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Application Note

Hybrid Calibration

VIC-3D 11

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Hybrid Calibration

Introduction

The hybrid calibration dialog uses both calibration grid and speckle correlation data to improve calibration results through bundle adjustment. This method has a number of advantages compared to traditional calibration methods using fiducial points only.

- A noise estimate for the input data is available for the speckle correlation results. By comparing this noise estimate to the calibration residual, residual bias in the calibration becomes obvious.
- The noise on speckle correlation data is typically lower than the noise on ellipse centers resulting in more reliable calibration.
- A large number of data points can be generated using speckle correlation.
- Meaningful error metrics, e.g., bias in strain or rigid motion, provide intuitive information about calibration quality (for some of the hybrid methods, see below).
- The distribution of projection errors reveals incorrectly calibrated distortions.
- The spatial distribution of noise sensitivity in all three axis directions can reveal problems with the stereo camera configuration.

In order to complete a hybrid calibration, the system must first be calibrated as normal using a calibration grid. Based on this calibration, a set of speckle images is then analyzed to generate the additional calibration data for hybrid calibration. Note that the imaging system selected in the stereo calibration is the one that will be used for hybrid calibration. Once the data has been generated, the hybrid calibration dialog can be launched from the menu bar by selecting **Calibration… Hybrid stereo system calibration**. This will show the following dialog:

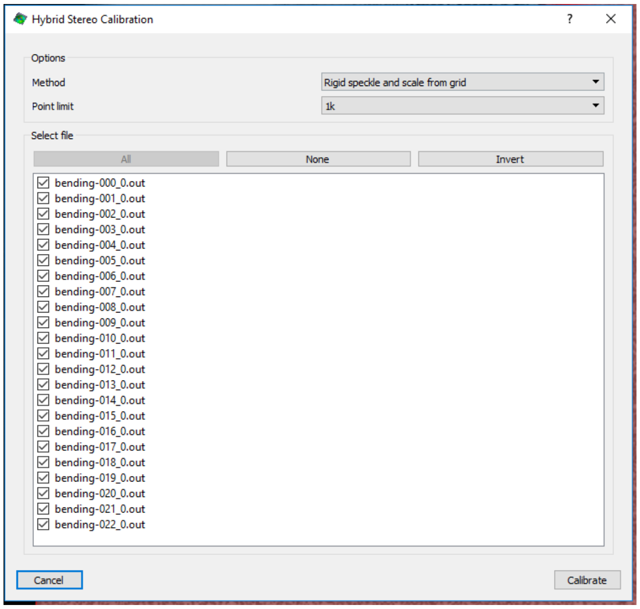

Figure 1: Hybrid calibration dialog

Hybrid Methods

There are three different methods for hybrid calibration available that can be selected from **Method** combo box:

Rigid speckle and scale from grid:

This method requires a set of images of a rigid calibration object undergoing tilt and out-of-plane motion. For this method, the speckle image sequence should be taken like a calibration sequence with a dot grid target. The only thing that is retained from the grid calibration is the scaling (along with the imaging system selection). With a proper calibration sequence, this method will give the best results because only speckle correlation data is used to determine the calibration parameters (aside from scaling).

Grid points and rigid speckle:

This method requires a set of images of a rigid object undergoing motion. The data points from the grid images are combined with points from the 3D correlation results. This method should be used if the speckled object is known to be rigid, but the motions of the object are insufficient for complete calibration. For instance, if only a few small translations and/or tilts of the object are available, this method can provide improved results versus using only the calibration dots from the traditional calibration target.

Grid points and deforming speckle:

This method will work with any image set, including images of the (deforming) test article itself. In essence, this method computes an optimal triangulation for the calibration points and point correspondences found by DIC for an entire dataset together.

Note that for all calibration methods, it is generally required to have a calibration object that fills the entire field of view. Additionally, for the hybrid methods it is required that the stereo configuration remains the same between the acquisition of dot calibration target and speckle images.

Point Limit

The number of calibration points used for hybrid calibration is limited by selecting a **point limit** from the combo box. For the first two methods, where the calibration object is rigid, this point limit is equivalent to the number of calibration dots on a traditional target. Note that increasing the number of calibration points may provide limited returns at some point, as the input points are no longer independent due to subset overlap. For instance, an image with 2,000 pixels in both axes will only provide approximately 4,000 independent data points with a subset size of 31 pixels. Selecting a higher point limit will not provide additional benefits.

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For the first two hybrid calibration methods that use a rigidity constraint, each calibration point is used in all views (images) it is present. Each image adds an additional view of the same rigid object, but no additional calibration points. This is different for the third method where no rigidity constraint is available. In this case, no two views of the same rigid object exist, i.e., each additional image adds additional calibration points, but no additional views. The point limit is therefore different for this method and will limit the total number of points collected from all images in the sequence. For this method, it is reasonable to use the maximum point limit available. Furthermore, it is recommended to limit the number of input data sets for this method (see file selection below). For instance, if a sequence of 4,000 images is used, only 16 points would be selected from each image even at a point limit of 64k. In such cases, it is best to manually deselect input files, as the point limiting algorithms does not decimate in time.

File Selection

The input files used for hybrid calibration can be selected from the file list. Note that a right-click in the list will pop-up a dialog with convenient options to select a subset of the input files, e.g., every other, one out of five or every N-th. This is particularly useful in cases where the input data is from a large sequence of a deforming object.

Calibration & Report

After pressing the **Calibrate** button, a text window will be displayed to report information about the progress and results of the calibration (Figure 2). Note that the calibration can take some time to complete, particularly when a large number of points is used in combination with complex camera models (prismatic and decentering distortions or non-pinhole models). When the calibration is complete, the calibration results and confidence margins are displayed (Figure 3).

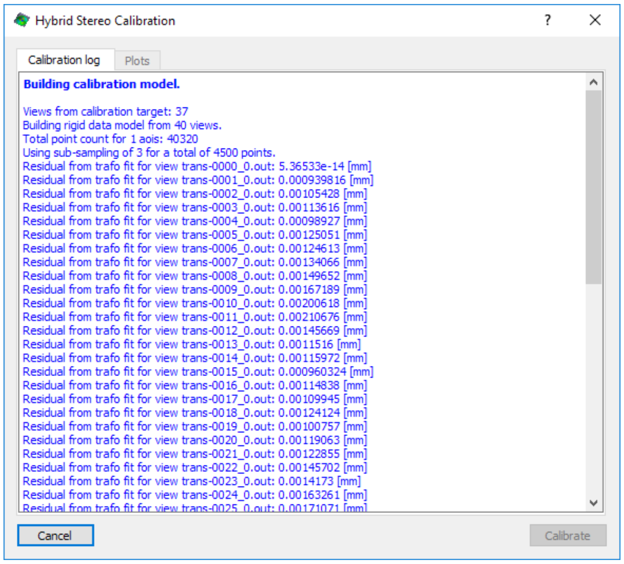

Figure 2: Hybrid calibration log

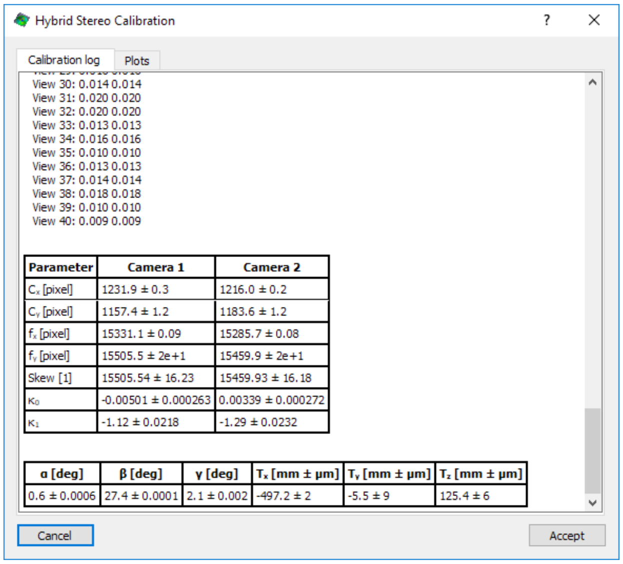

Figure 3: Hybrid calibration results

Visualization of Calibration Errors

The **Plots** tab can be used to display a variety of plots that can provide detailed insight into the quality of the calibration, particularly for the hybrid methods that use a rigid object. When a data file is selected, a message bar in the bottom of the dialog shows the projection error and the noise estimate from correlation. For the first two methods (rigid object), additional information about average strains and residuals from a rigid body transformation fit are also displayed. This information is helpful in determining problems with the calibration.

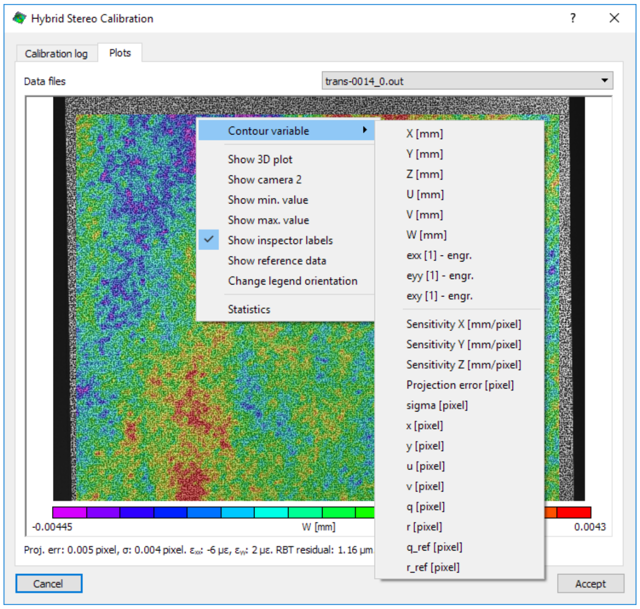

Figure 4: Hybrid calibration result plot

Noise and Projection Error: The average noise estimate and projection error displayed near the bottom of the dialog should be similar in magnitude, and the distribution of the projection error should be random throughout the entire image. If this is not the case, it normally indicates a problem with the calibration. There are a number of reasons why the projection error might be significantly higher than the noise estimate:

- The camera model cannot accurately capture the distortions. This normally results in a distinctive pattern in the spatial distribution of the projection error that remains similar for all data sets. It may be possible to correct such errors by selecting higher order or different types of distortions in the imaging systems dialog during the initial calibration.
- Heat waves often do not affect the noise estimate significantly but produce enough apparent displacement to increase the projection error. The spatial distribution of the projection error typically shows bands of increased error that vary from data set to data set. This problem should be addressed during image acquisition.

- If the object used for calibration is assumed to be rigid but deforms during calibration, a bias will result. This is difficult to distinguish from the following two cases. Repeating the calibration using the third method may provide further insight into whether the object is deforming or not.
- If the orientation of the cameras relative to each other changes during calibration, e.g., due to vibration, the projection error may increase.
- Synchronization problems have similar symptoms as the previous two error sources. Assuming that the calibration images of the dot target are similarly affected by this error as the speckle images, synchronization issues can be revealed by comparing errors from single camera calibration to the errors from stereo calibration. Such errors are normally flagged by the regular stereo calibration dialog.
- In situations where the errors are very low, e.g., 0.001 pixels, one of the errors may be two or three times higher than the other, and this often changes from image to image.
- Objects with significant curvature, surface discontinuities, defocus as well as very high tilt angles can also produce similar symptoms, but this is normally obvious when looking at the plots.

Displacement and Strain Distribution: The displacements (U, V and W) are shown with rigid body motion removed. Since the calibration object is rigid for the first two calibration methods, the resulting distributions should be random. Any distinctive patterns in the distributions of (residual) displacement or strain point to problems with the calibration.

Sensitivity: The (noise) sensitivity indicates how noise in the image matches impacts the measurement results. The sensitivity for the Z-direction is typically three to five times higher than for the in-plane directions, depending on the stereo angle. The noise sensitivity is typically lowest in the center of the image and increases towards the boundaries.

If the noise sensitivity is significantly higher at the boundary than near the image center, the stereo angle and/or focal length may be too low. This can result in excessive noise in all measurements.

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