CHAPTER 3: PREPARATION FOR THE MEASUREMENTS

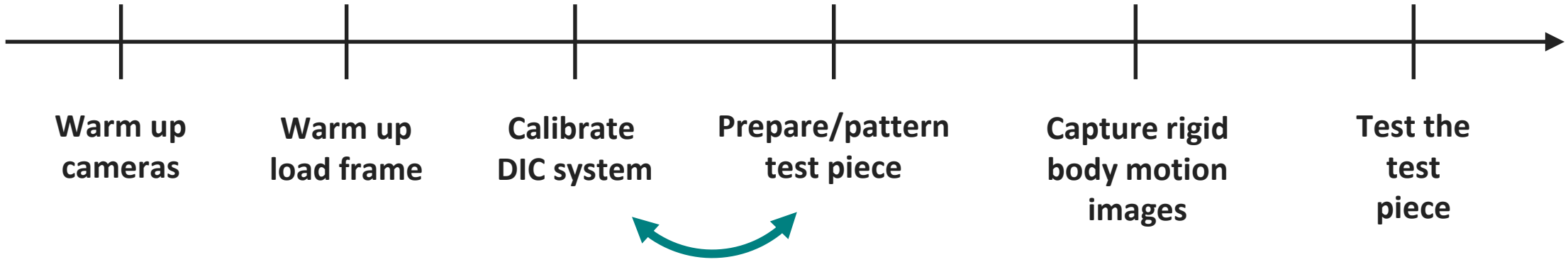
SEC. 3.1: PRE-CALIBRATION ROUTINE

Review the Test Procedure
Sec. 3.1.1

Stable environmental conditions

Consider adding a backdrop behind test piece

Ensure pattern will not be damaged

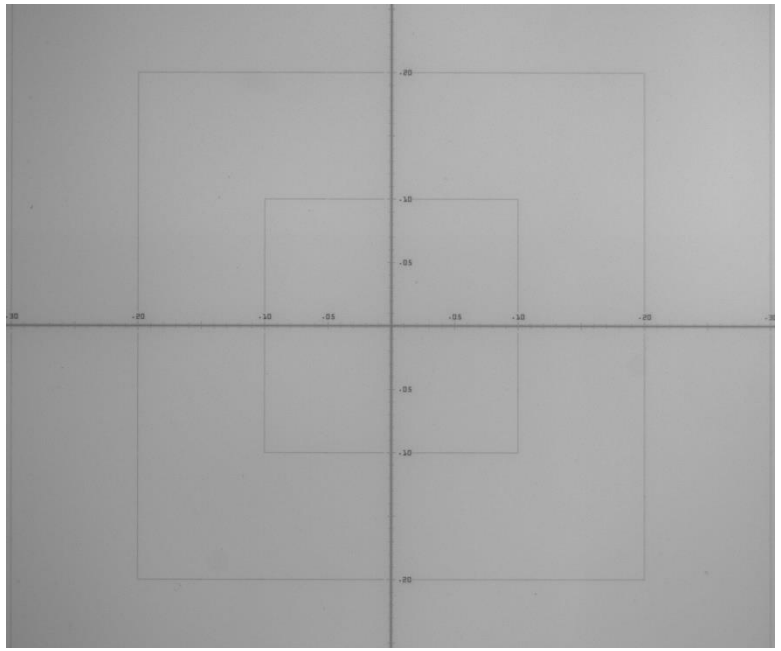


Load frame is adjusted/tuned/calibrated

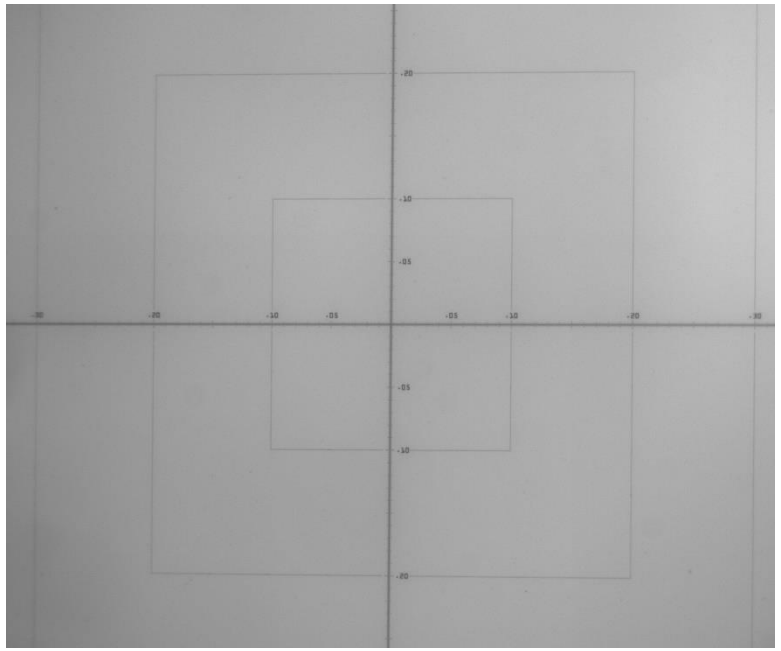
Cleanliness of Equipment
Sec. 3.1.2

- Ensure there is no dust, water marks, oil, smears, fingerprints, etc. on lens, camera detector, or calibration target.
- Recommendation 3.1: Keep a clear lens filter to protect lens
- Recommendation 3.2: Image a white sheet of paper and look for blurred spots or smears
  - *Translate the sheet:*
    - If spots/smears move with the paper, the dirt is on the paper; otherwise, the dirt is on the optical system
  - *Rotate the lens:*
    - If the spots/smears rotate with the lens, they are on the lens; otherwise, they are on the camera detector

UV filter



Left camera



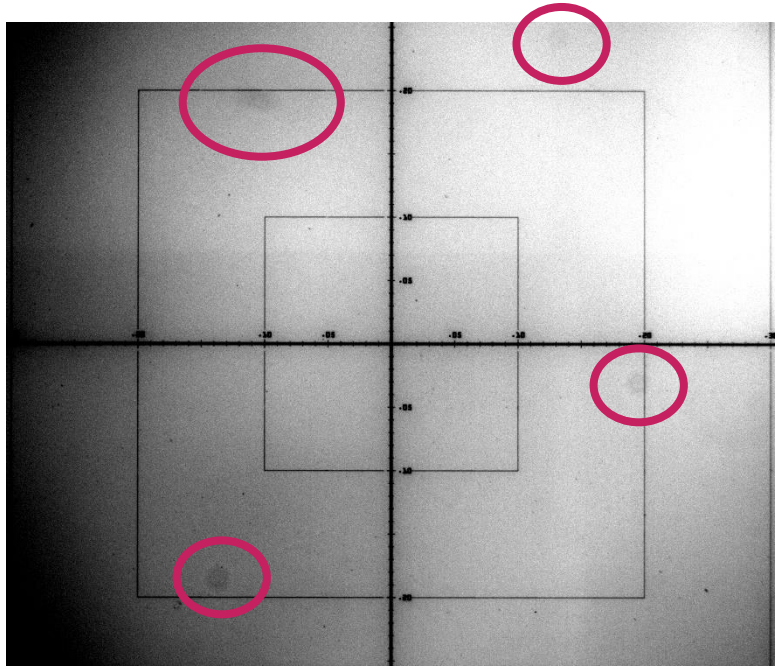
Right camera

Cleanliness of Equipment
Sec. 3.1.2

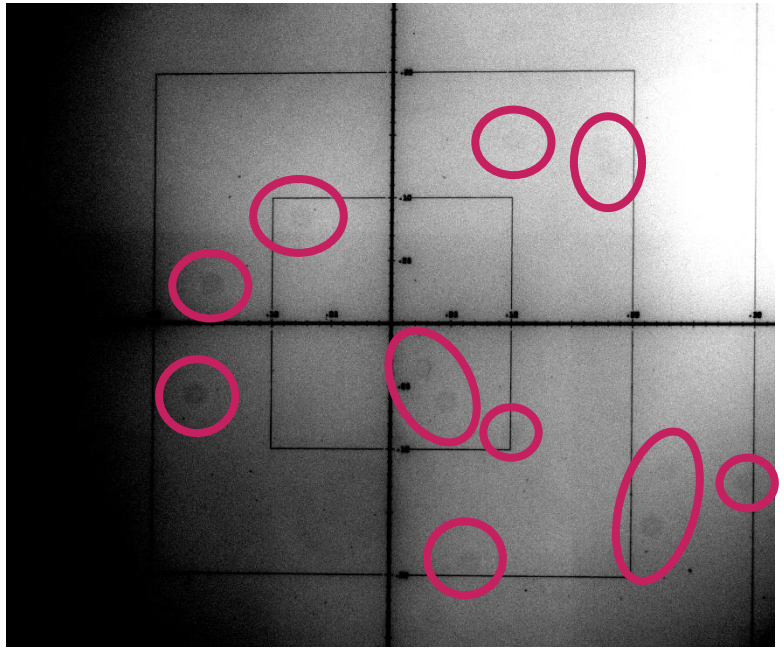
DEMO 05

- Ensure there is no dust, water marks, oil, smears, fingerprints, etc. on lens, camera detector, or calibration target.
- Recommendation 3.1: Keep a clear lens filter to protect lens
- Recommendation 3.2: Image a white sheet of paper and look for blurred spots or smears
  - *Translate the sheet:*
    - If spots/smears move with the paper, the dirt is on the paper; otherwise, the dirt is on the optical system
  - *Rotate the lens:*
    - If the spots/smears rotate with the lens, they are on the lens; otherwise, they are on the camera detector

UV filter



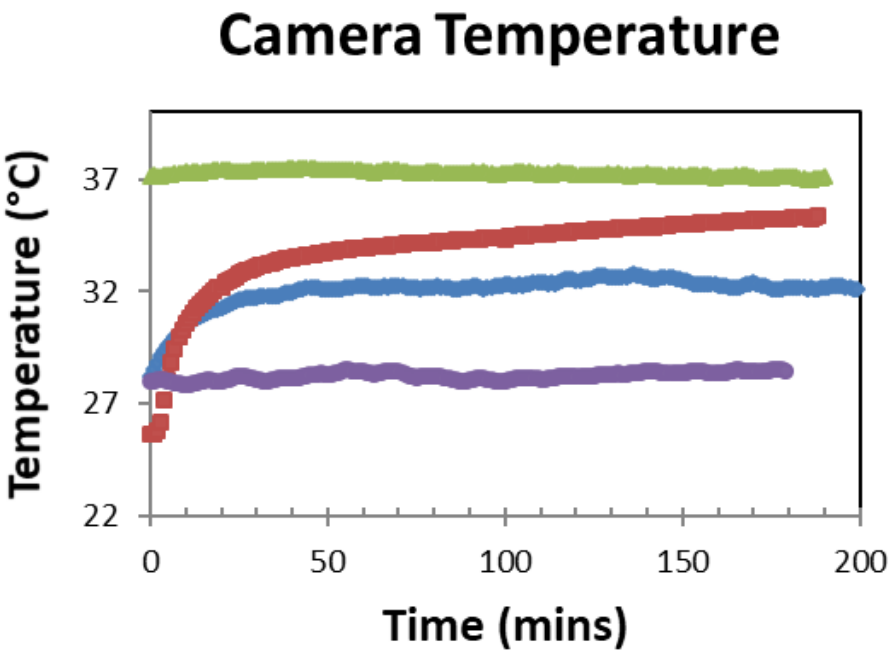
Left camera

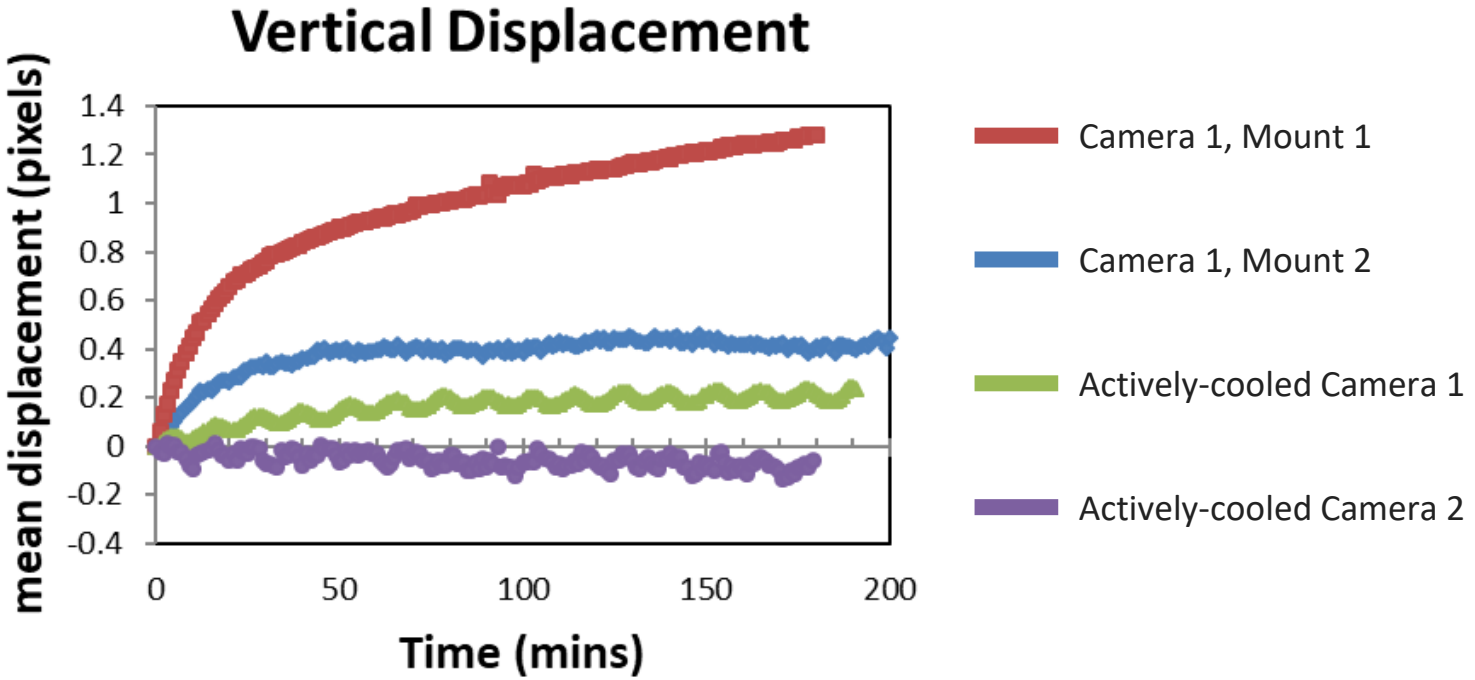


Right camera

Camera Warm-Up
Sec. 3.1.3

- Operate cameras at target frame rate until they are at a stable operating temperature
- Tip 3.2: Warm-up times vary from several minutes to several hours, and should be evaluated for each camera and frame rate.



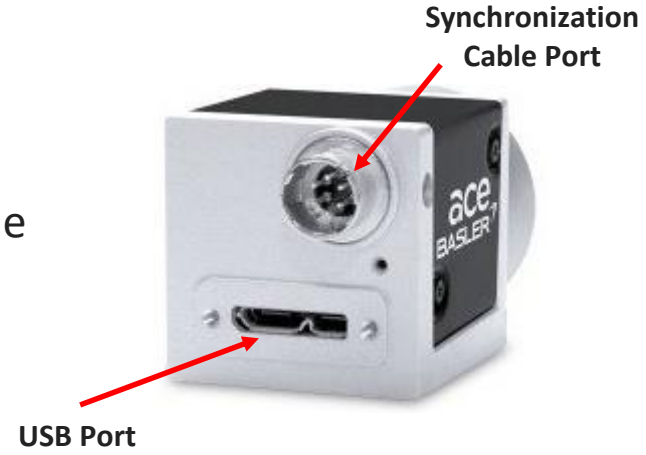


- Increasing temperature → increasing false displacements (red, blue curves)
- Temperature equilibrium depends on camera, frame rate, and mounting structure (red, blue curves)
- Actively cooled cameras more stable than others (green, purple curves)

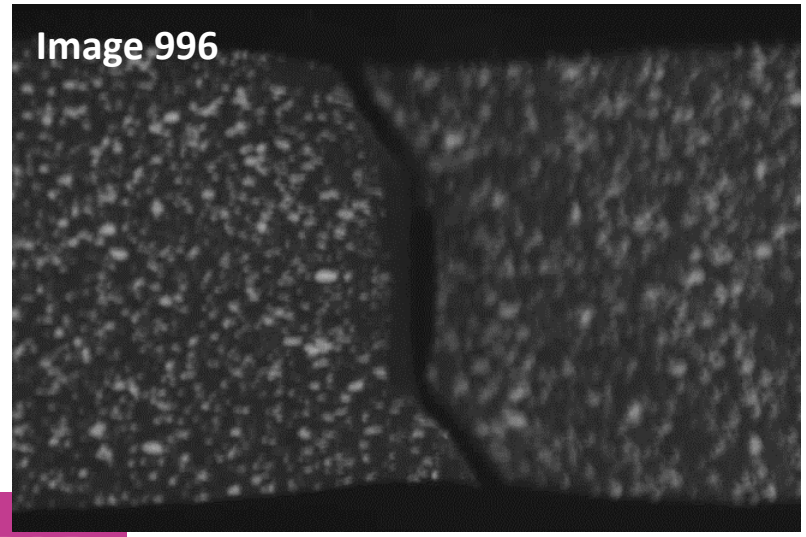
Synchronization
Sec. 3.1.4

- Caution 3.3: **Synchronization of the cameras in stereo-DIC is critical!** Any delay between the two cameras will result in errors in the DIC measurements.
  - Cameras can be synchronized via software or hardware

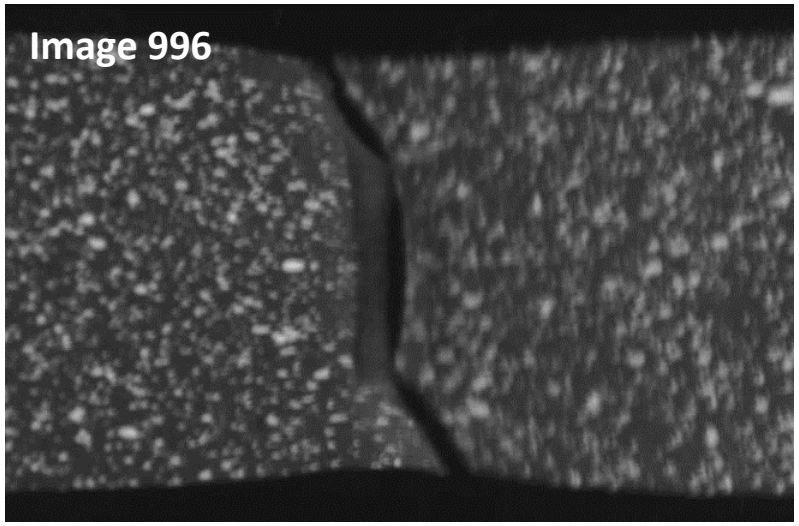
- Tip 3.3: Multiple ways to verify synchronization:
  - Image a moving test piece, correlate images, verify that the epipolar error is acceptable
  - Image a strobe light set to the same frequency as the image acquisition frequency
  - Measure strobe or exposure signal from the cameras on an oscilloscope
  - Image a dynamic event



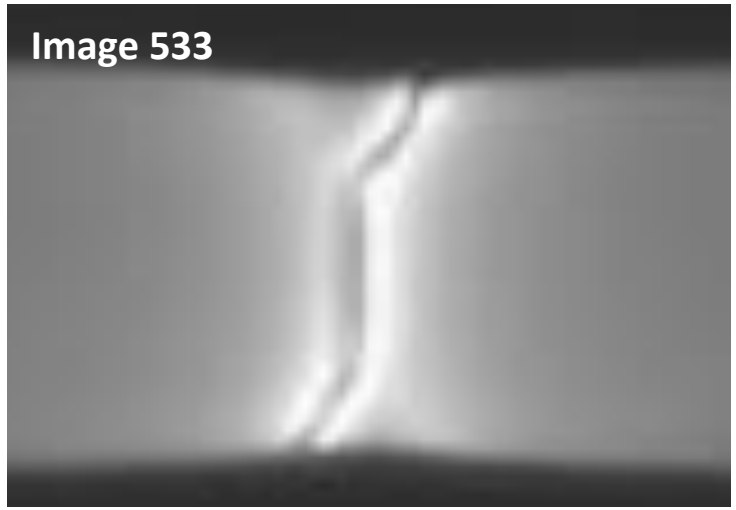
Left camera



Right camera

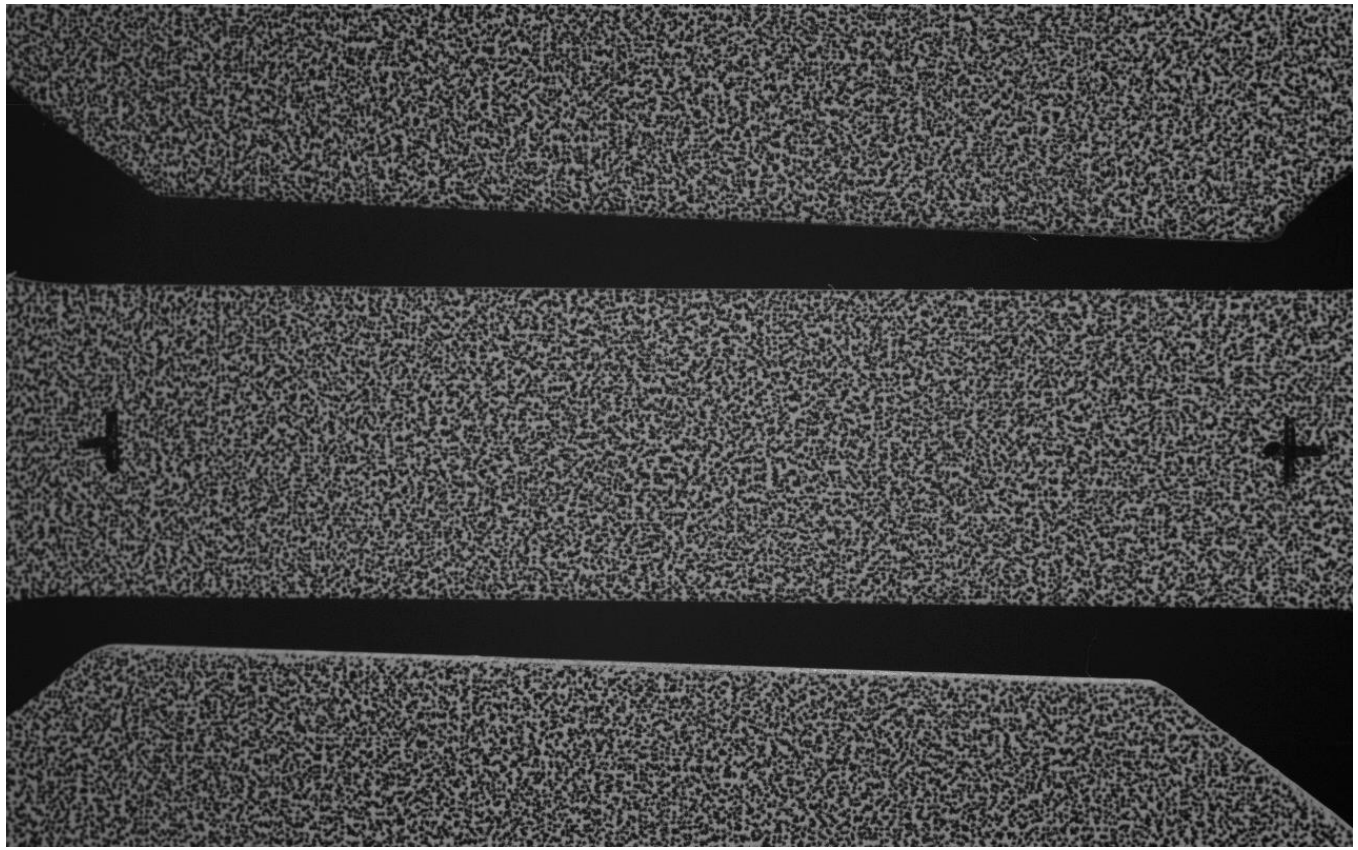


IR camera



Application of DIC Pattern
Sec. 3.1.5

- Recommendation 3.3: Apply two fiducial marks a known distance apart on the test piece
  - Useful for defining coordinate systems
  - Useful for checking absolute distances as part of calibration verification



Pre-Calibration Review of the System
Sec. 3.1.6

- Caution 3.4: This is the time to make adjustments and fix any issues with the DIC measurement setup. Once calibration images are taken, very few aspects of the DIC system can be changed.

- Sec. 3.1.3.1: Position test piece and cameras
- Sec. 3.1.6.2: Verify FOV, focus, DOF, magnification/SOD
- Sec. 3.1.6.3: Adjust polarization filters. Lock adjustable components (e.g. aperture, focus rings, translation/rotation stages). Strain relieve cables.
- Sec. 3.1.6.4: Review images, looking for
  - Glare
  - DIC pattern that is too coarse/fine
  - Defects in applied pattern
  - Out-of-focus regions
  - Poor contrast
  - Non-uniform lighting
  - Dirt or foreign object on lens
  - Vibrations

- Sec. 3.1.6.5: Accept DIC system

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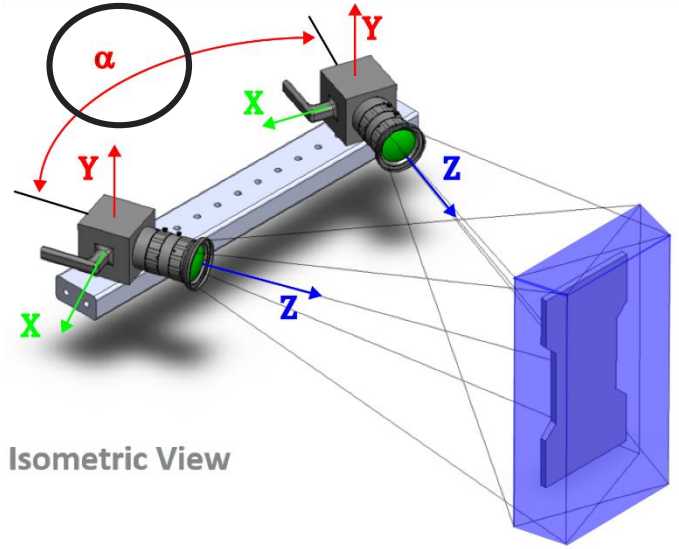
CHAPTER 3: PREPARATION FOR THE MEASUREMENTS

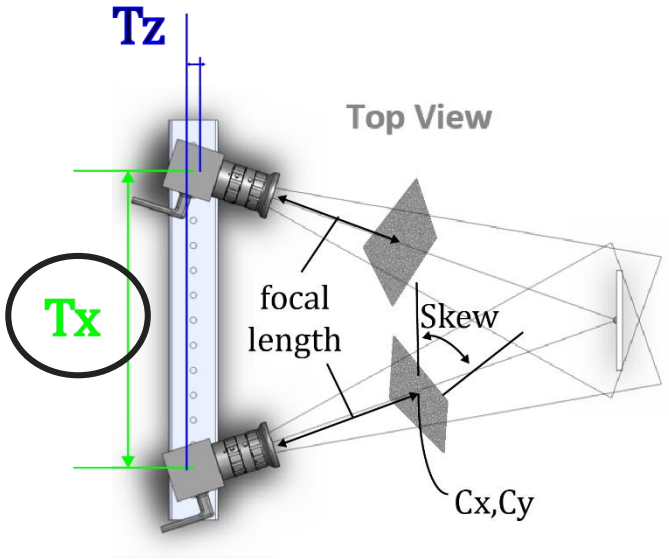
SEC. 3.2-3.3: CALIBRATION

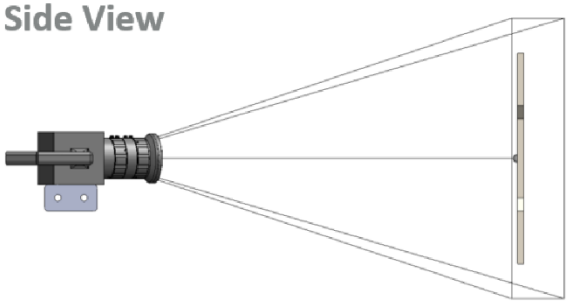
Purpose of Calibration – Stereo-DIC
Sec. 3.2.1

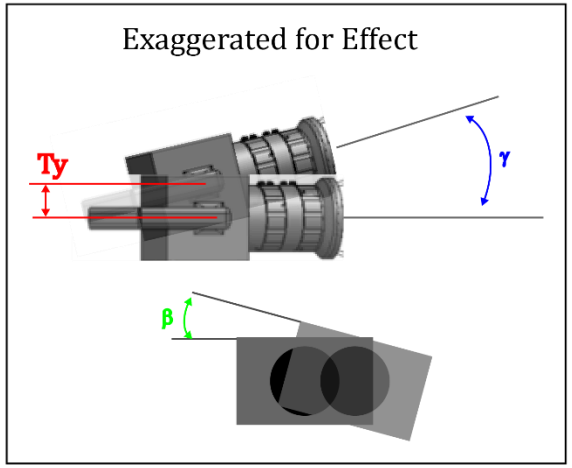
- *Intrinsic Parameters*
  - Focal length
  - Skew
  - Image Center (Cx, Cy)
  - Lens Distortions

- *Extrinsic Parameters*
  - Translations (X,Y,Z)
  - Rotations (α,β,γ)





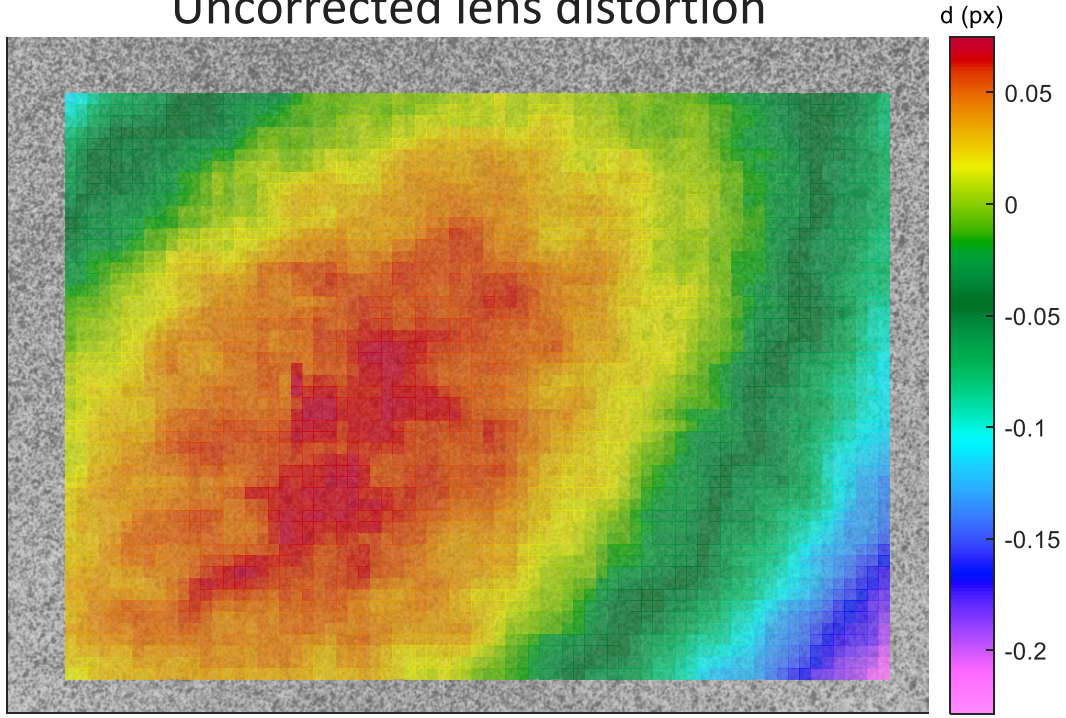




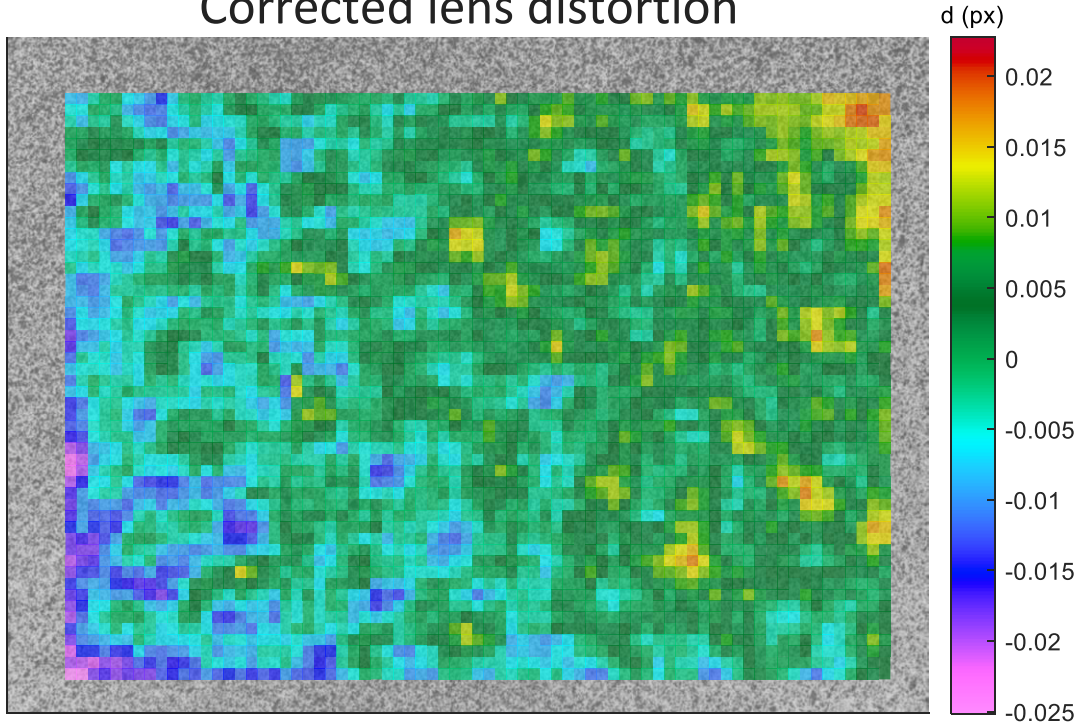
Purpose of Calibration – 2D-DIC
Sec. 3.2.1

- Caution 3.6 / Recommendation 3.5:
  - Calibration is still recommended for 2D-DIC, to correct for lens distortions.
  - If a full calibration is omitted, the magnitude of lens distortions should be evaluated.
    - Translate the sample in-plane and compute strains.
  - Also, the approximate image scale should be established.

Uncorrected lens distortion



Corrected lens distortion

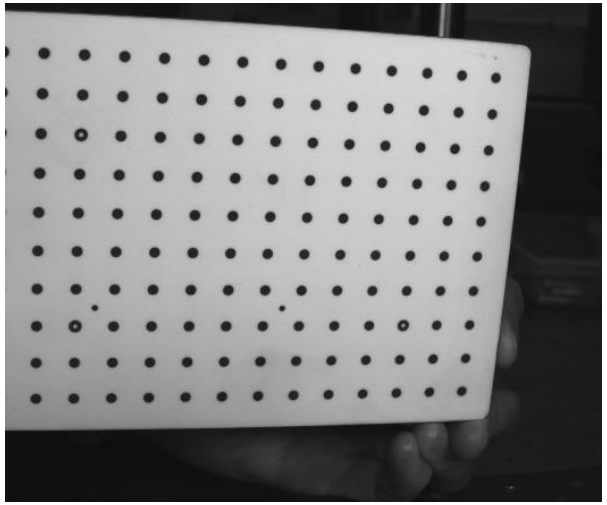


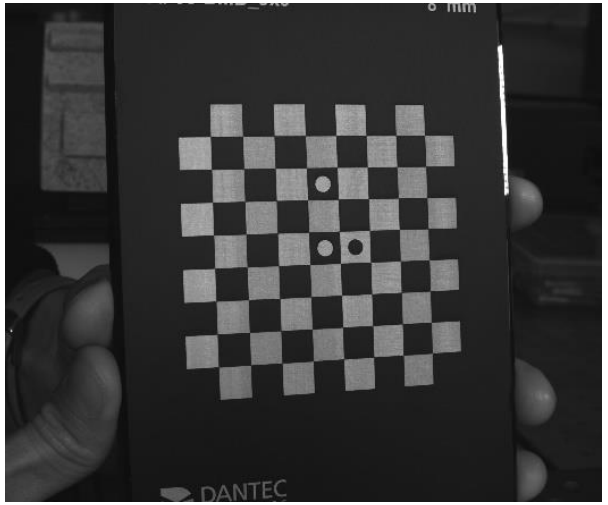
Select Calibration Target
Sec. 3.2.2.1

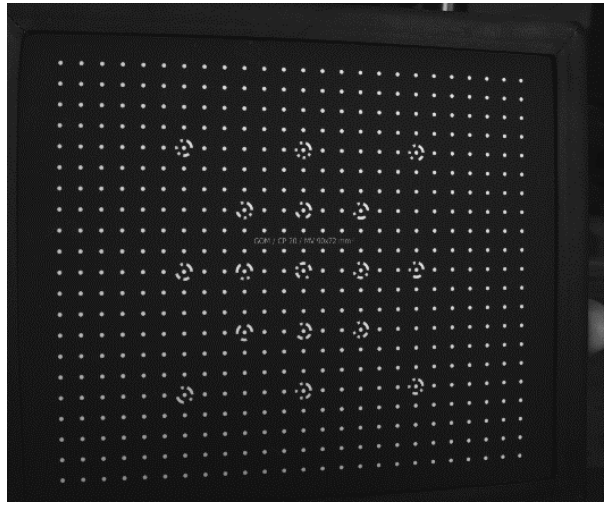
- Recommendation 3.6:
  - Target should be approximately the same size as the FOV or slightly smaller
  - Target shouldn't be smaller than ½ the size of the FOV

Calibration target examples from the Stereo DIC Challenge

https://sem.org/3ddic

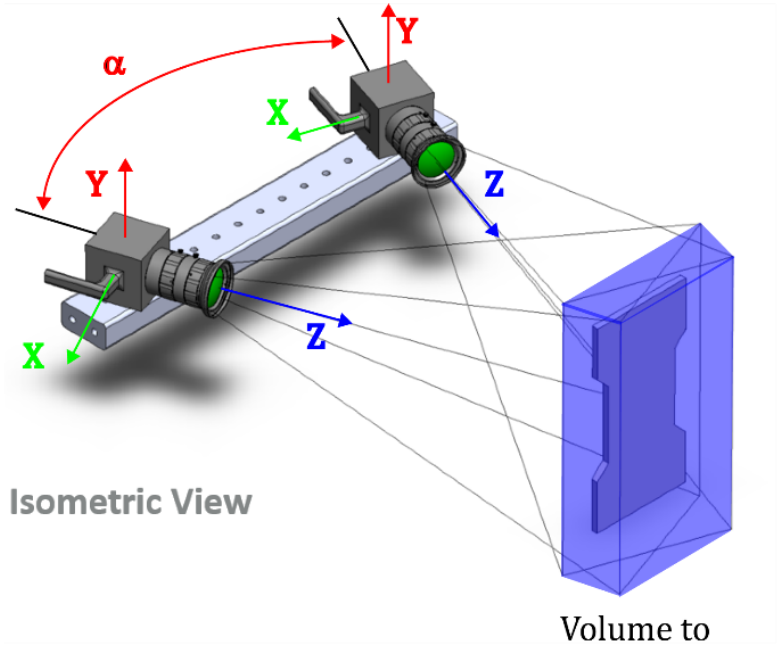


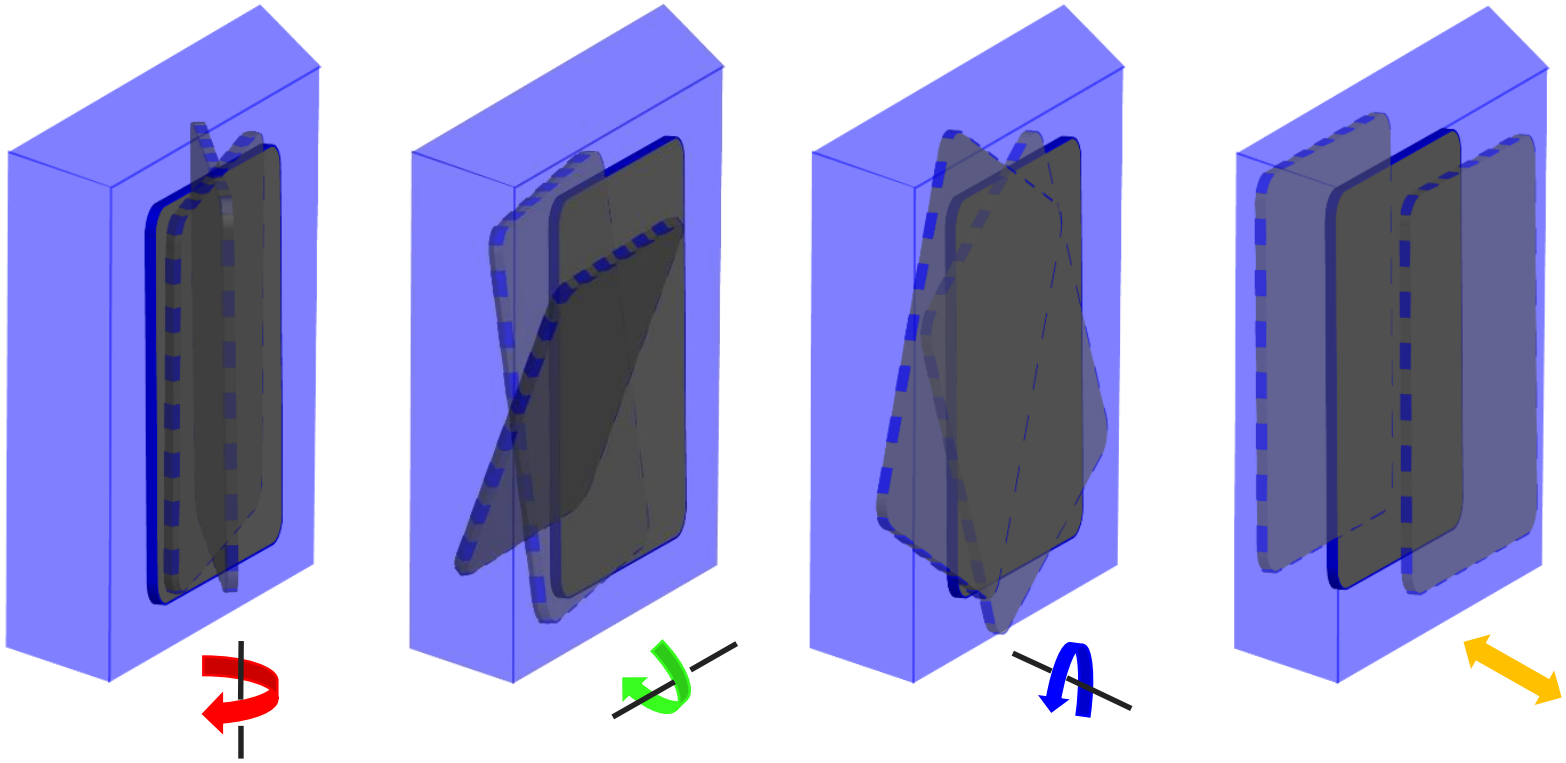




Acquire Calibration Images
Section 3.2.2.2-3.2.2.4

1. Clear working space
   - Recommendation 3.8:
   a) Move the test piece, not the stereo-rig, if possible
   b) Translate the stereo-rig
      - Caution 3.8: It is imperative that the stereo cameras are moved only as a rigid pair!
2. Adjust lighting and exposure
   - Caution 3.10: But not focus and aperture!
3. Acquire images that fill the field-of-view and depth-of-field





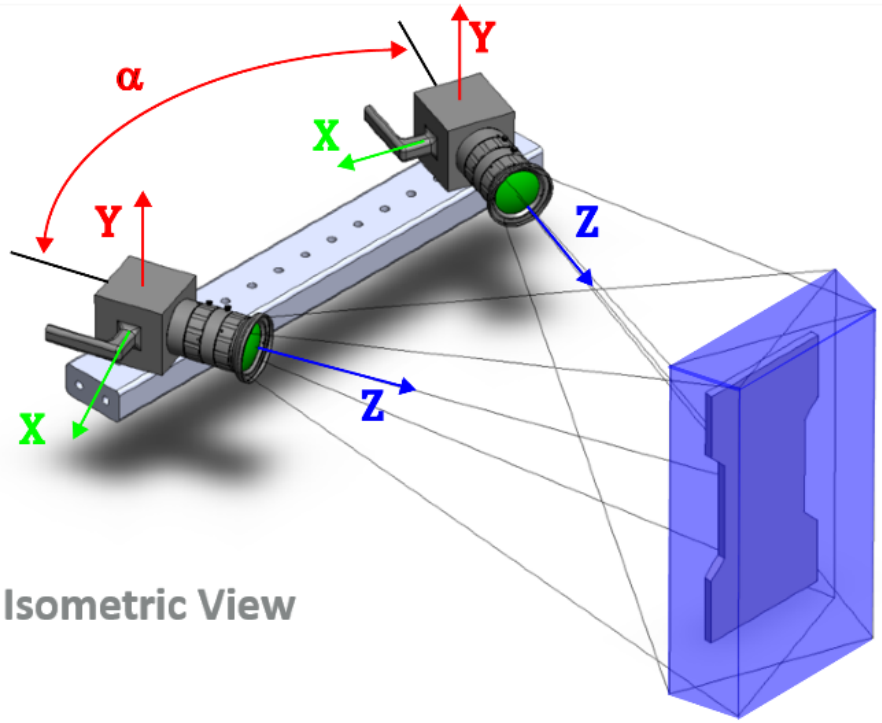
Acquire Calibration Images
Section 3.2.2.4

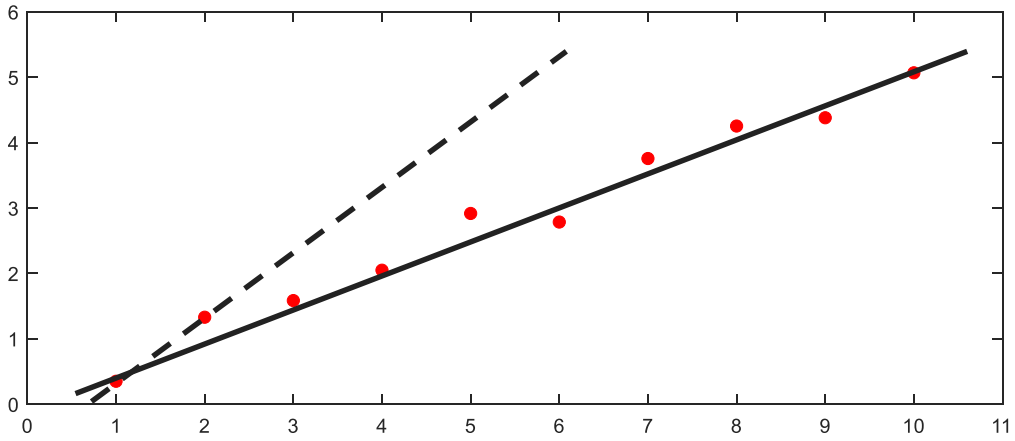
- Tip 3.6: The number of images recommended depends on calibration target and software ranging from *8* to *50-100*

- Caution 3.11: Quality over quantity!
  - Recommendation: Take care to gather images over entire volume

- Recommendation 3.11: Rigid calibration holder recommended, but may not be required, especially when exposure is less than 25 ms

- Caution 3.12: It is possible to achieve a “good score” with insufficient number of images





DEMO 07

Calibrate System and Review Calibration Results/ Parameters
Sec. 3.2.2.5-3.2.2.7

1. Select an appropriate camera or lens-distortion model and calibrate!

2. Review calibration results
   - Verify extracted features are correct (not dirt, glare etc)
   - Understand reason image/feature was rejected
   - Verify working volume was filled (i.e. dropped images were not all taken in the same region/ rotation)
   - Compare calibration score amongst individual images and to final score. Remove images if appropriate.
   - Save a copy of all pertinent information

Tip 3.8: All of the above is software dependent and may be user-defined; explore these effects

Calibrate System and Review Calibration Results/ Parameters Sec. 3.2.2.5-3.2.2.7

3. Review calibration parameters
   - Image center
   - Lens focal length
   - Angles
   - Distance between two cameras

Tip 3.9: This review is broad, and often focuses on range of values, rather than precise measurements

Example: 5MP Basler camera with 29 mm focal lens and 100 mm FOV

Caution 3.13: A good calibration score doesn't always mean success, but a bad calibration score rarely leads to success

Parameter	Theoretical	Good	Unexpected
Camera 1:			
Cx	1224 px	1210 px	-962 px
Cy	1024 px	1030 px	-50 px
Focal Length X	8405.8 px	8761 px	8000 px
Focal Length Y	8405.8 px	8612 px	9000 px
Camera 2:			
Cx	1224 px	1210 px	1225 px
Cy	1024 px	1010 px	1024 px
Focal Length X	8405.8 px	8375 px	4000 px
Focal Length Y	8405.8 px	8457 px	4100 px
Extrinsic:			
Stereo Angle (α)	25	25	50
β	0	0.1	5
γ	0	0.1	-4
Tx	160 mm	150 mm	300 mm
Ty	0 mm	5.1 mm	-1 mm
Tz	375 mm	370 mm	200 mm

Non-physical

Should be same for spherical lenses

Focal lengths don't match between cameras

Angles not optimal for DIC

Non-physical

Calibrate System and Review Calibration Results/ Parameters
Sec. 3.2.2.5-3.2.2.7

How to convert focal length from pixels to physical units

(Focal Length [px]) * **(Pixel size [µm/px])** = **(Focal Length [mm])**

Focal length from calibration | **Physical size of pixels on detector** | **Physical focal length of the lens**

~ 8551 px * **3.45 µm/px** ≈? **29 mm lens**

Not the image scale!
Look on camera brand website.

$f_{x,0}$ = 8761 px
$f_{y,0}$ = 8612 px
$f_{x,1}$ = 8375 px
$f_{y,1}$ = 8457 px

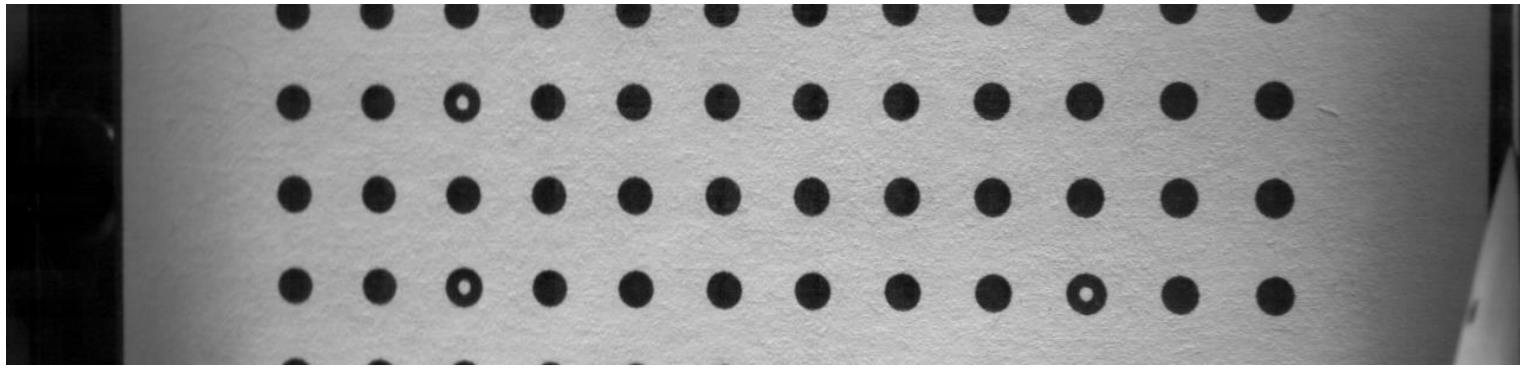
Sensor Vendor	Sony
Sensor	IMX250
Shutter	Global Shutter
Max. Image Circle	2/3"
Sensor Type	CMOS
Sensor Size	8.4 mm x 7.1 mm
Resolution (HxV)	2448 px x 2048 px
Resolution	5 MP
Pixel Size (H x V)	3.45 µm x 3.45 µm
Frame Rate	75 fps
Mono/Color	Mono

iDICs

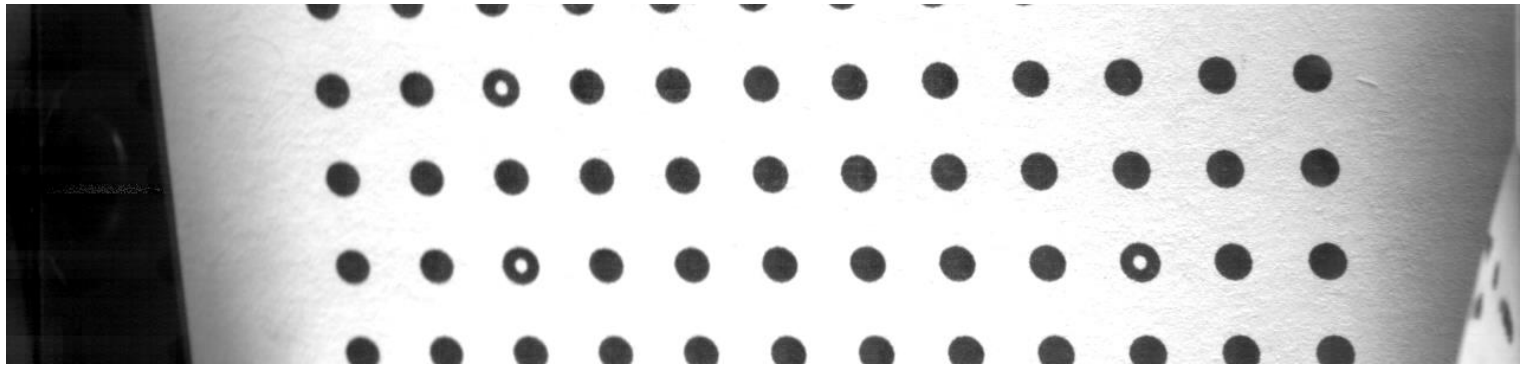
What’s wrong with my calibration?

What's wrong with my calibration?

Calibration target perpendicular to light source

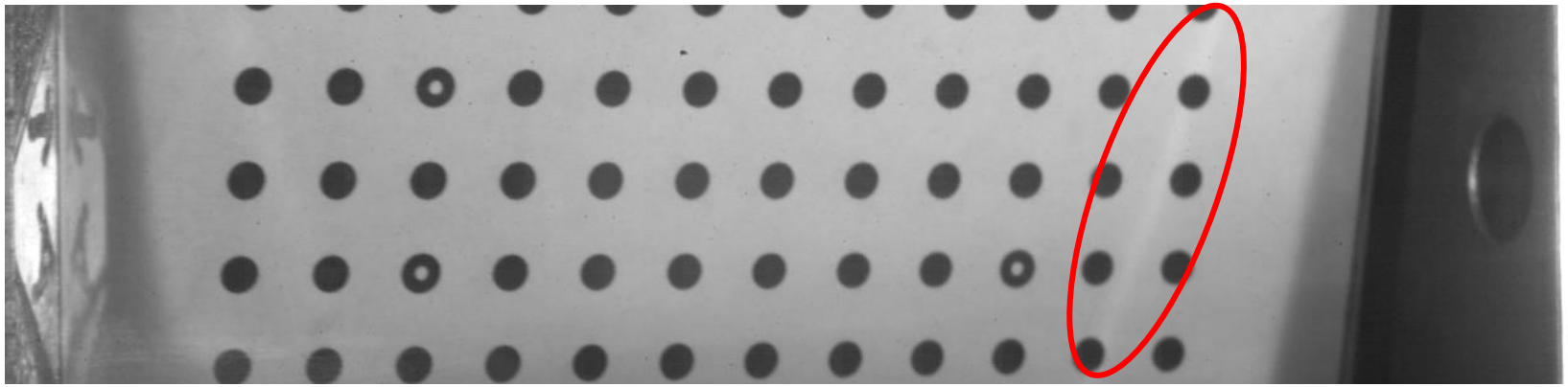


Calibration target titled to light source



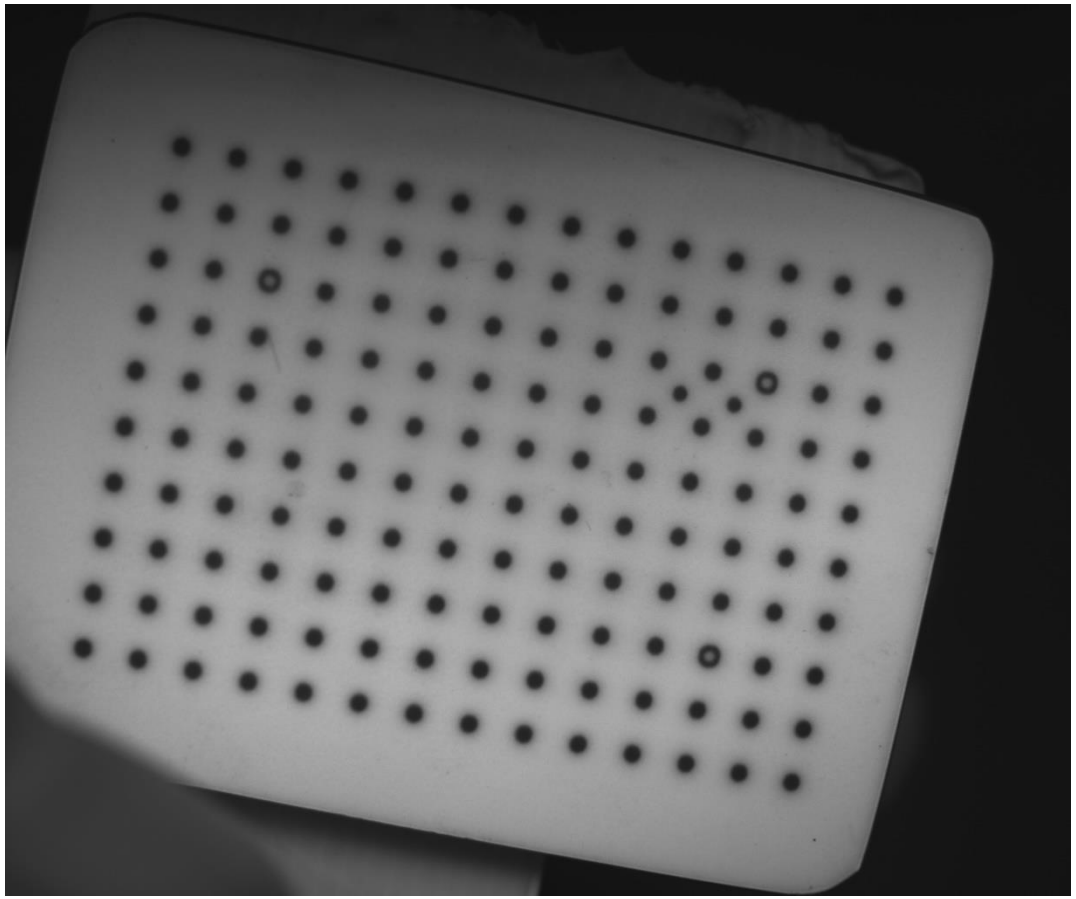
Saturated light due to tilt

What’s wrong with my calibration?



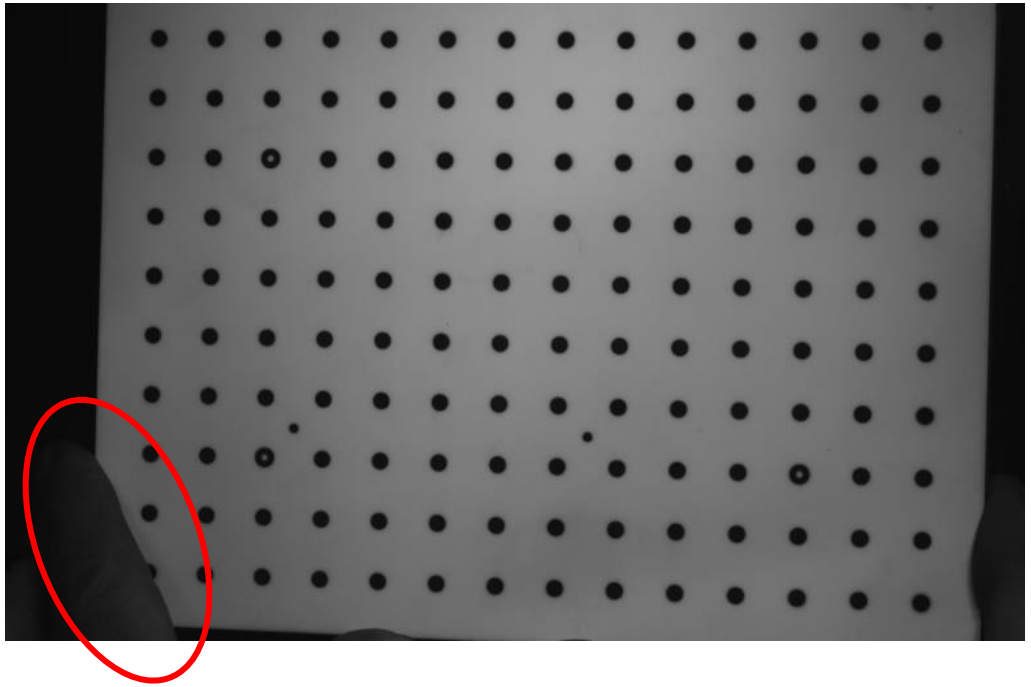
Reflections or glares

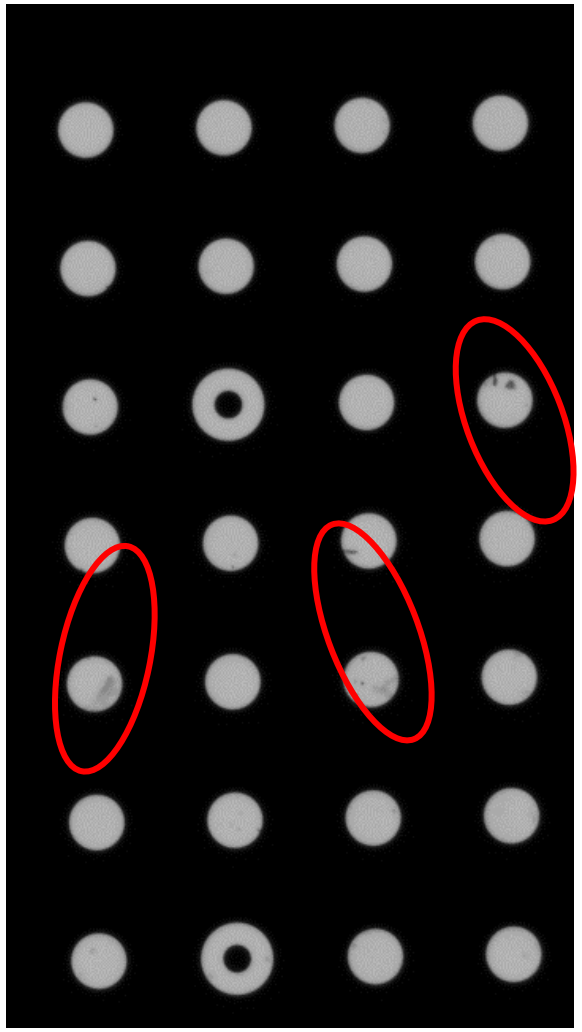
What's wrong with my calibration?



Shadows

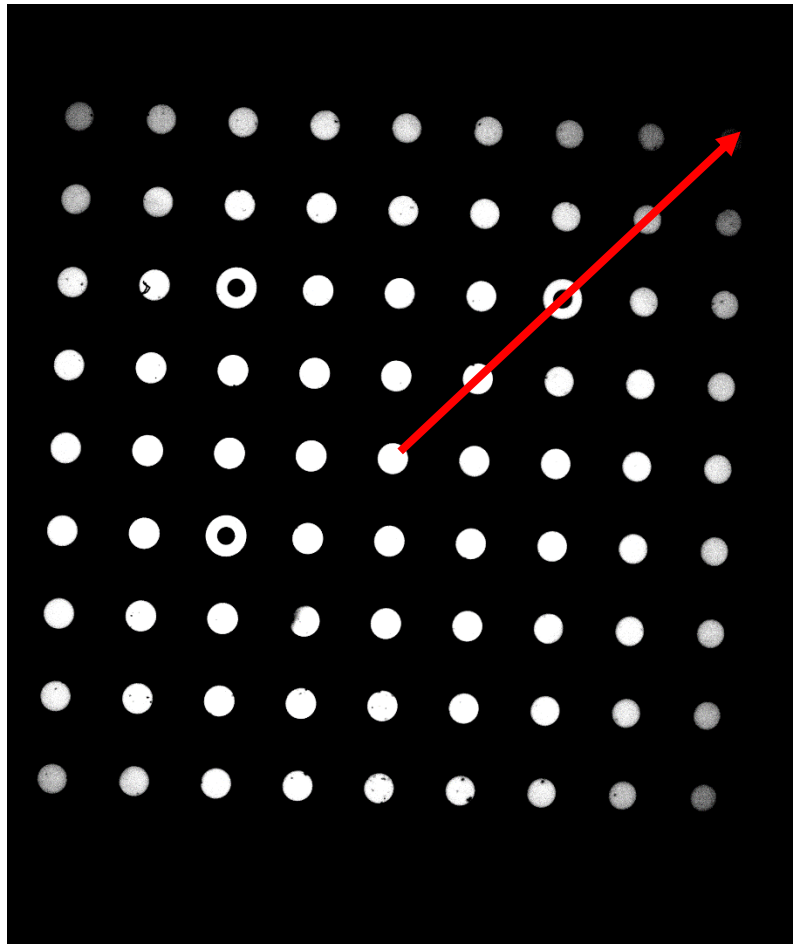
What's wrong with my calibration?





Dirt or other obstructions

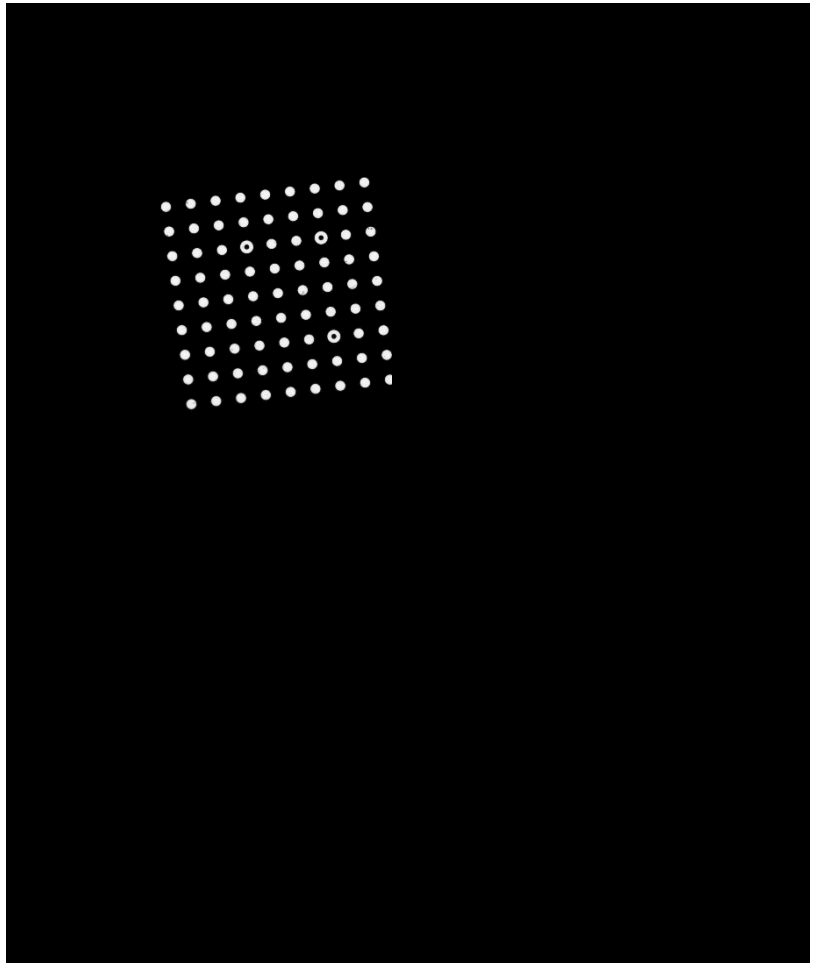
What's wrong with my calibration?



Decreasing Intensity towards the edges of your calibration target

Vignetting

What's wrong with my calibration?



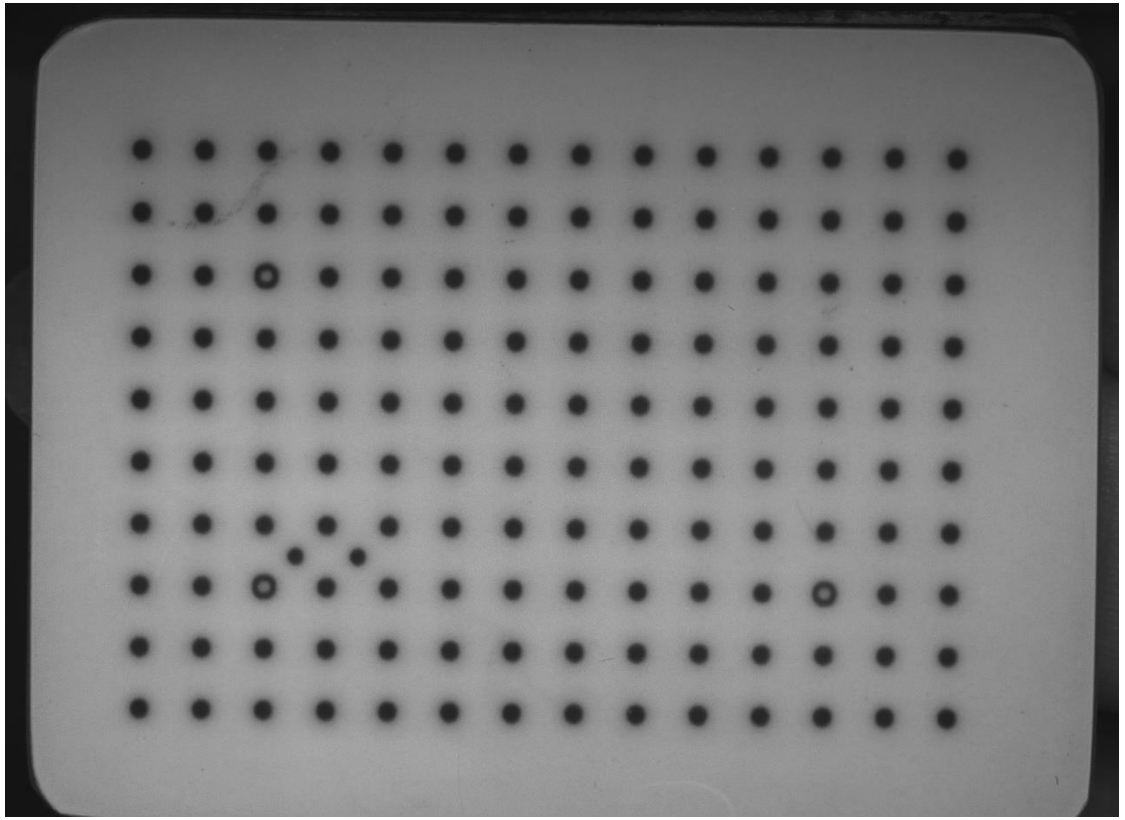
Calibration target should not be smaller than approximately half of the FOV

Smaller targets may produce an acceptable calibration score, but precautions must be taken outside the scope of this course

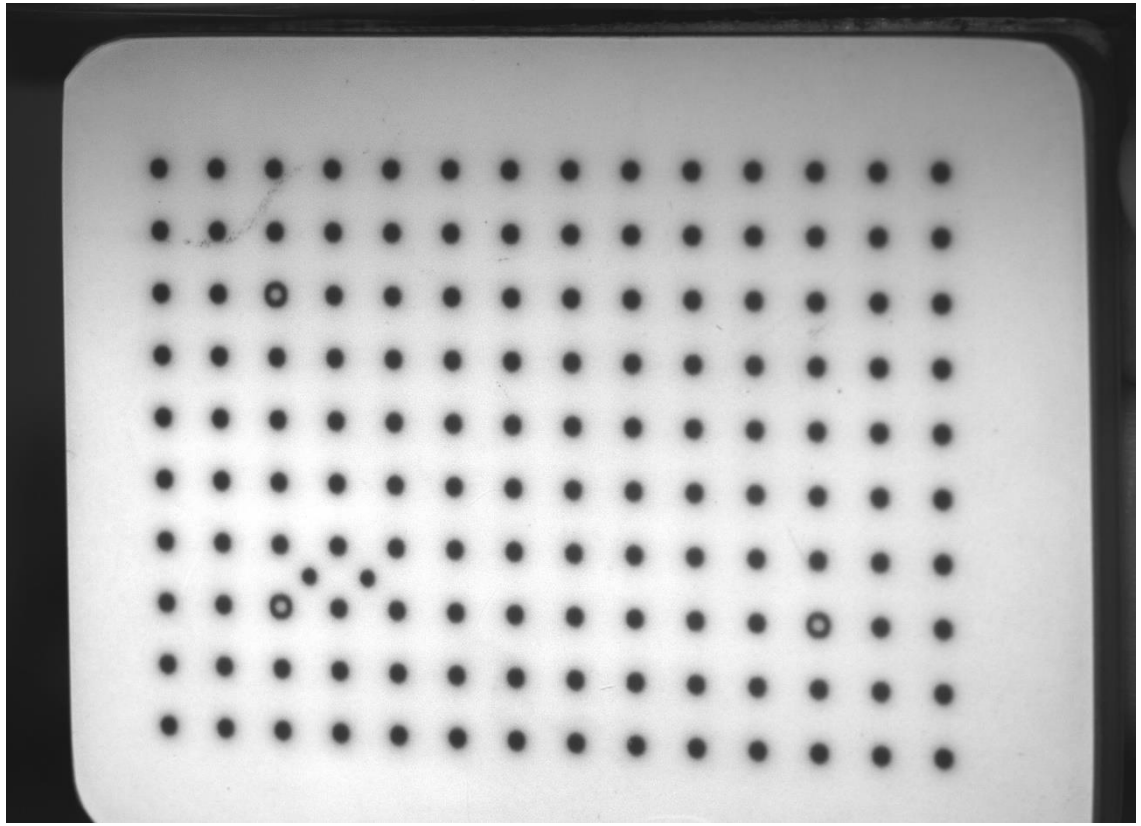
Calibration target is too small for FOV

What's wrong with my calibration?

Left Camera



Right Camera

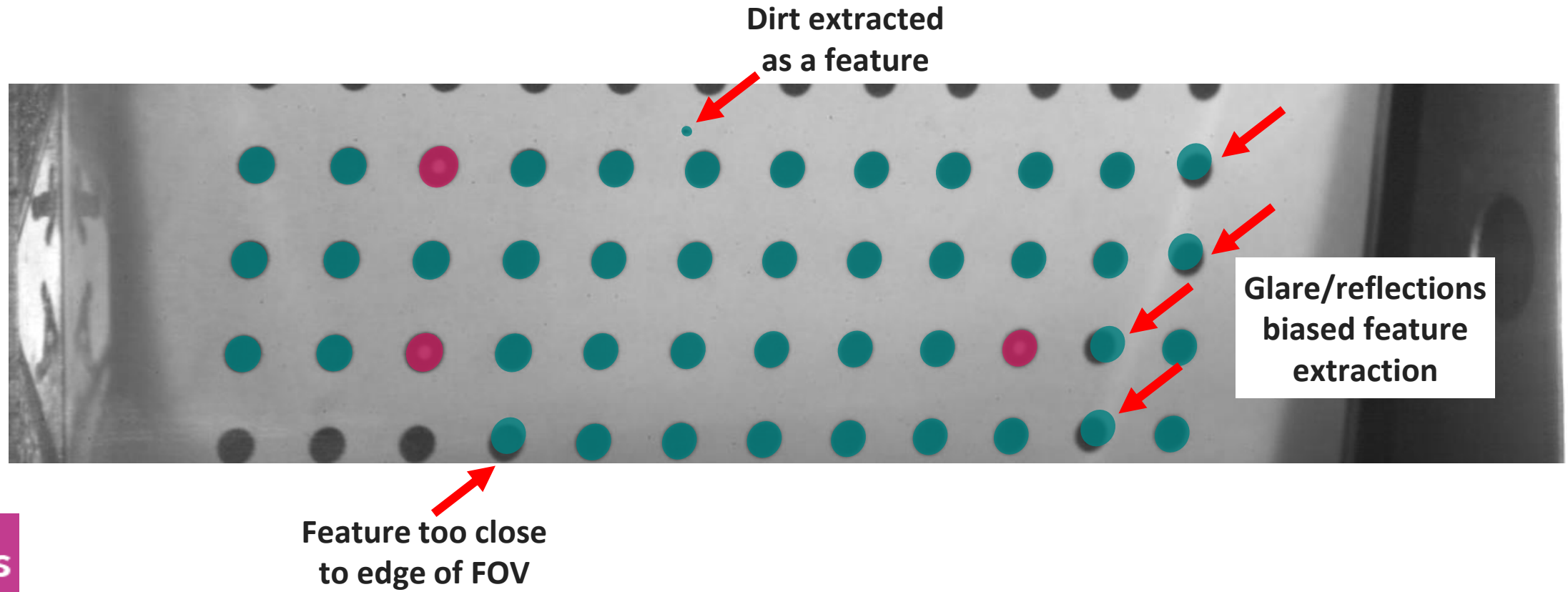


Lighting or apertures are unbalanced

What's wrong with my calibration?

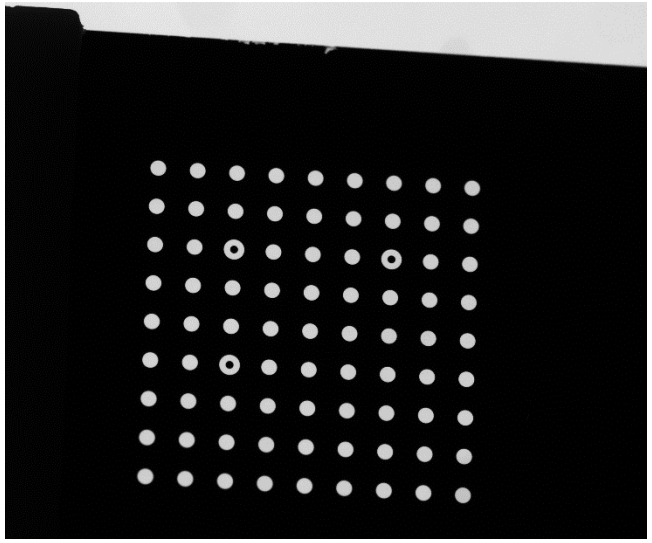
- Compare calibration score amongst individual images and to final score. Remove images if appropriate.

	I1	I2	I3	I4	I5	I6	I7	I8	I9	Final
Cam0	0.0256	0.0274	0.0298	0.0224	0.0238	0.0289	0.0225	0.0271	0.0215	**0.0718**
Cam1	0.0267	0.0231	0.0287	0.0249	0.8567	0.0276	0.0253	0.0242	0.0268	

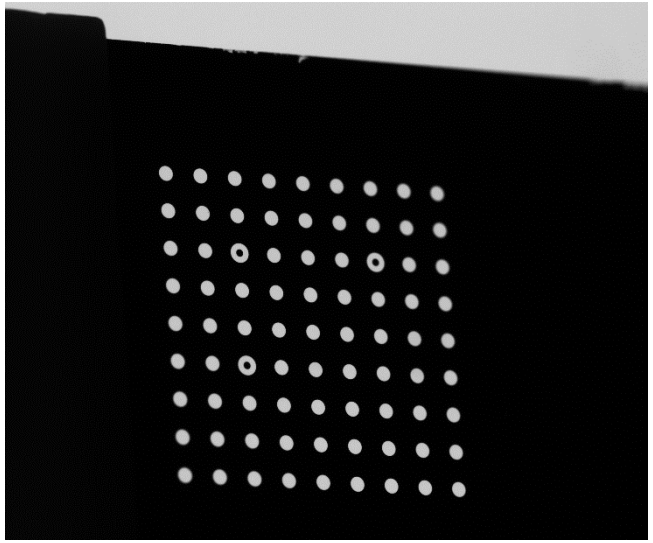


What's wrong with my calibration?

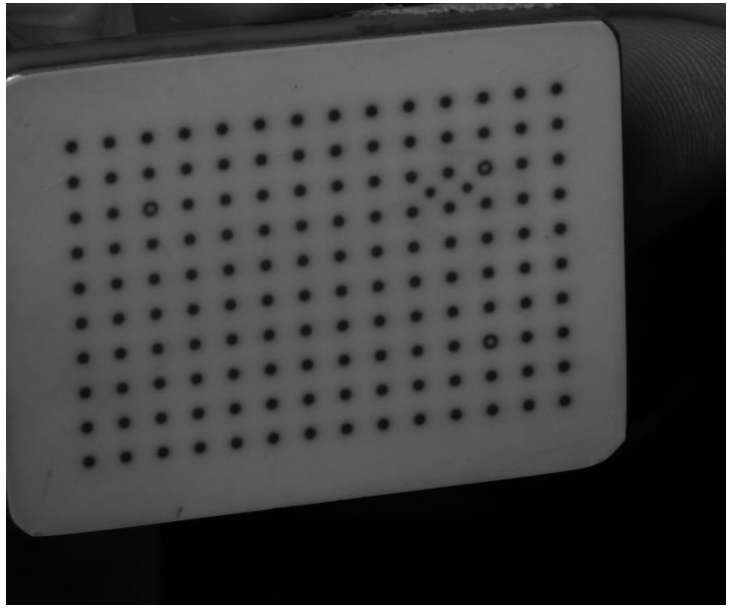
Left Camera



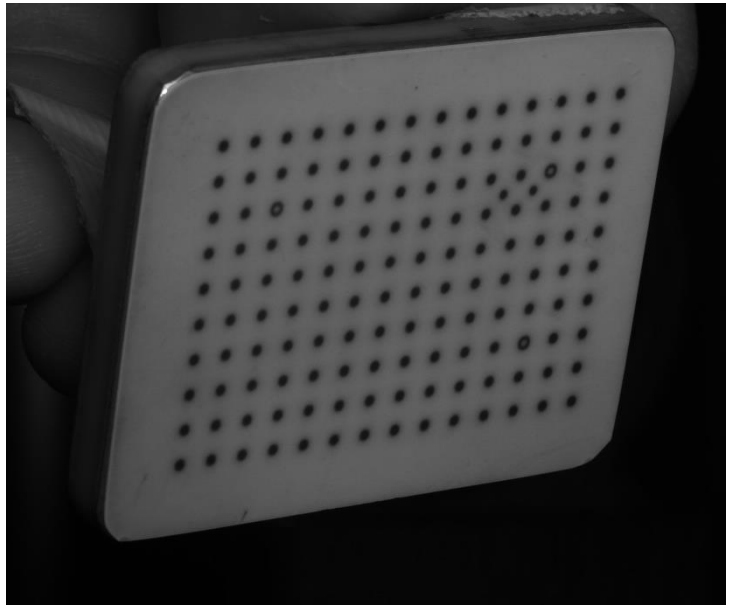
Right Camera



Left Camera

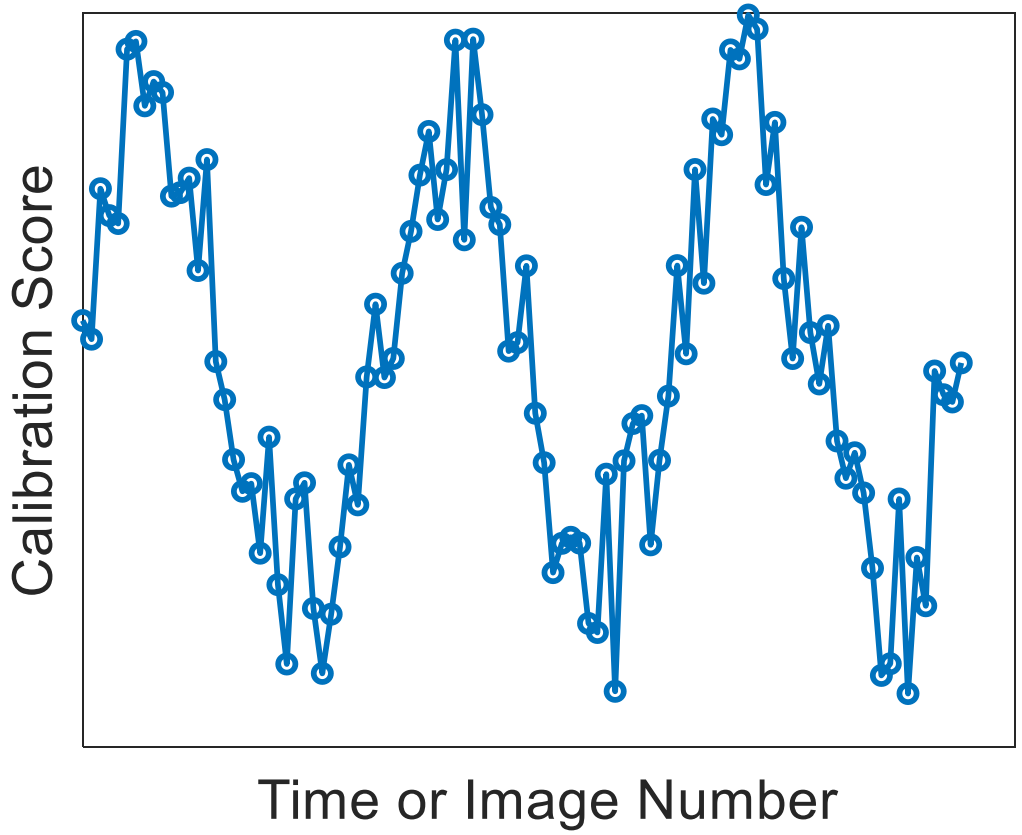


Right Camera



Angle is too extreme for one or both cameras

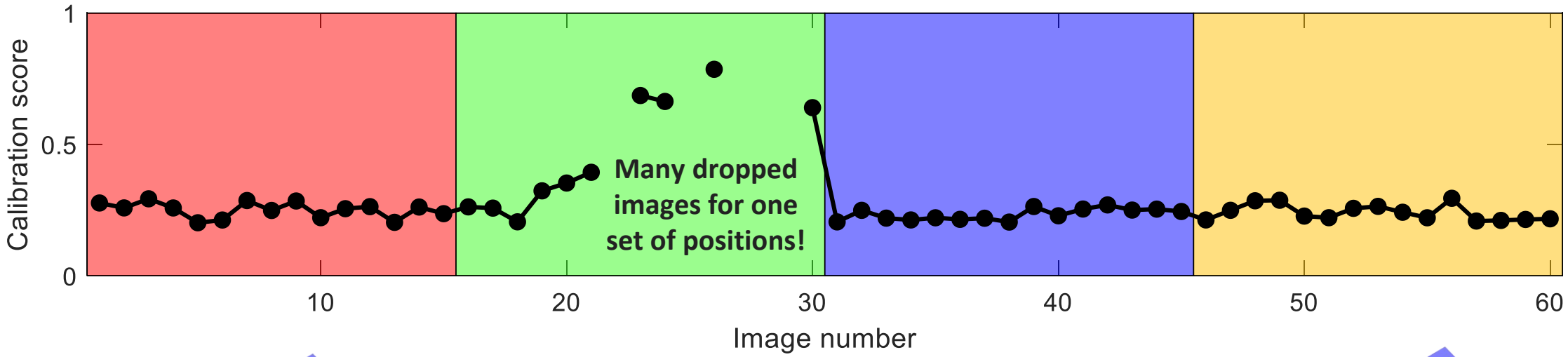
What's wrong with my calibration?

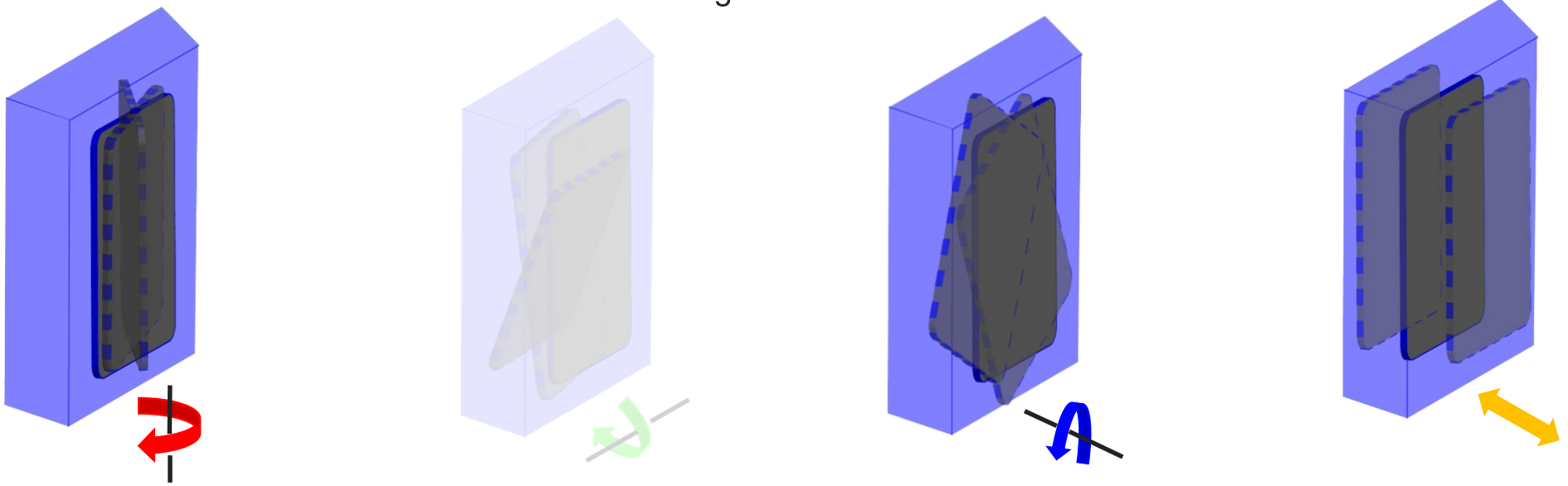


Vibrations potentially due to unstable camera mounting system or fluctuating calibration target

What's wrong with my calibration?

- Verify working volume was filled (i.e. dropped images were not all taken in the same region/ rotation)





What's wrong with my calibration?

Thanks for playing!!

Images for Calibration Verification and Noise-Floor Analysis
Sec. 3.3.1

1. Reset system to point cameras at test piece
2. Adjust lighting
3. Acquire static images

Recommendation 3.13: Take images at same frame rate and duration as the test

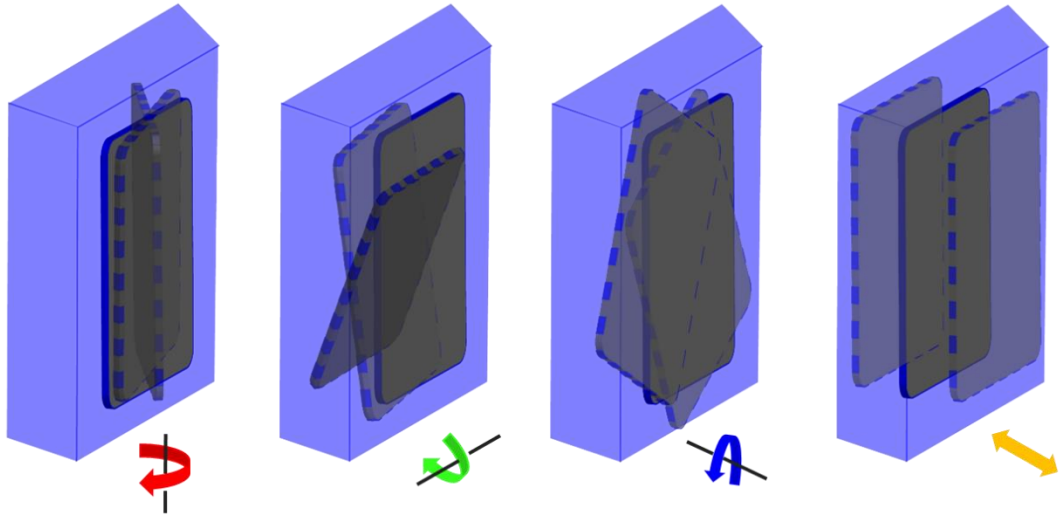
4. Review images
   - Glare
   - DIC pattern that is too coarse/fine
   - Defects in applied pattern
   - Out-of-focus regions
   - Poor contrast
   - Non-uniform lighting
   - Dirt or foreign object on lens
   - Vibrations

Caution 3.14: If you adjust anything, the calibration will have to be repeated!

5. Acquire rigid body motion images

Recommendation 3.14: At minimum, translate the test piece within the volume it is expected to move

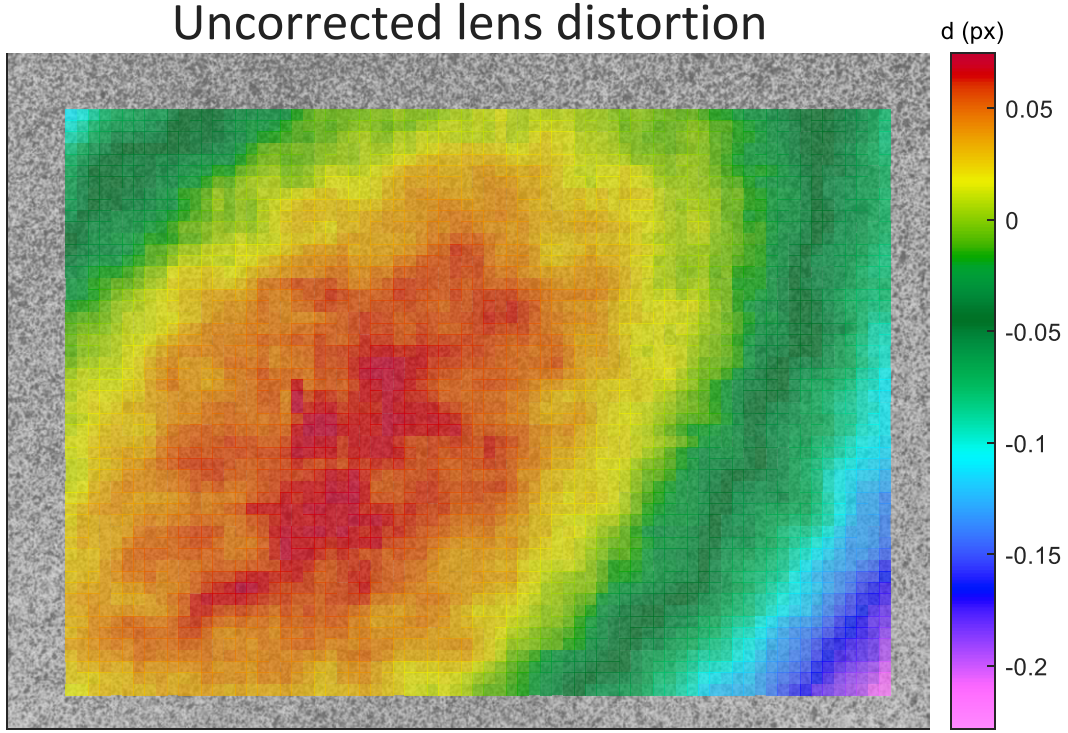
Recommendation 3.15: For 2D-DIC, capture two image sets:
- In-plane translations (used to check for lens distortions and quantify noise floor)
- Out-of-plane translations and rotations (strain error)



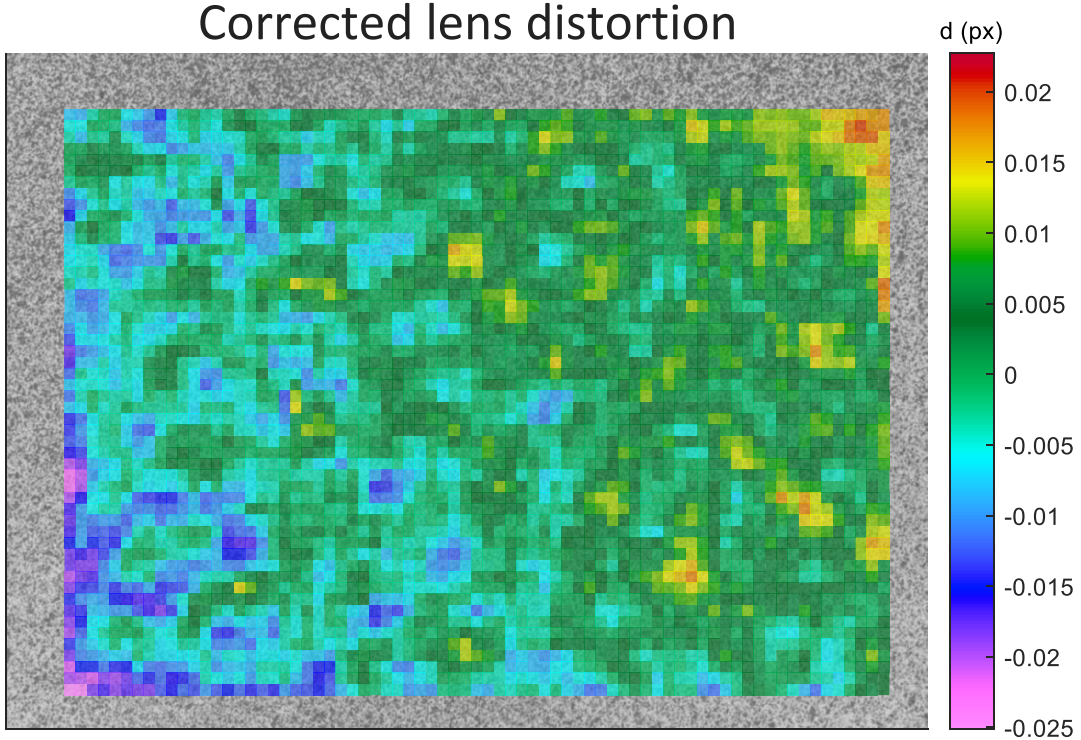
Verification of Calibration
Sec. 3.3.2

- Correlate static and rigid body motion images
  1. Recommendation 3.16: Evaluate lens distortion

Uncorrected lens distortion

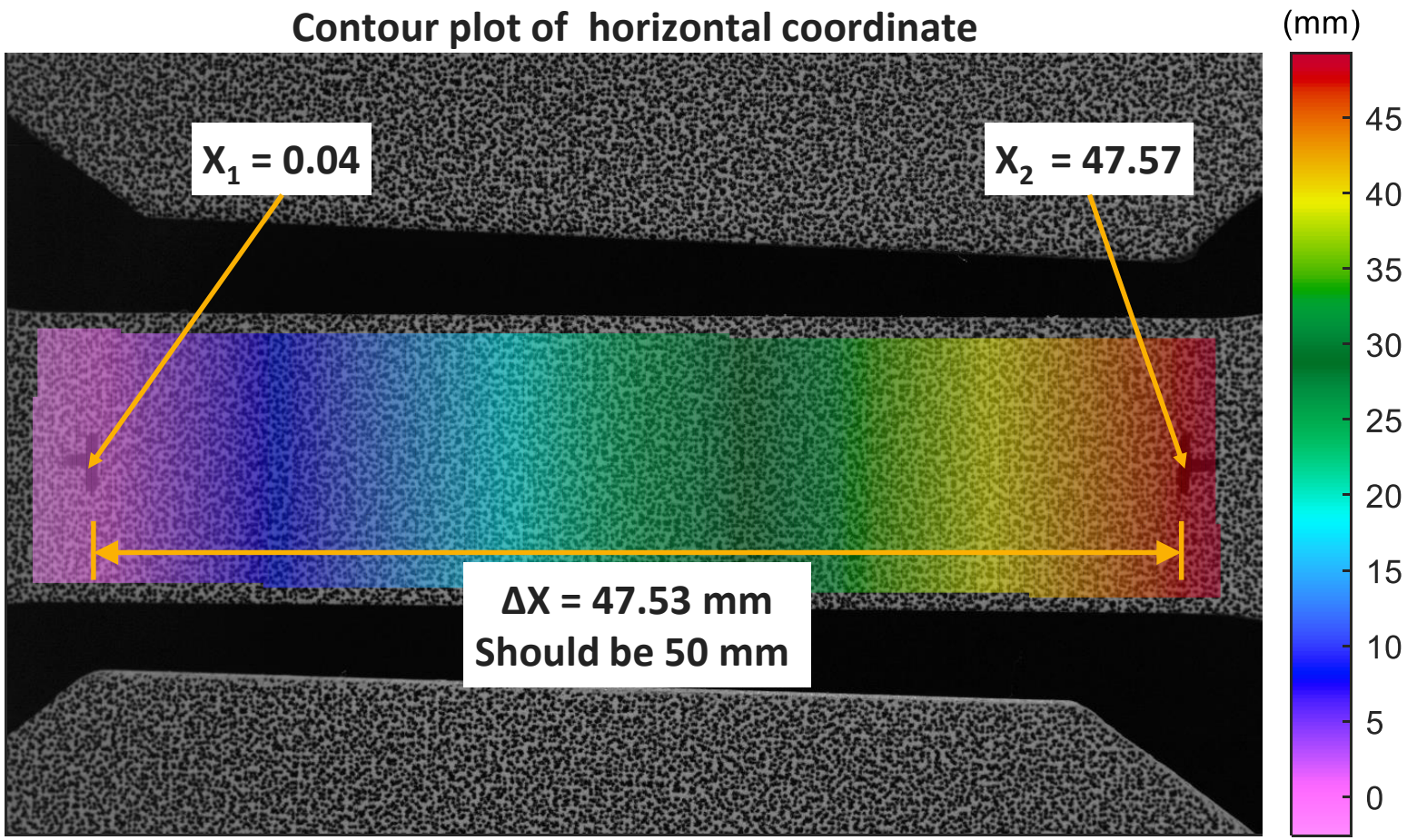


Corrected lens distortion



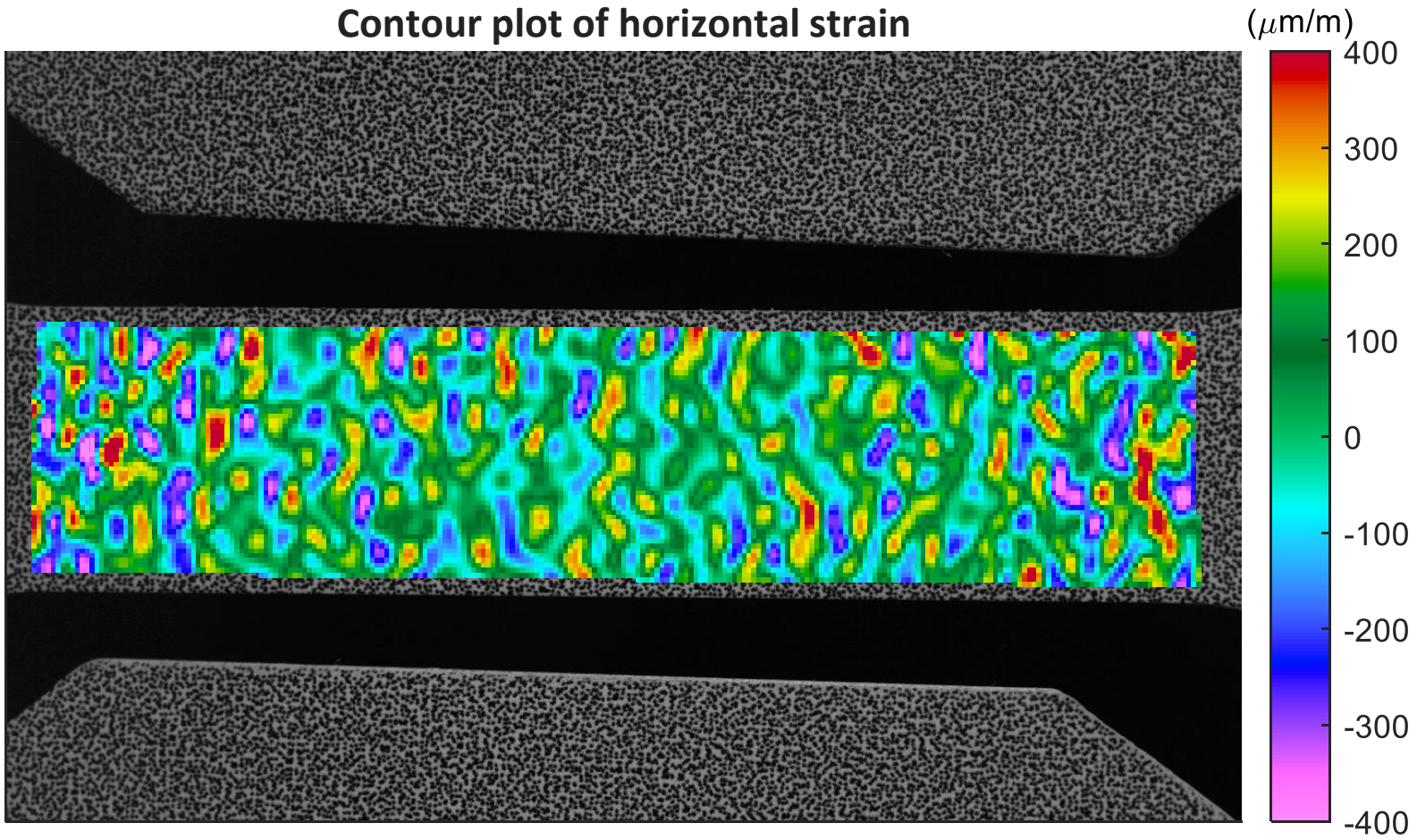
Verification of Calibration
Sec. 3.3.2

- Correlate static and rigid body motion images
  1. Recommendation 3.16: Evaluate lens distortion
  2. Recommendation 3.17: Evaluate fiducial marks and applied distances



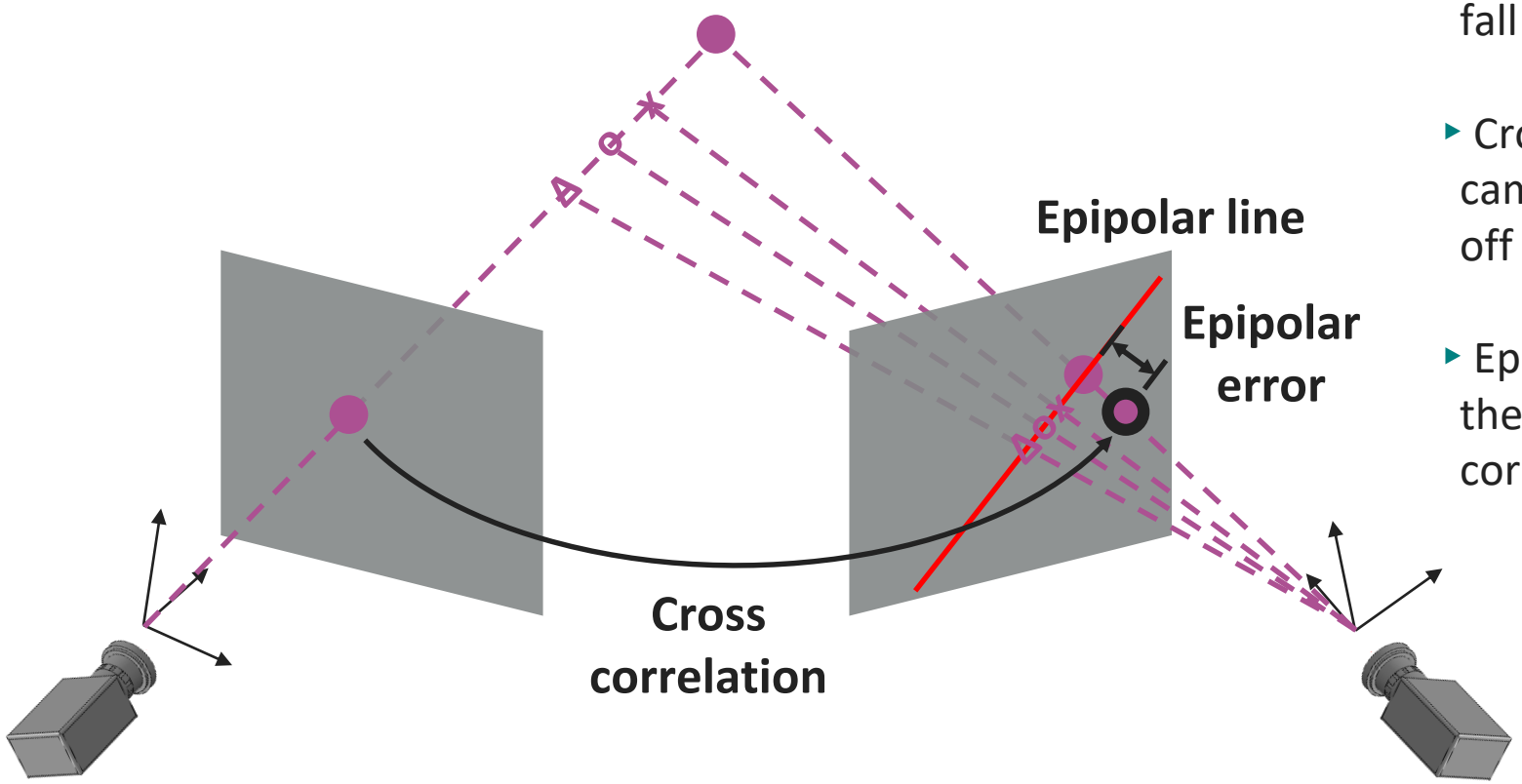
Verification of Calibration
Sec. 3.3.2

- Correlate static and rigid body motion images
  1. Recommendation 3.16: Evaluate lens distortion
  2. Recommendation 3.17: Evaluate fiducial marks and applied distances
  3. Recommendation 3.18: Perform abbreviated noise floor analysis



Verification of Calibration
Sec. 3.3.2

- Correlate static and rigid body motion images
  1. Recommendation 3.16: Evaluate lens distortion
  2. Recommendation 3.17: Evaluate fiducial marks and applied distances
  3. Recommendation 3.18: Perform abbreviated noise floor analysis
  4. Tip 3.13: Epipolar error is directly related to error in DIC measurements



Epipolar Geometry

- Stereo-camera calibration defines epipolar geometry
- Every point in one camera should fall on a line in the second camera.
- Cross-correlation from left-to-right camera may identify a point that is off the epipolar line
- Epipolar error is the distance from the point identified by cross-correlation to the epipolar line
- Tip 3.13: Epipolar error should be on the order of your calibration score.