TIME-RESOLVED PARTICLE IMAGE VELOCIMETRY (PIV) POST PROCESSING

APPLICATION NOTE PIV-027 (A4)

Introduction

Particle image velocimetry (PIV) is a velocity and acceleration measurement technique in which tracer particles spread throughout a flow media are illuminated by a thin sheet of laser light and then a series of images are captured by a camera at short time intervals between images. The displacements of the tracer particles are calculated through an image cross-correlation method in order to determine the velocity. The final step in PIV is vector post-processing.

Post processing occurs after the cross-correlation technique has been applied to the images, and a raw vector field has been determined. Post processing of the vector field removes spurious vectors and noise through validation and conditioning. Vectors can be validated based on nearby vectors both in space (spatial) and, in the case of time-resolved vector fields, in time (temporal).

Vector Validation

Vector validation can occur in a variety of different ways; essentially a technique is used to determine if the vectors are valid based on some statistical criterion. One example of vector validation is called “global validation.” The most basic global validation filter is a range filter. With a range filter, vectors outside of some user-defined range are eliminated (for example ±100 m/s). Another example of a global validation involves calculating the mean and standard deviation of the entire instantaneous vector field. Any vector whose magnitude exceeds the standard deviation by a prescribed amount (e.g., three standard deviations), is eliminated.

One of the most common types of vector validation is the local validation filter. In local validation, each vector in the field is analyzed individually and compared to a set group of nearest neighbors. For example, a 3 × 3 neighborhood may be used in which the mean or median value of the 3 × 3 nearest neighbors is calculated and compared to the vector under interrogation. If the vector of interest differs from the mean or the median of the nearest neighbors by more than a prescribed amount, the vector is eliminated. In practice, spatial neighborhoods larger than 3 × 3 are often used.

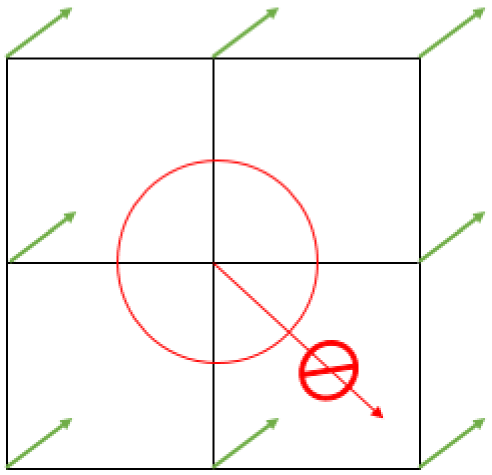

Figure 1. Local validation of a vector based on a spatial neighborhood of 3 × 3 vectors (8 vectors contribute).

Vector Conditioning

While vector validation is concerned with removing bad vectors, vector conditioning involves correcting a vector field. One type of vector conditioning is bad vector replacement. In cases where the vector field has a “hole” in it, either from a vector that could not be calculated based on the cross correlation or a vector that was eliminated through the validation step, vector replacement replaces the empty spot in the vector field with a calculated value – for example the mean or median of its nearest neighbors.

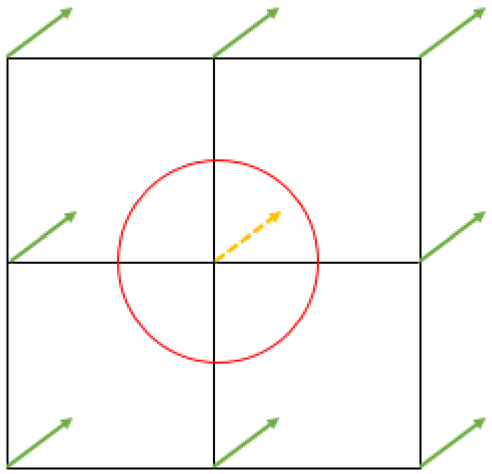

Figure 2. Vector replacement based on the mean value of 3 × 3 spatial neighboring vectors (8 vectors contribute).

Another type of vector conditioning is low-pass filtering, commonly referred to as “smoothing.” This vector conditioner applies a Gaussian kernel over a vector of interest and its neighbors in order to allow neighboring vectors to influence each other. The outcome is a field where the high frequency spatial noise fluctuations are reduced. Visually this tends to smooth out the vector field.

Time-Resolved Post Processing

All of the vector validation and conditioning steps that have been covered so far have been discussed in terms of *spatial* neighborhoods. This means that a vector is validated or conditioned based on the values of the nearest neighbors in space. This is done because in general, in most fluid mechanics applications with appropriate spatial resolution, fluids elements near each other are behaving similarly.

If PIV data is captured at a fast enough rate, the same can be said for vectors that represent the same location in space, but at slightly different moments in time. If the capture rate of the PIV system is significantly faster than the characteristic time-scale within the flow, then the vectors close to each other temporally (in time) will also be behaving similarly and as such, these vectors may also be utilized in the validation and conditioning process.

In the example of a 3 × 3 spatial neighborhood and one time-step forward and one time-step backward, as shown in Figure 3, the result is that 26 vectors are used to determine the validity of the vector under interrogation, resulting in a vastly improved body of statistics upon which to base the determination as compared to only spatial validation (8 vectors).

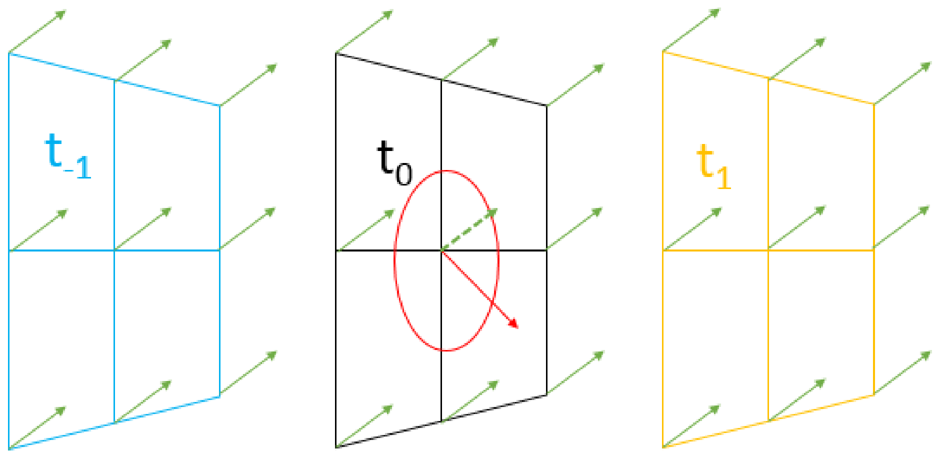

Figure 3. Local validation of a vector based on a spatial neighborhood of 3 × 3 vectors AND a temporal neighborhood of one time-step forward and one time-step backward (26 vectors contribute).

An added benefit of temporal post-processing is that not only spatial noise, but also temporal noise consisting of random noise present in any vector field, can also be eliminated or reduced while simultaneously preserving the true high-frequency information.

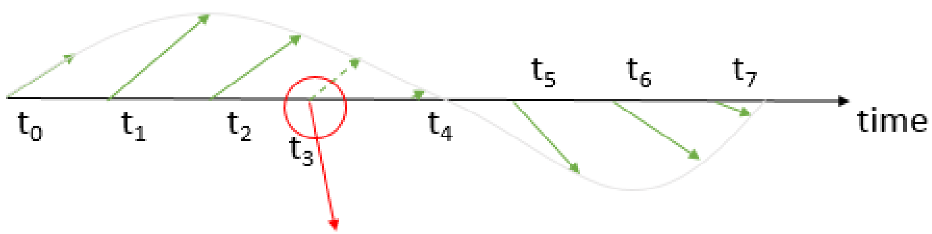

Figure 4. Temporal post-processing in which random noise is reduced.

Software Implementation

Practically speaking, time-resolved post processing is implemented during the post-processing step, where both spatial and temporal validation and conditioning can be performed simultaneously. A screenshot from the TSI PIV INSIGHT4G™ processing software is shown in Fig. 5, in which the time-resolved post processing pipeline for vector validation and conditioning is shown.

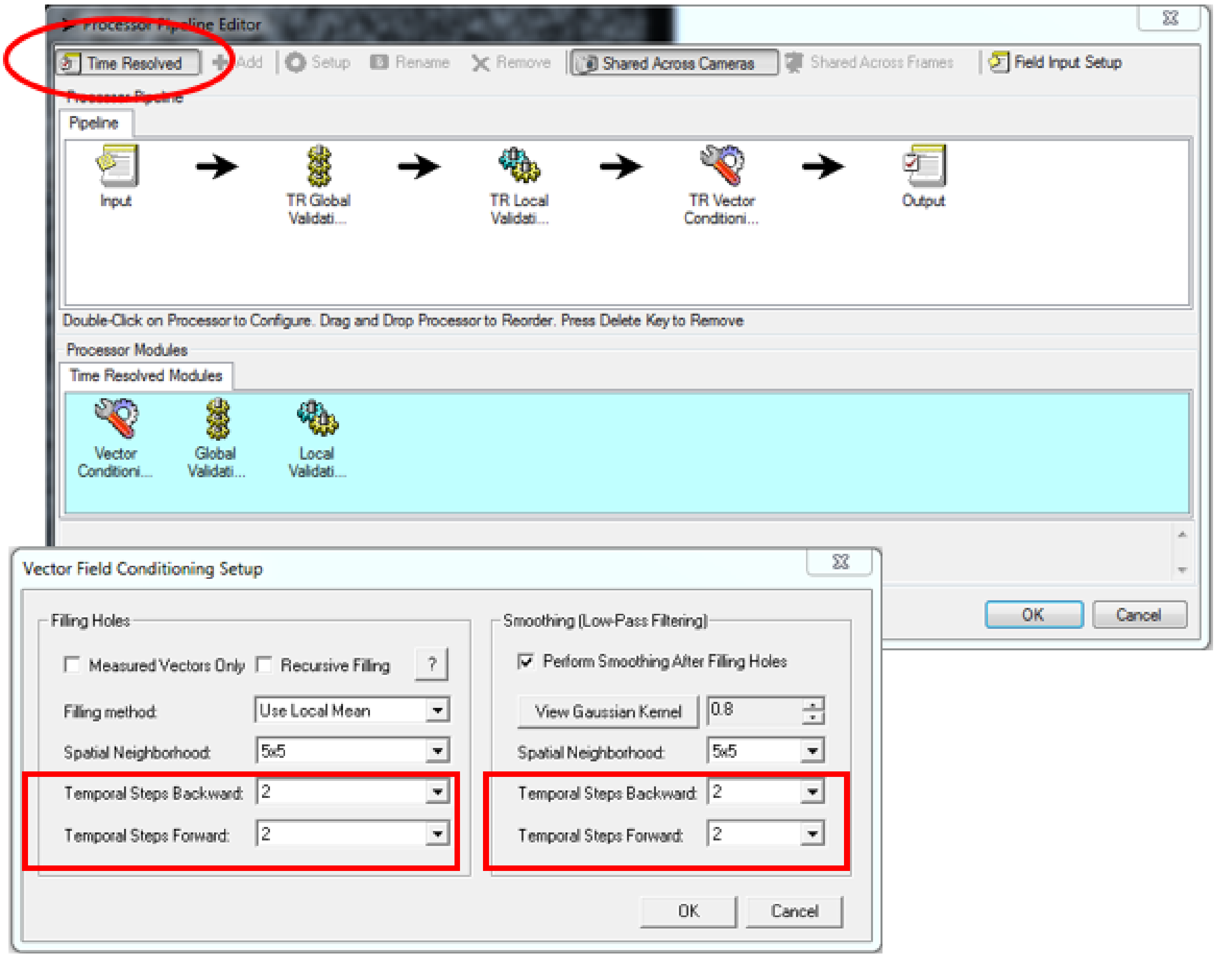

Figure 5. Time-resolved post-processing pipeline as implemented in INSIGHT4G™ software.

The spatial neighborhood as well as the temporal steps used in both the forward and backward direction are specified independently, increasing the flexibility with which the technique may be used.

Conclusion

For time-resolved PIV systems, temporal post-processing is a beneficial step in increasing the accuracy, eliminating noise, and reducing the uncertainty in vector fields, by increasing the number of vectors used in validation and effectively utilizing all of the information available.

UNDERSTANDING, ACCELERATED

TSI Incorporated – Visit our website **www.tsi.com** for more information.

USA	**Tel:** +1 800 680 1220	**India**	**Tel:** +91 80 67877200
UK	**Tel:** +44 149 4 459200	**China**	**Tel:** +86 10 8219 7688
France	**Tel:** +33 1 41 19 21 99	**Singapore**	**Tel:** +65 6595 6388
Germany	**Tel:** +49 241 523030		

PIV-027-Rev. A (5/20/2020) A4 Printed in U.S.A.