A Scheimpflug camera model for stereoscopic and Tomographic PIV

T. Astarita

1. Department of Aerospace Engineering, University of Naples Federico II, Napoli, Italy
2. Corresponding author: astarita@unina.it

Keywords: Optical calibration, Camera model, Stereo PIV, Tomo PIV

By applying the Stereo PIV (Soloff 1997 and Willert 1997) technique it is possible to measure simultaneously the three components (3C) of the velocity vector in a plane (2D). On the other hand the tomographic PIV (Elsinga 2006) enables the measurement of the complete velocity field in a control volume (3C3D).

Currently, in both techniques an angular optical configuration is used. In this case the optical axes of the camera lens and the normal to the mean measurement plane can form a relative large angle, increasing the accuracy of the velocity measurement. However it is necessary to fulfill the Scheimpflug condition in order to get a perfect focus over the whole image.

In both cases, 3D reconstruction of the flow field is possible only if an accurate calibration of the optical systems is made. Normally, in PIV, the depth of field is limited so first a planar calibration pattern is positioned in the middle of the laser sheet (parallel to it) and then the pattern is moved across it. Various images at different z positions are acquired and then processed in order to find a correspondence between the world (or object) coordinates (x, y, z) to the camera ones (X, Y):

\[
\begin{bmatrix}
X(x,y,z) \\
Y(x,y,z)
\end{bmatrix} = F(x) = F(x,y,z)
\]  

(1)

In principle the mapping function \( F \) can be any function that well approximates the optical system. Soloff (1997) proposed to use a polynomial in \( x, y, \) and \( z \) while Willert (1997) introduced the use of the standard 2D direct linear transformation camera model that is equivalent to a linear rational interpolation.

In order to take into account also the possible image distortion Willert (1997) proposed an extension of the rational interpolation with nonlinear terms. Clearly in the field of camera vision and photogrammetry many camera models have been proposed in the past and also recently the advent of the computer vision has been a stimulus to the development of more refined camera models. Most of the calibrations models reported in the literature are derived from the camera pinhole model. Simplicity the optical system is modelled by supposing that all the viewing rays pass through a pinhole.

The 3D direct linear transformation DLT model is the simplest pinhole model and, since it is linear, it is not able to account for any nonlinear distortions. One of the most used model is the one proposed by Tsai (1987) that only recently (Wieneke 2005 and Willert 2006) has been applied to stereoscopic PIV. The Tsai pinhole model differs from the standard DLT method because the radial distortion terms are considered. An even more reliable pinhole model can be easily constructed if also the tangential distortion terms (Brown 1971) are considered.

The mentioned camera models were not designed exactly for a Scheimpflug camera configuration, nevertheless the linear part is perfectly compatible. When the Scheimpflug angle is large the parameters found are not simply related to the real optical configuration.

In the present paper a new camera pinhole model that directly takes into account the Scheimpflug condition is developed and compared with the other standard methods.

The main advantage of the present method is the direct correspondence between the camera model parameters and the real optical configuration; furthermore it is also possible to include correctly the distortion term in the pinhole (lens) plane. The former point is particularly useful for the simple generation of synthetic images.

Results shows that both the pinhole based camera models are able to correctly estimate the physical parameters and in particular the Scheimpflug based one correctly estimate also the Scheimpflug angles and optical center coordinates. The values of the intrinsic and extrinsic parameters predicted from the DLT model are in very good accordance with the non-linearly optimized ones enabling to have a good first guess that ensure also the convergence of the optimization routine.

References