The algorithm is applied to the PIV standard images distributed through the Internet (http://www.vsj.or.jp/piv). It gives a correct velocity vector distribution as a result even if a pair of the successive images has a large time interval.

***Keywords*:** PIV, PTV, particle pairing, genetic algorithms.

1. Introduction

A lot of DPIV techniques have been developed and applied to various flows. The principle of DPIV is classified into particle tracking and pattern tracking. The particle tracking is particularly considered to have a high spatial resolution because each particle is tracked between more than or equal to two successive images. The conventional PTV such as the four step PTV (Kobayashi et al., 1989), the binary correlation method (Uemura et al., 1990), the spring model method (Okamoto et al., 1995), and the KC method (Etoh and Takehara, 1995), however, identifies each particle using only its local information such as predictable particle path or neighboring particle patterns. In the improved relaxation method recently developed (Ohmi and Lam, 1998), the probability of each particle-pairing is updated according to its neighboring particle information and finally the highest probability gives its correct particle pairing. The neighboring particle information, however, might make the matter worse in a low particle density area. The conventional PTV including the relaxation method accordingly has a risk that some erroneous vectors appear in the measured flow field. Consequently, it is necessary to develop a new PTV technique which is able to measure a correct velocity vector field based on not a small local area of the field but the whole flow field or a large area of the field.

Particle pairing algorithms based on the mechanics of natural selection and natural genetics, have been developed before (Ohyama et al., 1993; Shen and Meng, 1997). The algorithms using Genetic Algorithms (abbreviated to GAs) must give a better result because they find out an optimal solution by taking all the field into account. The developed algorithms, however, adopt the sum total of distance between pairing particles or the morphological similarity of a particle group as a fitness function on condition that the time interval between two successive images is extremely small. Erroneous vectors might accordingly appear because of miss-pairing when the particle density becomes relatively high or the time interval increases.

In this study, we propose a new particle pairing algorithm using GAs which adopts a fitness function based on the similarity between respective small particle patterns in the two tracer images over the field. Since the proposed algorithm is performed after correcting fluid rotation, it is robust against a high particle density and an increase in the time interval.

2. Particle Pairing Algorithm

2.1 Coding

Genetic algorithms (Goldberg, 1989) are searching algorithms for obtaining an optimal solution which require many individuals as a population. Genetic operations such as "Reproduction," "Crossover," and "Mutation," are applied to these individuals according to a fitness function. Reproduction is a process in which individuals are copied according to their fitness function values. In Crossover each pair of the mated individuals undergoes crossing over and then creates two new individuals. The primary role of Mutation operator is to flee from a local optimal solution. This procedure consequently creates a new generation and then is repeated from generation to generation. Finally, an optimal solution that has a highest fitness is obtained.

To apply genetic algorithms to the particle pairing problem, we have to correspond the space on the problem to a GAs' space. Its correspondence is called "Coding." Here, let us suppose that in Figs. 1 (a), (b) there are two tracer particle images with a constant time lag. The $\{a_1,a_2,....,a_n\}$ and $\{b_1,b_2,....,b_n\}$ are strings of labeled particles respectively in the first and second images. A certain combination for particle pairing between a_i and b_j as shown in the Fig. 1 (c) is one individual. In this case, the string $\{b_5,b_2,b_3,b_7,...,b_1\}$ which corresponds respectively to the string $\{a_1,a_2,...,a_n\}$ represents a chromosome for the individual and is briefly expressed in figures as {5,2,3,7,...,1}. Many individuals, which have random and different chromosomes, are prepared as an initial population. The three genetic operations are performed to the prepared individuals and are repeated step by step according to a fitness function.

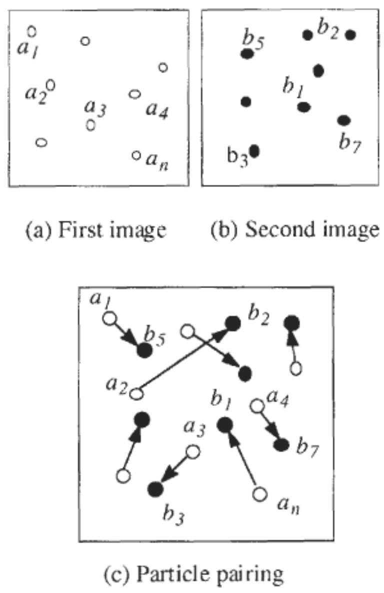


Fig. 1. Coding.

2.2 Fitness Function

We adopt a particle pattern matching for fitness as shown in Fig. 2. For the pattern matching, a particle cluster is formed to include an objective particle and its neighboring ones and then all the vectors from the objective particle to the neighboring ones are calculated as shown in the figure. Here, the number of particles in a candidate particle cluster in the second image is one larger than that in its original particle cluster in the first image because one of the neighboring particles might replace another one due to fluid distortion during the two images.

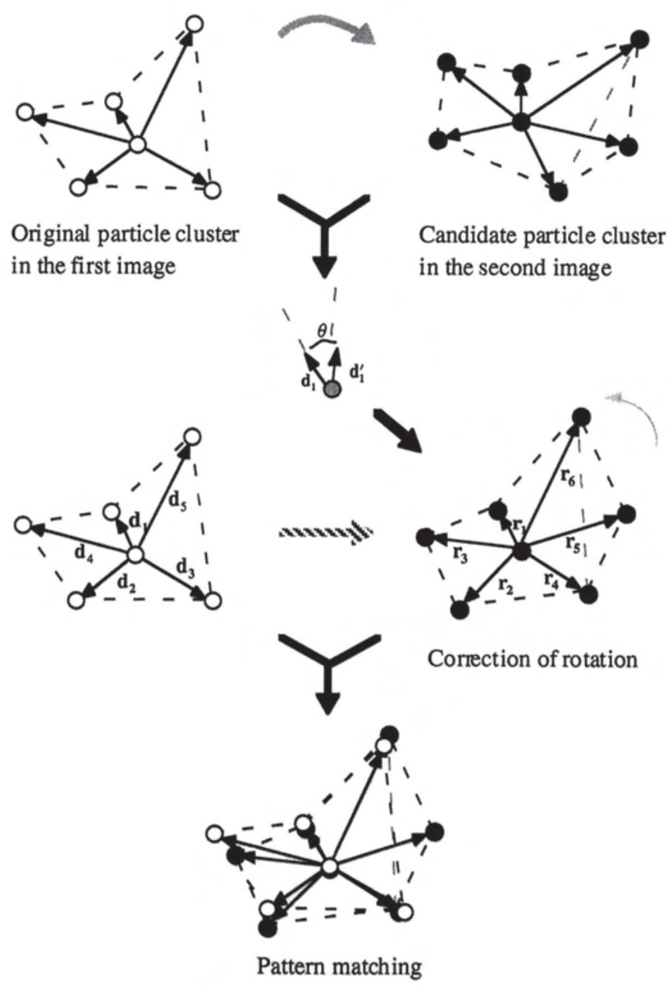


Fig. 2. Particle pattern matching.

Since a particle cluster might rotate during a time interval between the first and second images, the correction of rotation is necessary for the pattern matching at the beginning. An angle between the shortest vectors in the first and second images, which are considered to give the smallest distortion, is calculated and then its rotation is corrected as shown in the figure. After the correction, the pattern matching is performed using the following fitness function F.

$$F = \sum_{n} \sum_{i=1}^{l} \min \frac{|r_j - d_i|}{|d_i|}$$

where d_i and r_j are the above-mentioned vectors respectively in an original cluster and its candidate. The l is the number of vectors in the original cluster and n is the number of all the particles in the field. Thus, the fitness function takes all the field into account. In this case, a minimum of the fitness function is an optimal solution.

2.3 Genetic Operators

A simple genetic algorithm is composed of three operators, namely “Reproduction,” “Crossover,” and “Mutation.”

(1) Reproduction

Reproduction is a process in which individuals are copied according to their fitness function values. The copying means that individuals with a higher fitness value have a higher probability of contributing one or more offspring with the same genetic materials to the next generation. Here, some individuals with a lower fitness value are extinguished and then individuals with a higher fitness value replace them.

(2) Crossover

After reproduction, crossover proceeds in two steps. First, two individuals are mated at random with a proper probability. Second, each pair of the mated individuals undergoes crossover and then creates two new individuals. Figure 3 shows the crossover operation. In this figure, the strings are represented with a positive number of labeled particles. First, each parent string is divided into two parts at a random position. Second, the two parts are exchanged each other and then the same positive numbers in the back part as those in the front part replace the numbers which don't exist in the front part as shown in the figure. By the above procedure, two offspring are newly produced from the parents.

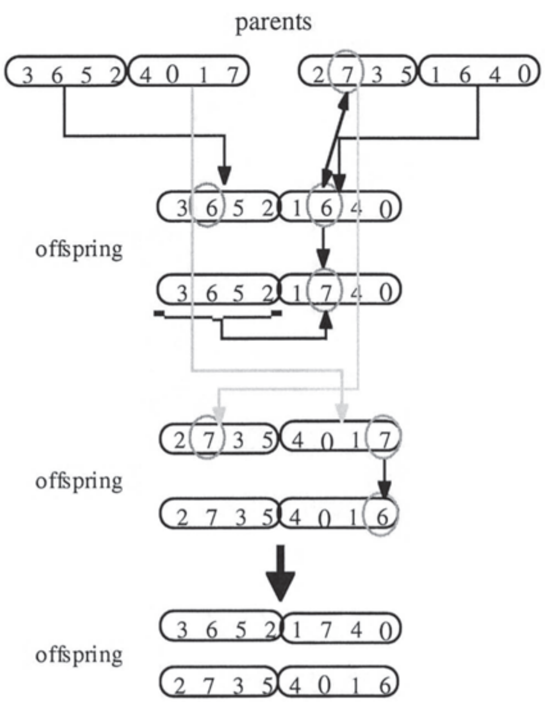


Fig. 3. Crossover operation.

(3) Mutation

The above two operators, reproduction and crossover, can effectively search for a good solution with a high fitness value. The operators, however, may occasionally obtain not a global optimal solution but a local one. It means that the two operators lose some potentially useful genetic materials. In artificial genetic systems, the third operator that protects against such an irrecoverable loss is “Mutation.” The last operator is performed as shown in Fig. 4. Two numbers in randomly selected individuals exchange each other.

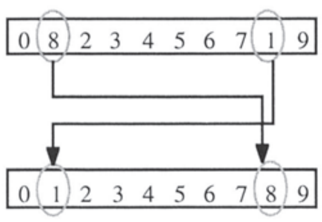
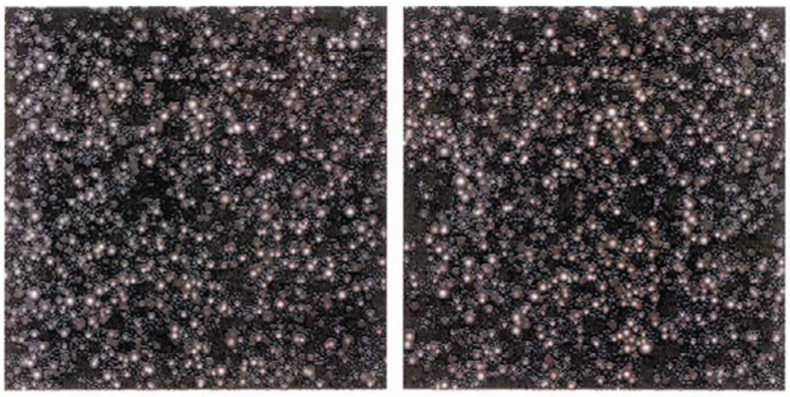


Fig. 4. Mutation operation.

The primary role of the mutation operator is to flee from a local optimal solution. The operator, however, might destroy individuals with a higher fitness value. To avoid such destruction, an individual with the highest fitness value unconditionally survive to the next generation.

3. Application to the PIV Standard Images

Figures 5 (a), (b) show the PIV standard images with a constant time interval, distributed through the Internet (http://www.vsj.or.jp/piv), which is accessible from anywhere in the world (Okamoto et al., 1997). The images are generated by computer graphics based on a calculated flow velocity field. In this case, the two images are quite different due to the largest time interval (t=0 and 4). The algorithm for particle pairing using GAs is applied to the PIV standard images. Although the algorithm is able to apply to all the image at the same time, each image is divided into four parts for the processing to decrease the processing time. The particle pairing between the first



(a) First image (t=0) (b) Second image (t=4)

Fig. 5. PIV standard images distributed through the Internet (http://www.vsj.or.jp/piv).

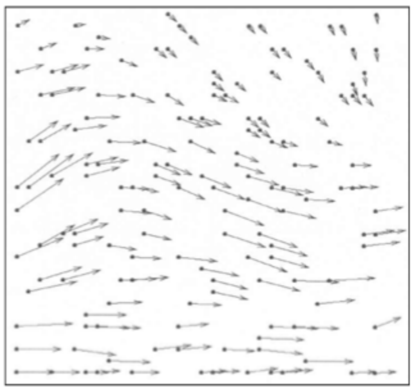


Fig. 6. Velocity vector distribution obtained by the proposed particle pairing algorithm using GAs.

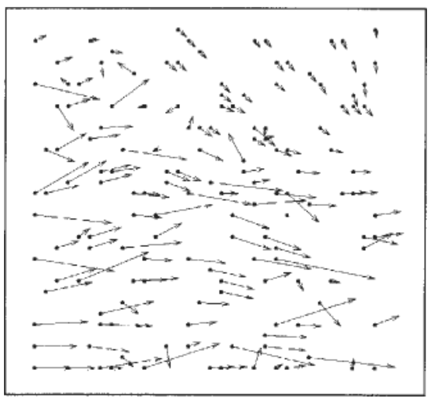


Fig. 7. Velocity vector distribution obtained by the GA-based PTV (Ohyama et al., 1993).

and second images gives a velocity vector distribution as shown in Fig. 6. In this test, the population size is 30, the probability of reproduction is 0.4, the probability of crossover is 0.6, and the probability of mutation is 0.3. The number of the neighboring particles is 8. After two thousands and five hundreds generations, the fitness F reaches a minimum. The perfect velocity vector distribution without miss-pairing is obtained. Figure 7 comparatively shows a velocity vector distribution obtained by the GA-based PTV (Ohyama et al., 1993) which adopts the sum total of distance between pairing particles as a fitness function. A lot of erroneous vectors appear in the field.

4. Conclusions

The proposed algorithm for particle pairing gives a correct velocity vector field because its particle pairing is evaluated not locally but largely over the field, and becomes effective for even flows visualized with a high particle density or for two successive visualized images over a relatively large time interval.

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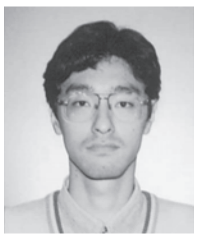

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