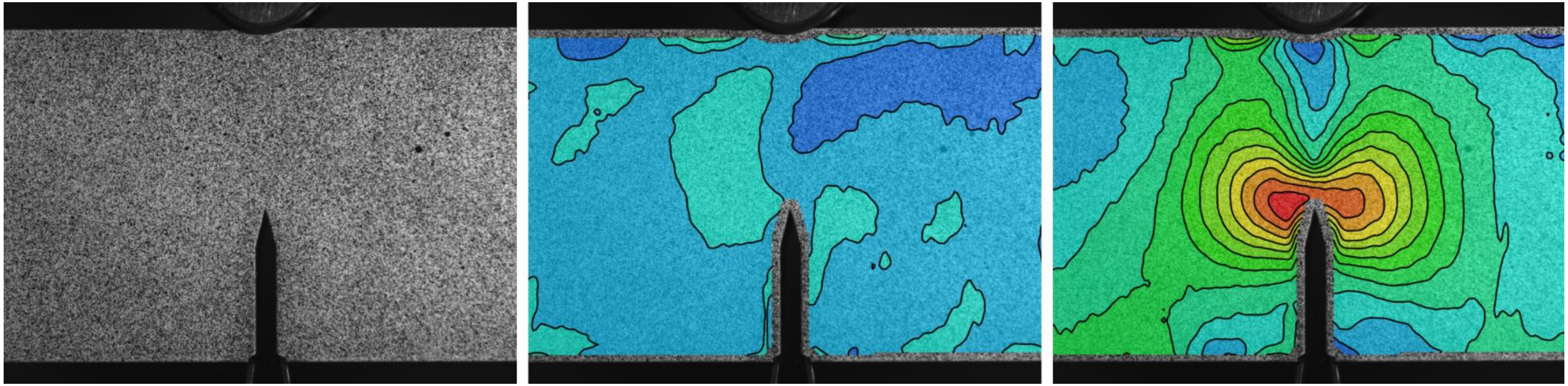
correlated SOLUTIONS

Digital Image Correlation:

Overview of Principles and Software

Correlated Solutions, Inc.

correlatedsolutions.com

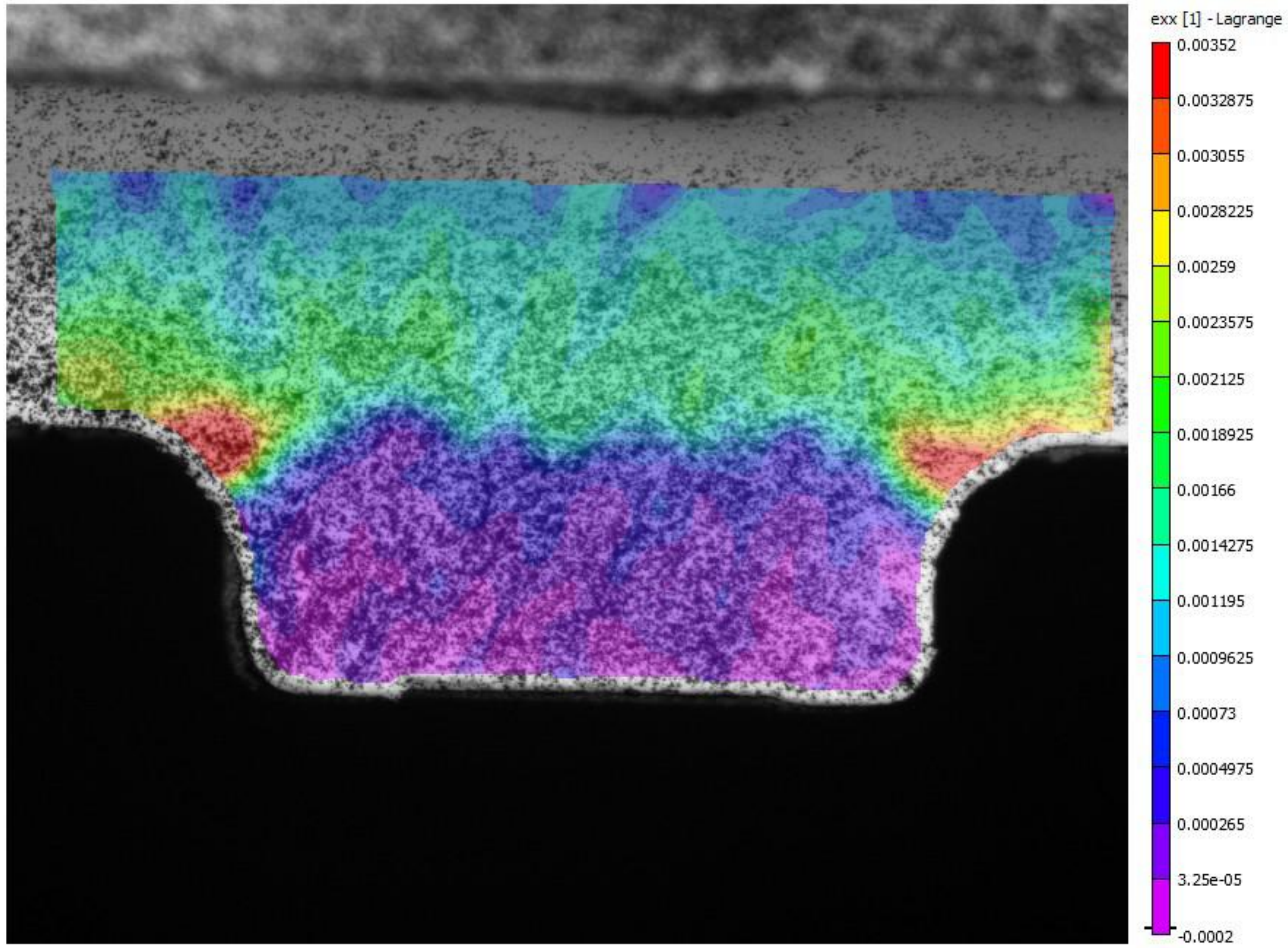


2-D Digital Image Correlation

Fundamentals

Deformation Measurement

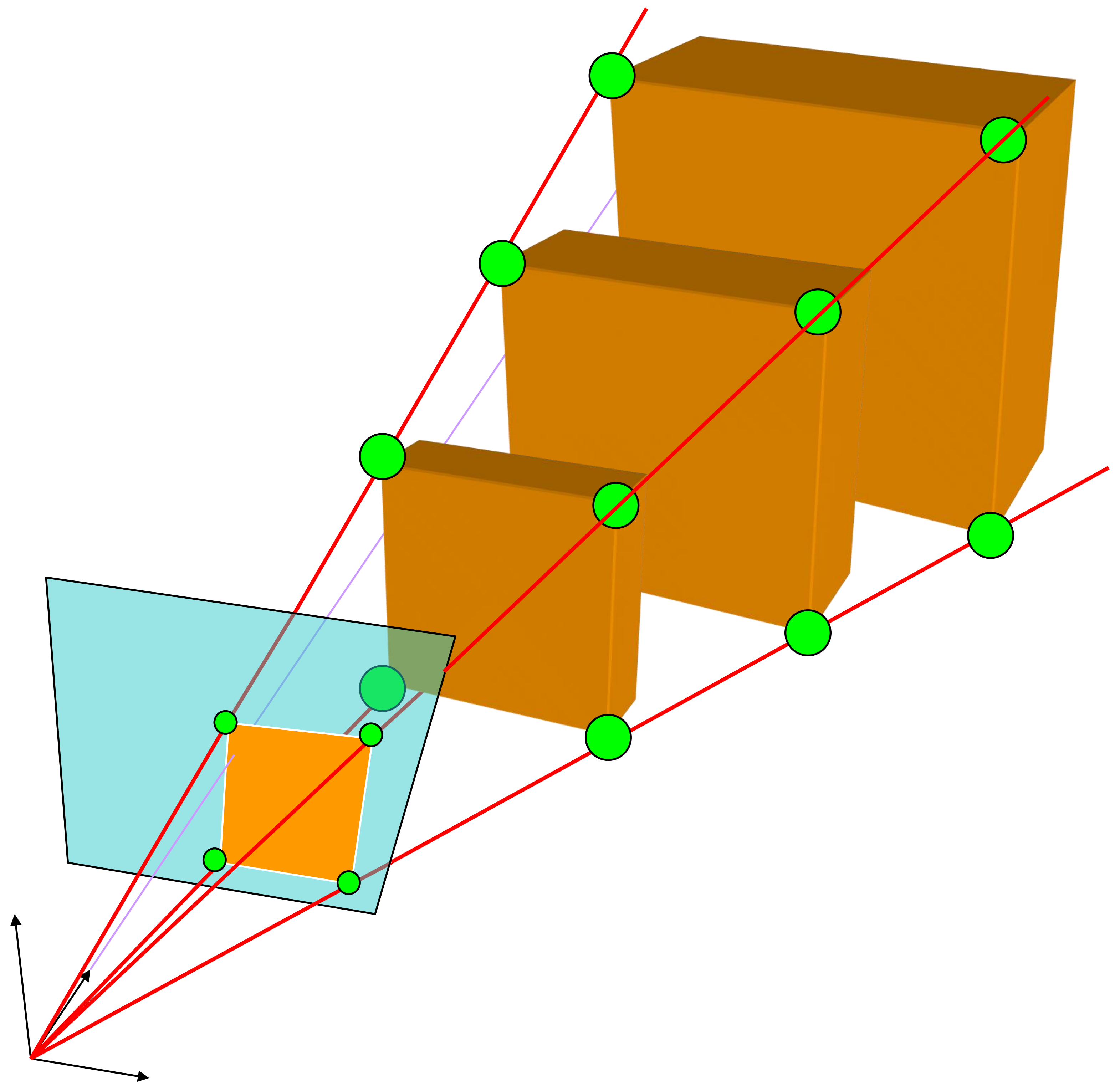
- Full-field measurement
- Non-intrusive
- Planar specimen only
- No out-of-plane motion



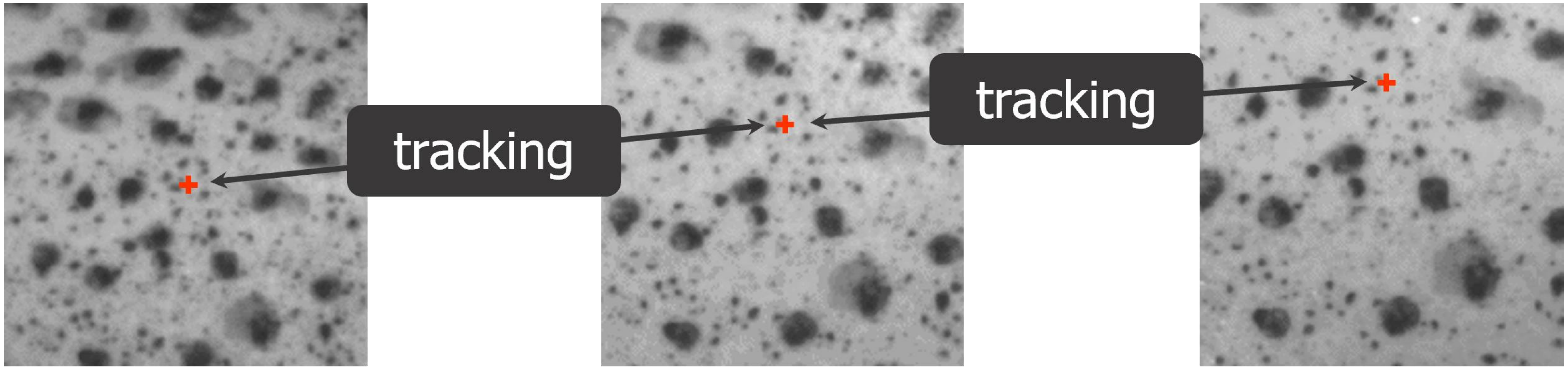
Deformation Measurement

- Large range of size scales (10^{-9} to 10^{2} m)
- Large range of time scales (static to 5,000,000 fps)

- Monocular (cyclopean) vision cannot determine the size of objects
- Consequence: a 200% isotropic deformation of an object produces the same image as if the object was moved to one-half its original distance from the visual sensor
- We must assume the object is planar, parallel to and at a constant distance from the visual sensor during the entire experiment



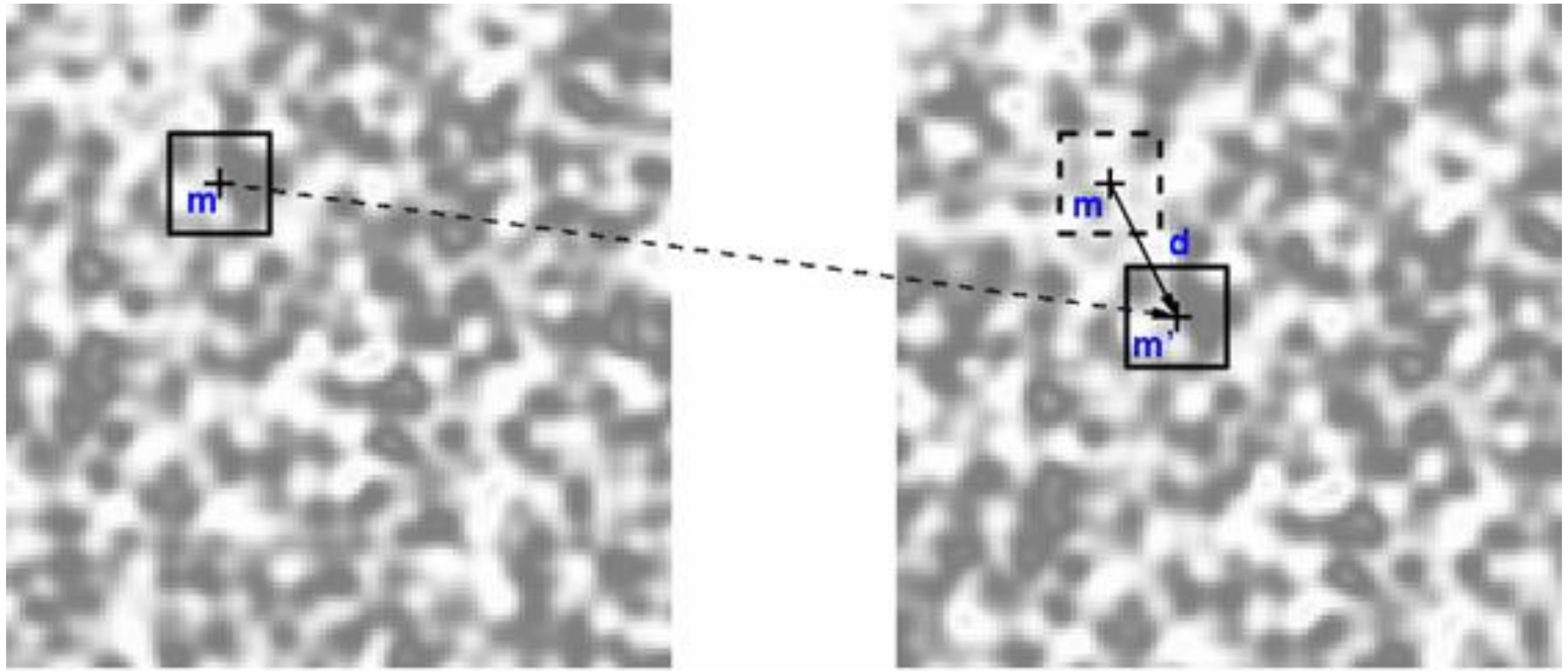
How? Given a point and its signature in the undeformed image, search/track in deformed image for the point which has a signature which maximizes a similarity function.



Time t Time t' Time t''

In practice, a single value is not a unique signature of a point, hence neighboring pixels are used.

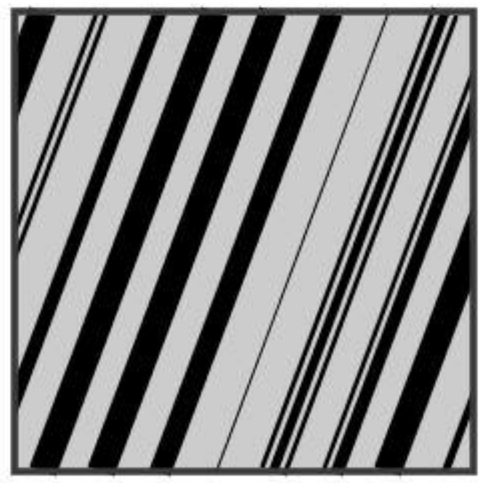
Such a collection of pixel values is called a subset or window.



The uniqueness of each signature is only guaranteed if the surface has a **non-repetitive**, **isotropic**, **high contrast pattern.**

Random textures fulfill this constraint (speckle pattern).

Repetitive
Anisotropic
High-contrast



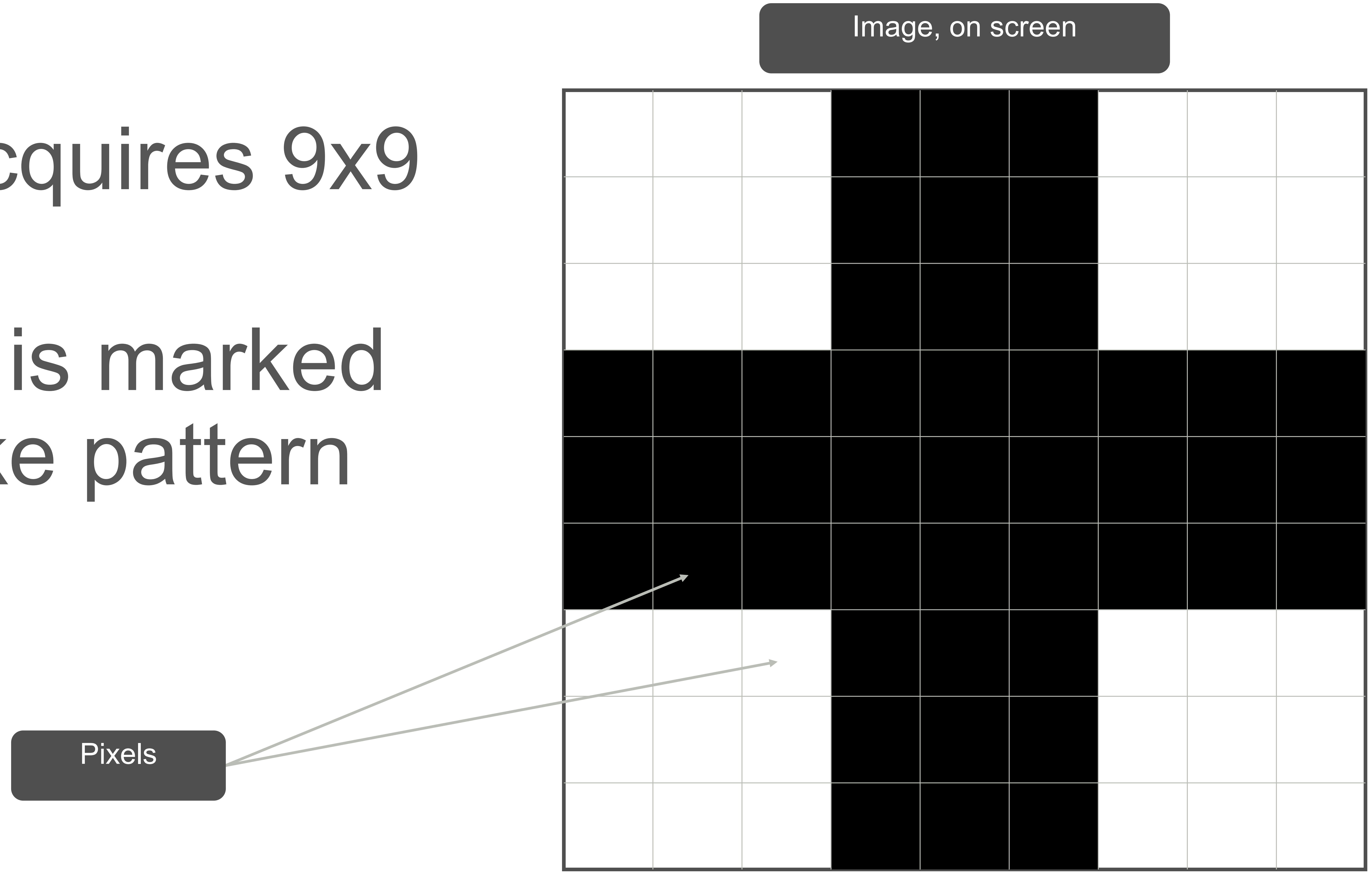
Non-repetitive
Anisotropic
High-contrast

Non-repetitive
Isotropic
Low-contrast

Non-repetitive
Isotropic
High-contrast

Example

- The camera acquires 9x9 pixel images
- The specimen is marked with a cross-like pattern



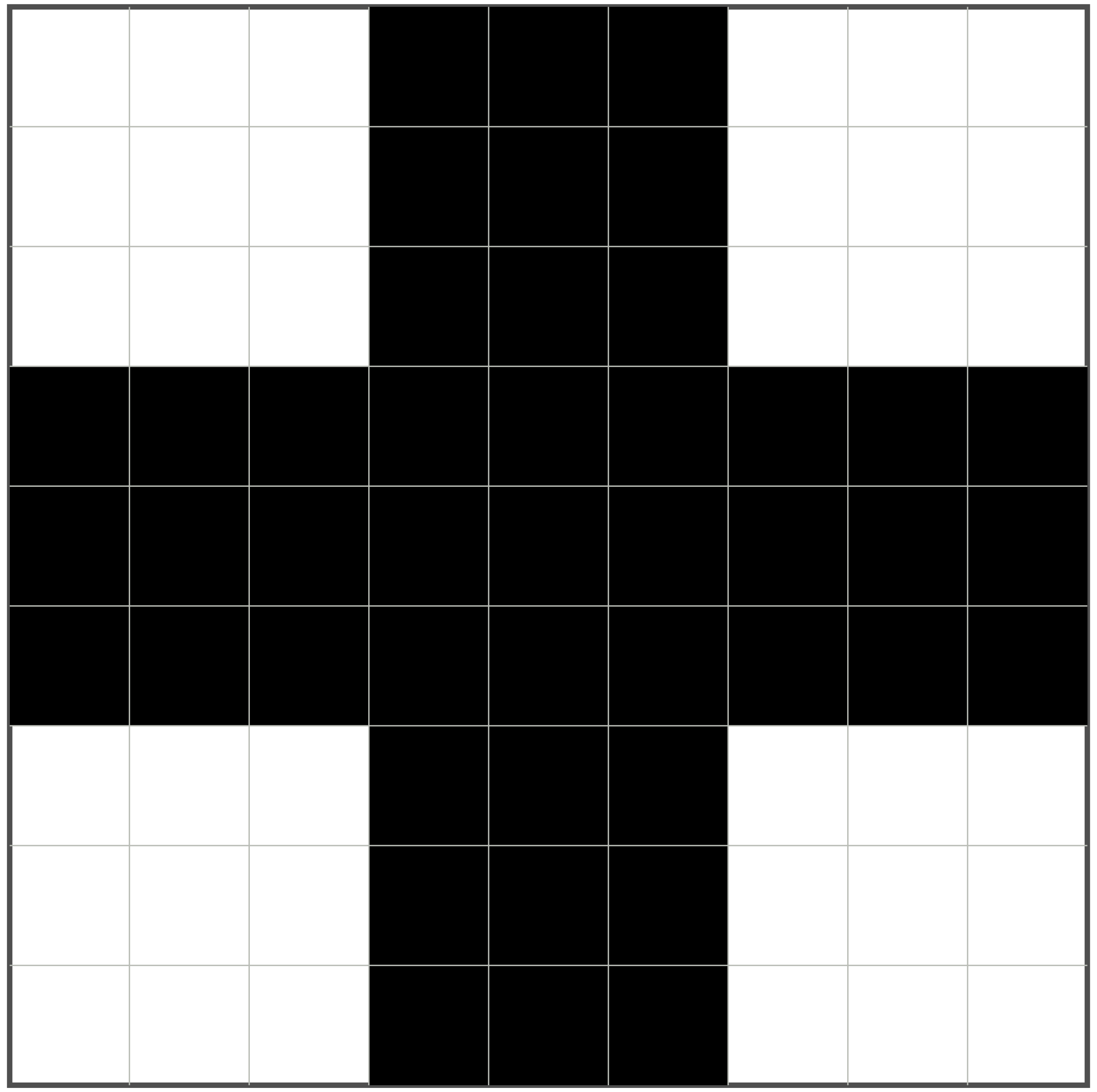
Example

- White pixels
  - gray level 255
- Black pixels
  - gray level 0
- An image is a matrix of natural integers

Image, in memory

255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255

Image, on screen



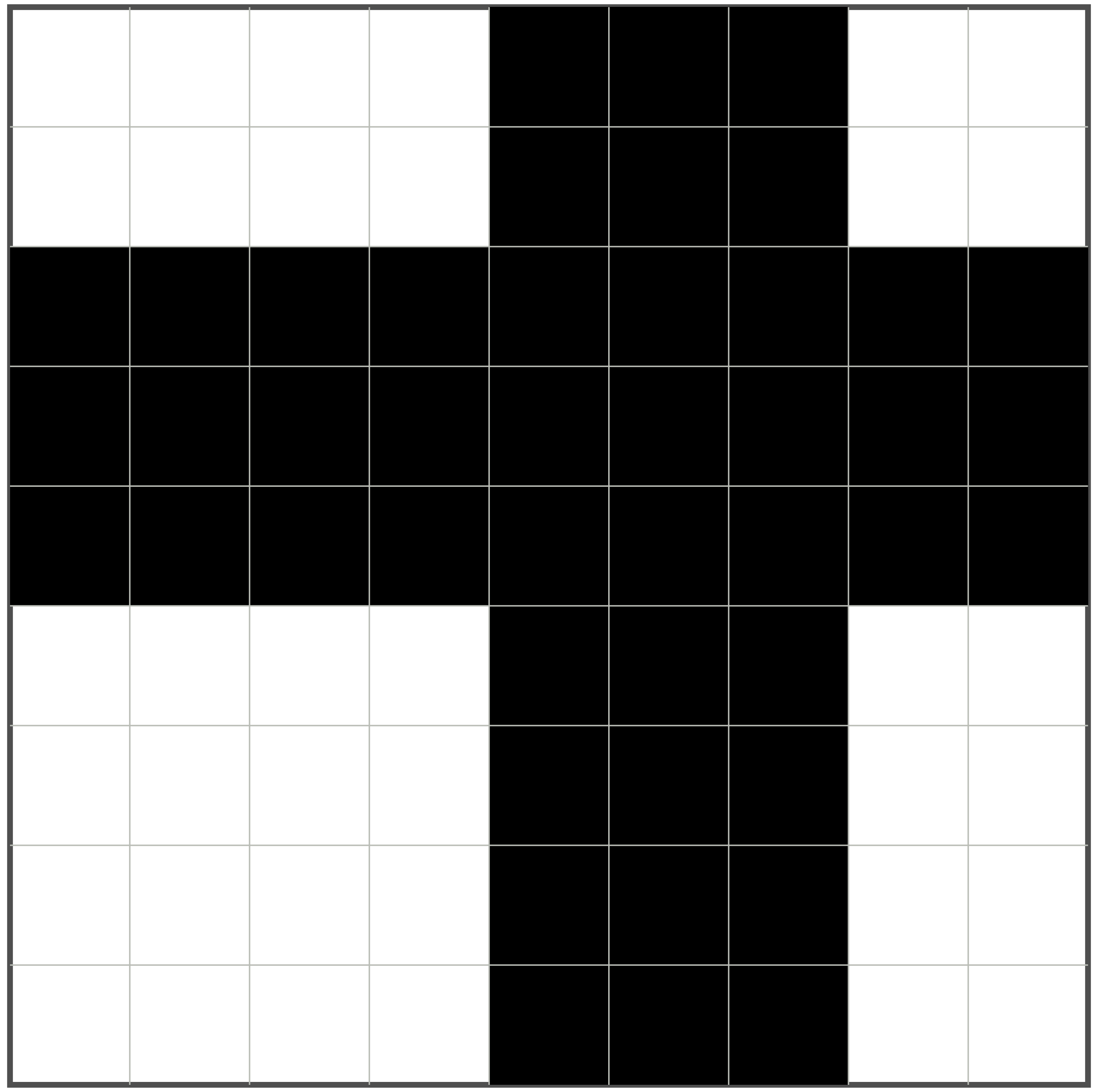
Example

- The specimen moves such that its image moves 1 pixel up and right.

Image after motion, in memory

255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255

Image after motion, on screen



correlated SOLUTIONS

Example

- We define a 5x5 subset in the reference image (before motion).
- **Problem:** find where the subset moved (matching)

Image before motion

255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255
255	255	255	0	0	0	255	255	255

Subset

?

Image after motion

255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
?	0	0	0	0	0	0	0	0
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255
255	255	255	255	0	0	0	255	255

Solution

- Check possible matches at several locations and use a similarity score (correlation function) to grade them.
- Classic correlation function: sum of squared differences (SSD) of the pixel value (smaller values = better similarity)

$$C(\overline{x,y},\underline{u,v}) = \sum_{i,j=-n/2}^{n/2}\left(I(\overline{x+i,y+j}) - I^*(\overline{x+u+i,y+v+j})\right)^2$$

Pixel coord., reference image

Pixel value at (*x*+*i*; *y*+*j*)

Pixel value at (*x*+*u*+*i*; *y*+*v*+*j*)

Image before motion

Image after motion

n: subset size (9 in our example)

Displacement (disparity)

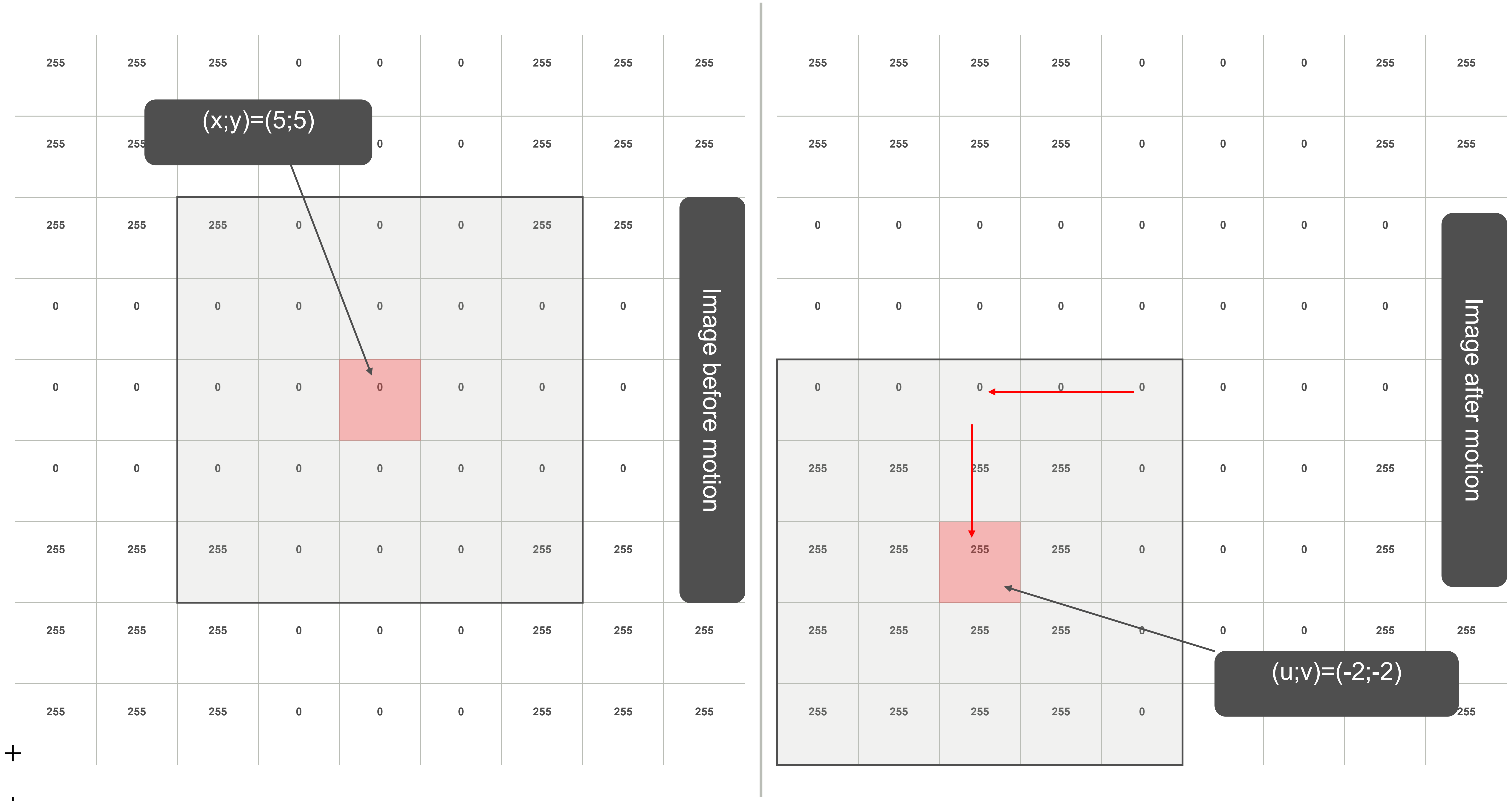
Correlation function

correlated SOLUTIONS

2D DIC Principle

Example

subset at **(x;y)=(5;5)**, displacement candidate **(u;v)=(-2;-2)**



$$C(5,5,-2,-2)=\sum_{i,j=-2}^{2}(I(5+i,6+j)-I^{*}(5-2+i,5-2+j))^{2}$$

$$(255-0)^2+(0-0)^2+(0-0)^2+(0-0)^2+(255-0)^2+$$
$$(0-255)^2+(0-255)^2+(0-255)^2+(0-255)^2+(0-0)^2+$$
$$(0-255)^2+(0-255)^2+(0-255)^2+(0-255)^2+(0-0)^2+$$
$$(0-255)^2+(0-255)^2+(0-255)^2+(0-255)^2+(0-0)^2+$$
$$(255-255)^2+(0-255)^2+(0-255)^2+(0-255)^2+(255-0)^2=1{,}170{,}450$$

Example

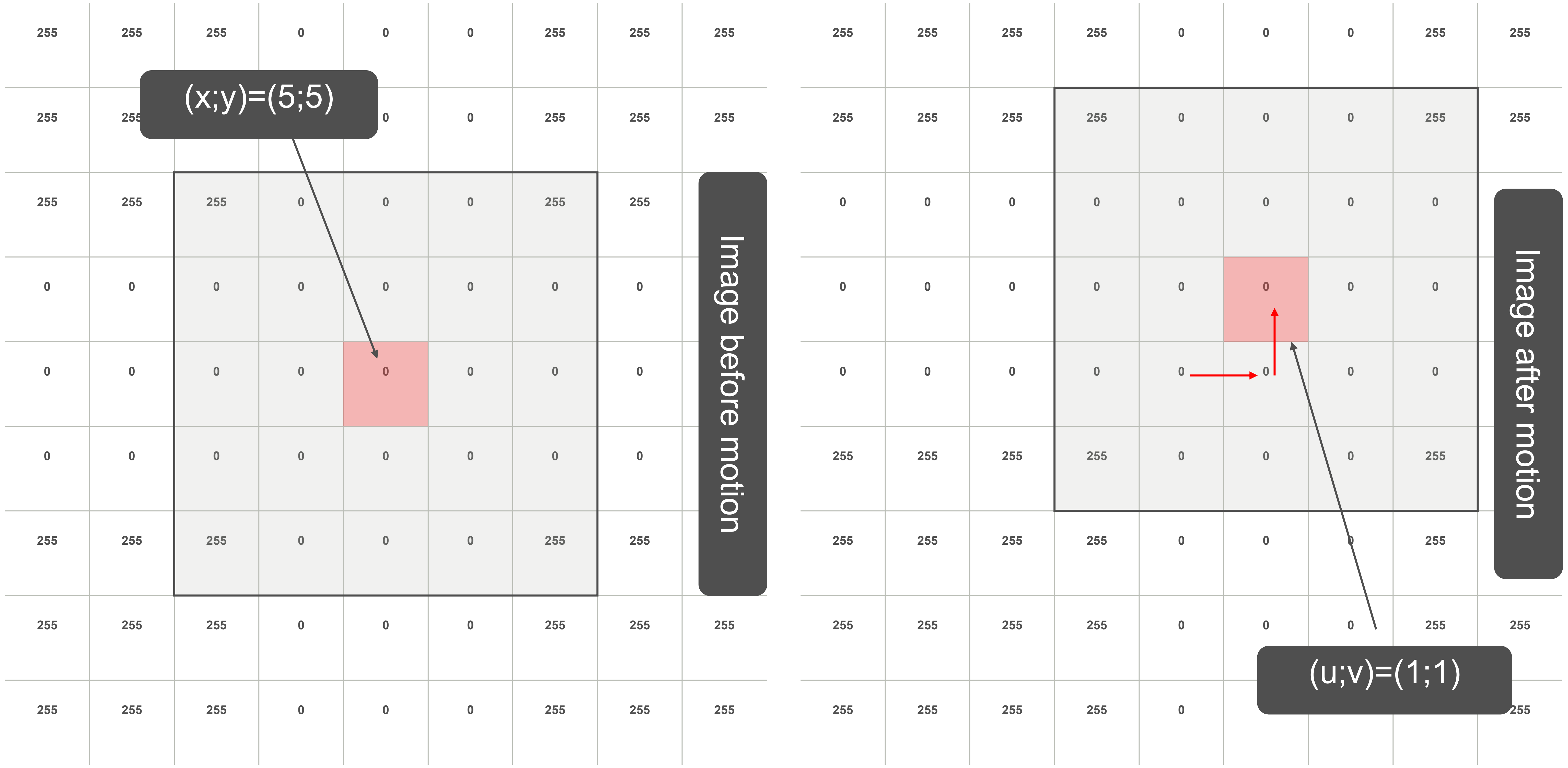
subset at **(x;y)=(5;5)**, displacement candidate **(u;v)=(1;1)**

$$C(5{,}5{,}1{,}1) = 0$$

Better correlation score than candidate

(u;v)=(-2;-2) [1,170,450]

Indeed, it is the smallest score achievable (perfect match).



Example

In real world applications, **images are corrupted** by some noise

The SSD function will likely never be 0 for a perfect match.

Image before motion

255	254	254	2	0	1	254	251	253
253	255	253	1	4	3	255	254	252
251	253	252	0	2	2	250	251	251
2	3	0	1	1	2	3	0	1
1	3	3	0	2	1	0	3	0
0	0	2	0	3	0	2	0	0
252	254	250	0	1	0	251	252	254
254	255	253	0	2	0	253	255	252
251	252	250	2	0	0	250	254	255

Image after motion

254	253	252	253	3	0	2	249	253
250	255	251	252	1	2	0	253	254
0	1	3	3	2	0	1	2	0
1	0	3	0	2	1	1	0	3
1	3	2	0	1	1	2	2	0
253	254	250	252	0	2	1	255	254
252	254	253	251	3	2	0	250	253
255	249	253	250	0	1	1	253	251
251	253	254	251	2	3	3	254	252

Example

The **specimen moves** such that **its image moves 0.5 pixel to the right**

Need to interpolate the image at non-integer locations

254	254	255	128	0	1	126	255	253
253	252	253	127	4	3	130	251	255
254	255	251	126	2	2	129	252	253
2	3	0	1	1	2	3	0	1
1	3	3	0	2	1	0	3	0
0	0	2	0	3	0	2	0	0
254	251	253	127	1	0	128	251	252
255	252	254	126	2	0	127	254	255
254	251	250	128	0	0	127	249	253

Perfect match

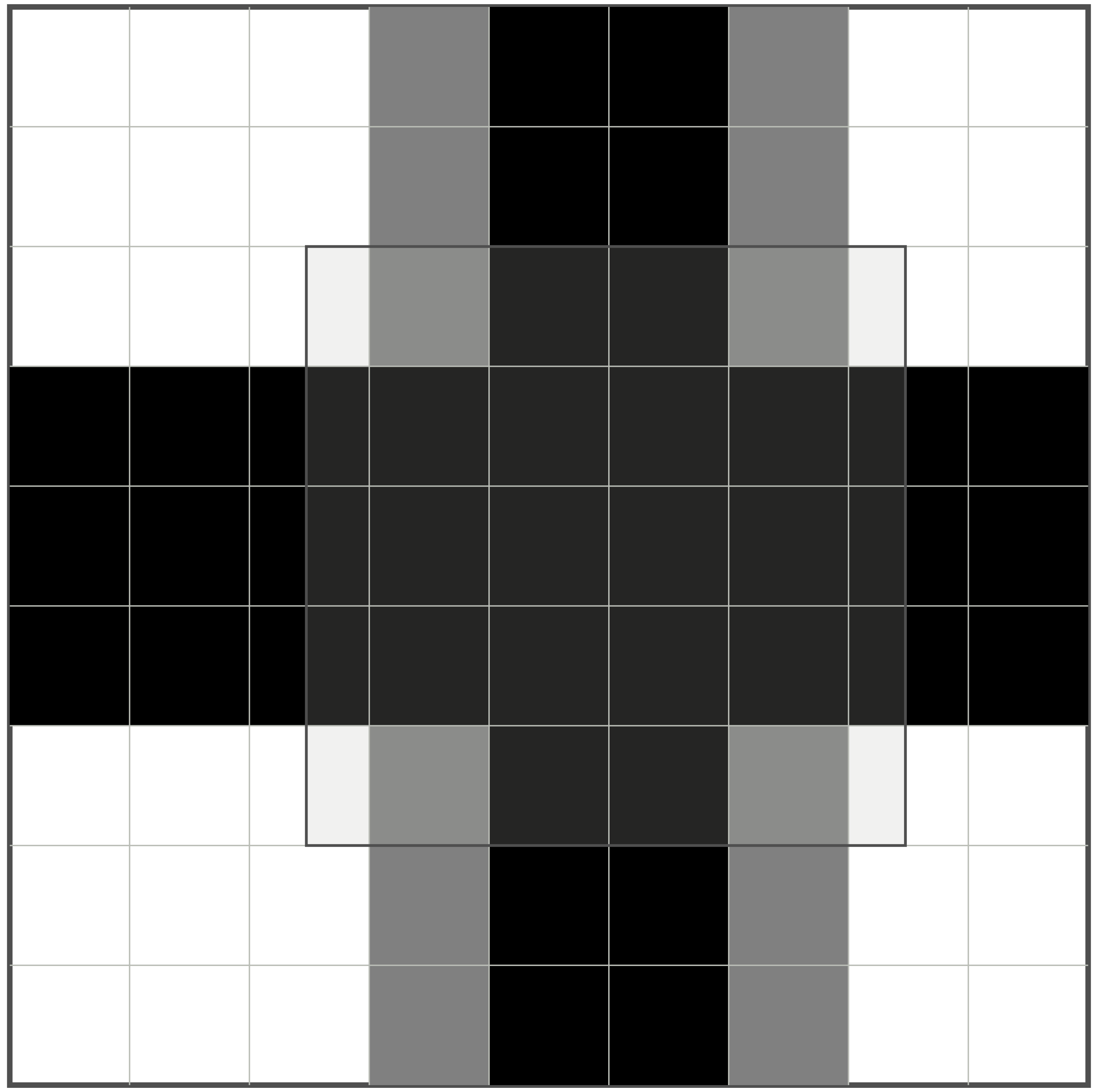
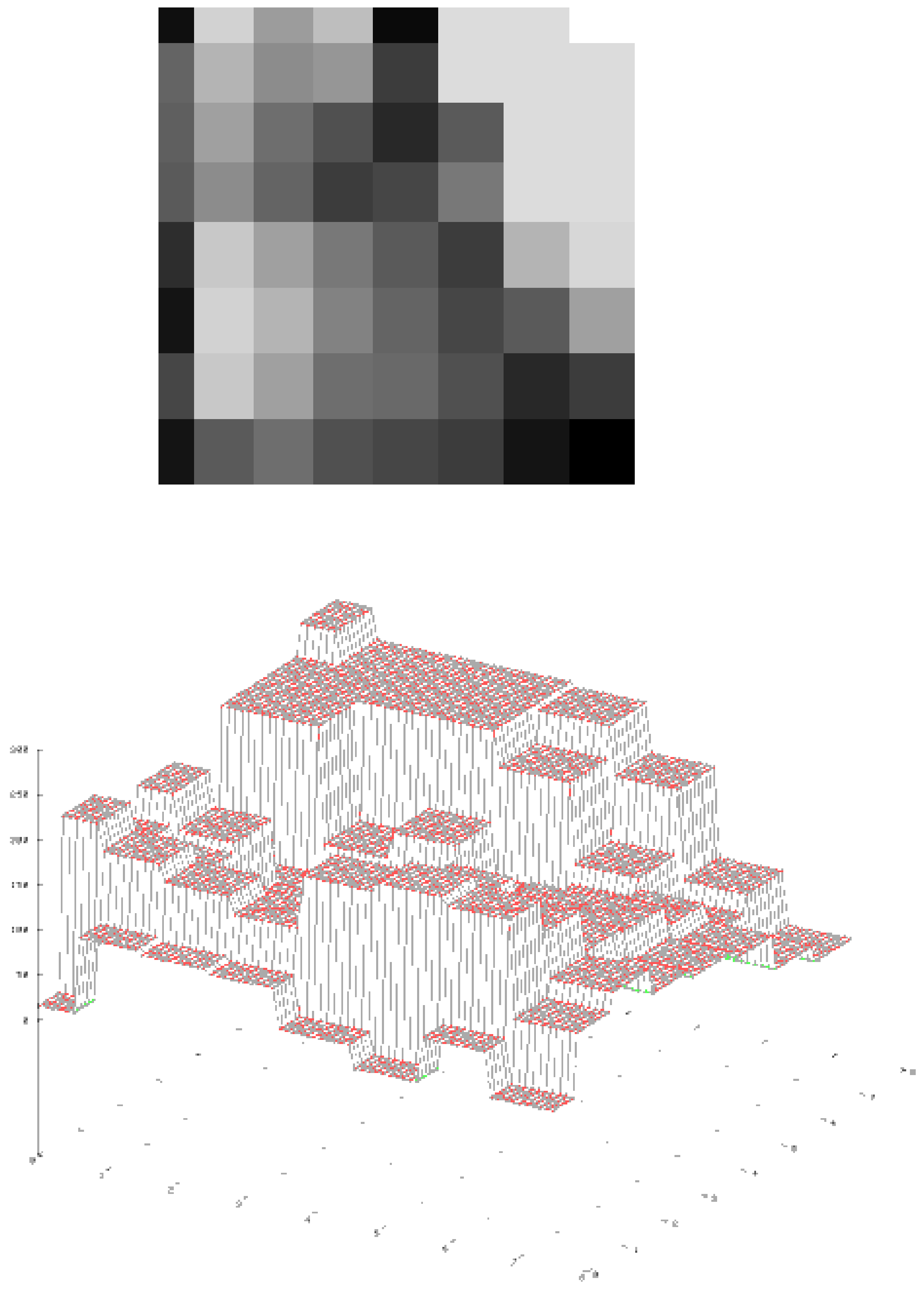


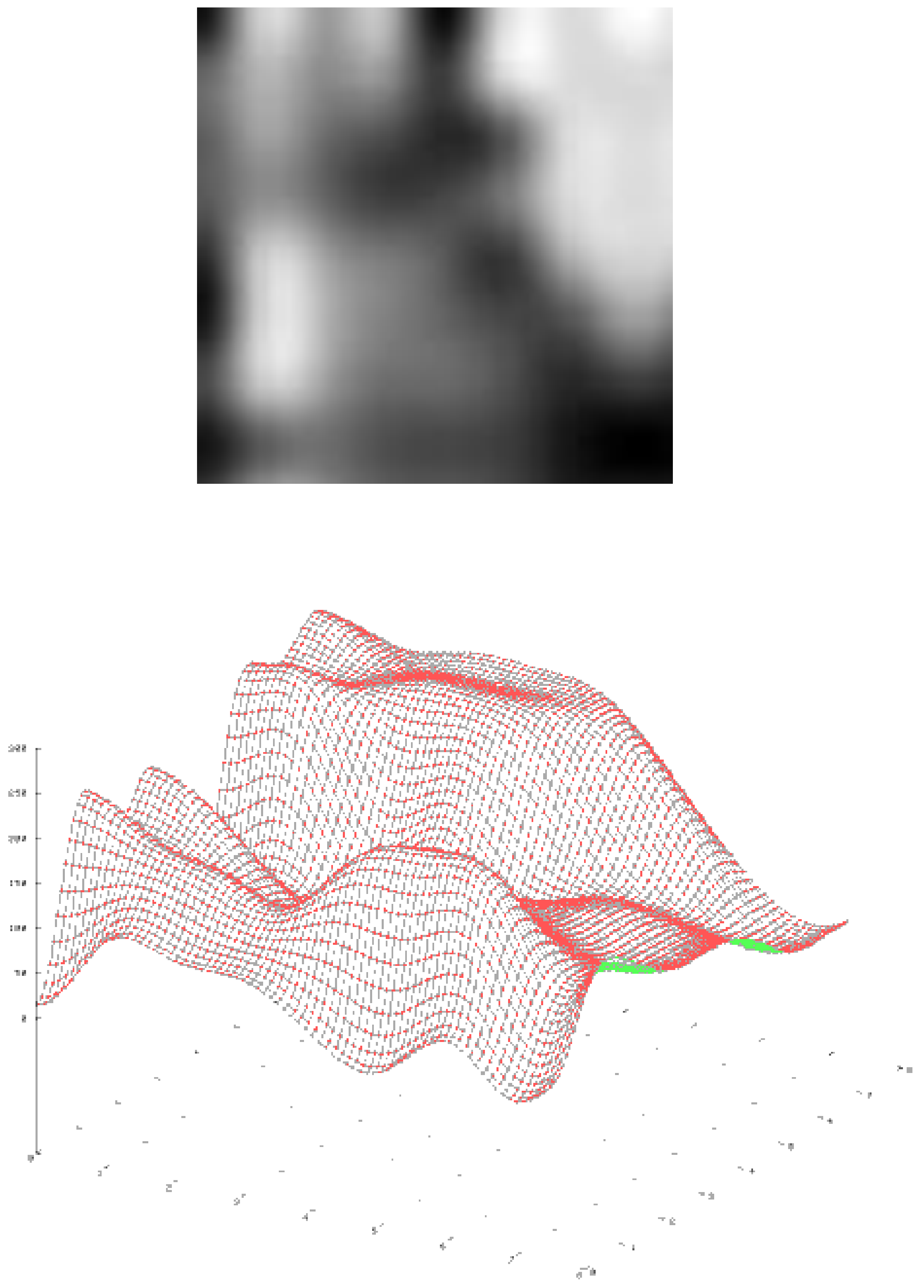
Image Interpolation

Optimization algorithms require the criterion to be continuous

Images are discrete so we need to reconstruct the continuous information by means of interpolation



Raw image

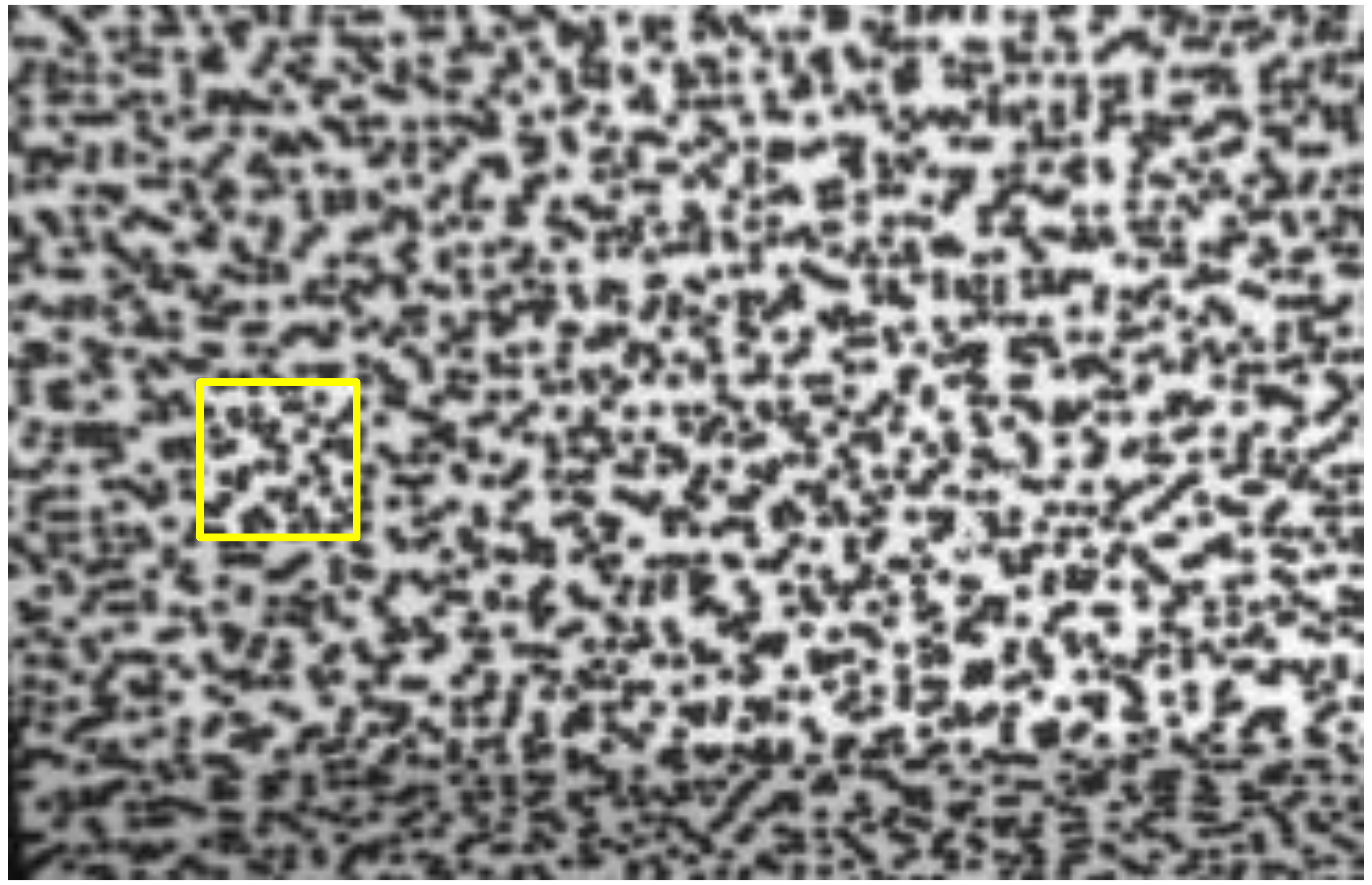


Optimized 8-tap filter

Finding the Match

Matching accomplished as optimization problem

Consider the 1-D case - horizontal displacement only



Photometric Mapping

- During image acquisition
  - Lighting conditions may change
  - Sensor integration time adjusted
  - Pattern may become lighter/darker when expanded/compressed

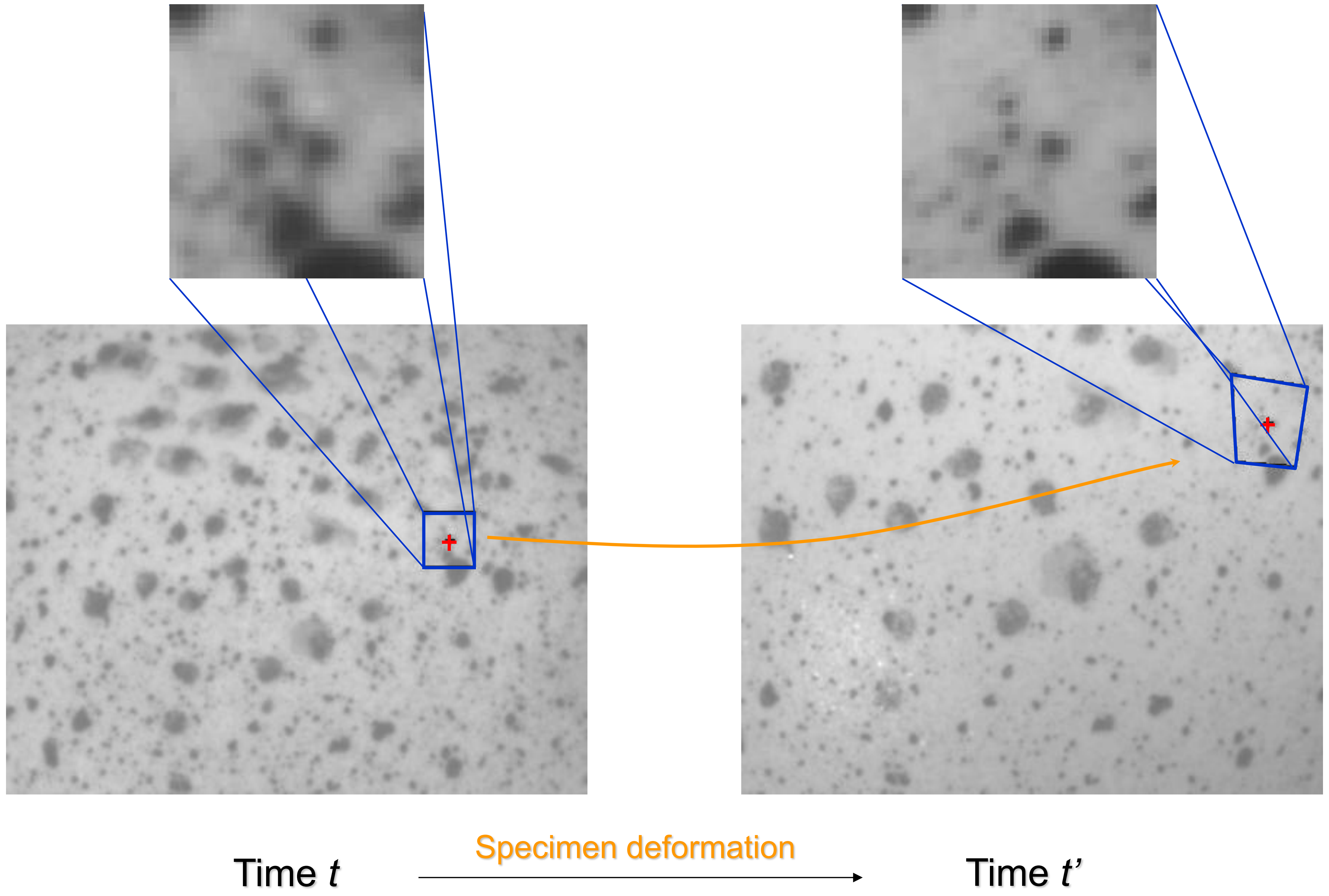
Photometric Mapping

- The photometric mapping is not guaranteed to be an identity, hence the DIC algorithm may have false matches
- Solution: model the photometric transformation and use it to design a robust correlation function

Displacement Mapping

General circumstances:

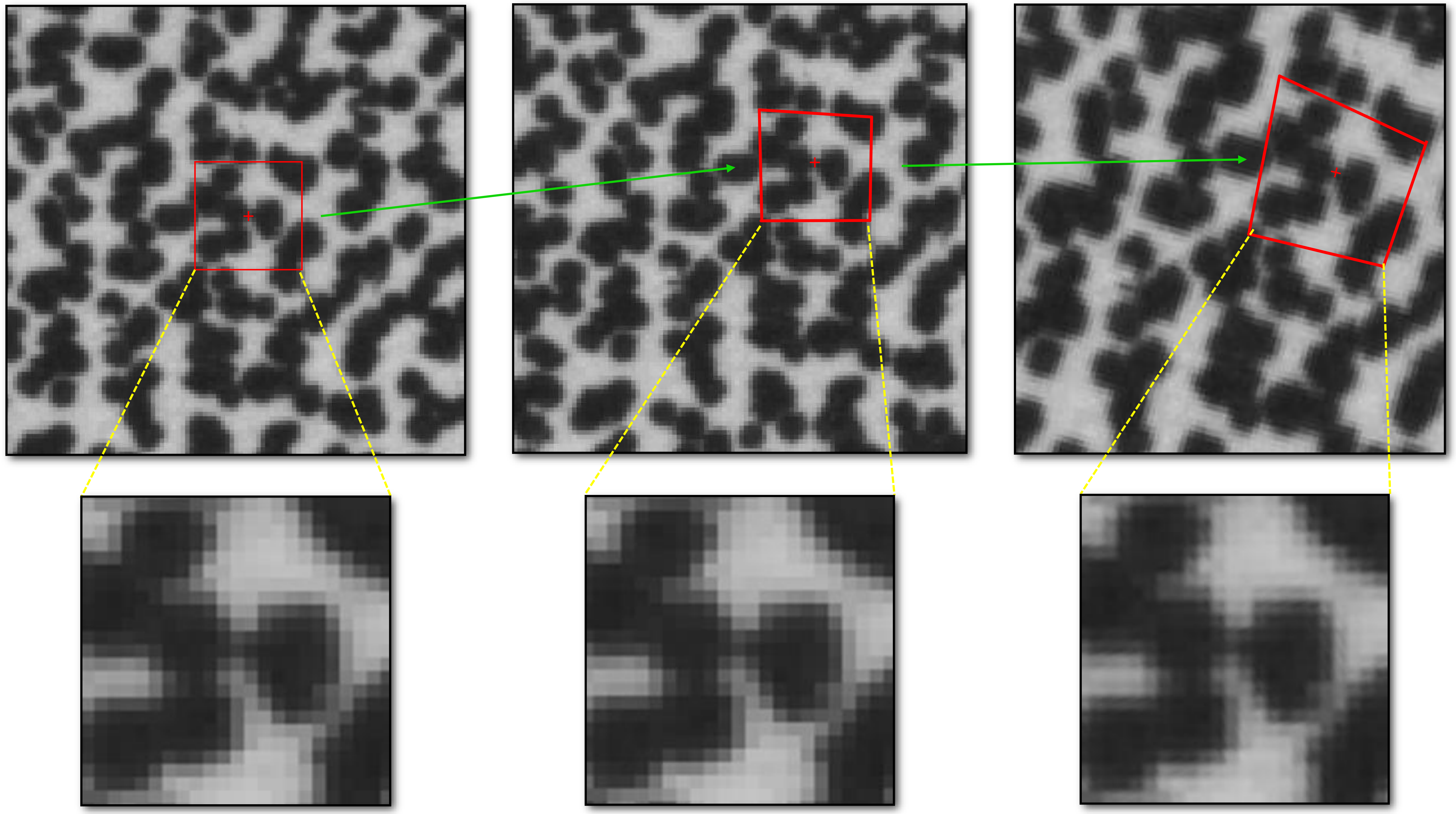
The subset in the deformed image has changed shape, e.g. a square initial subset is likely to be non-square.



Displacement Mapping

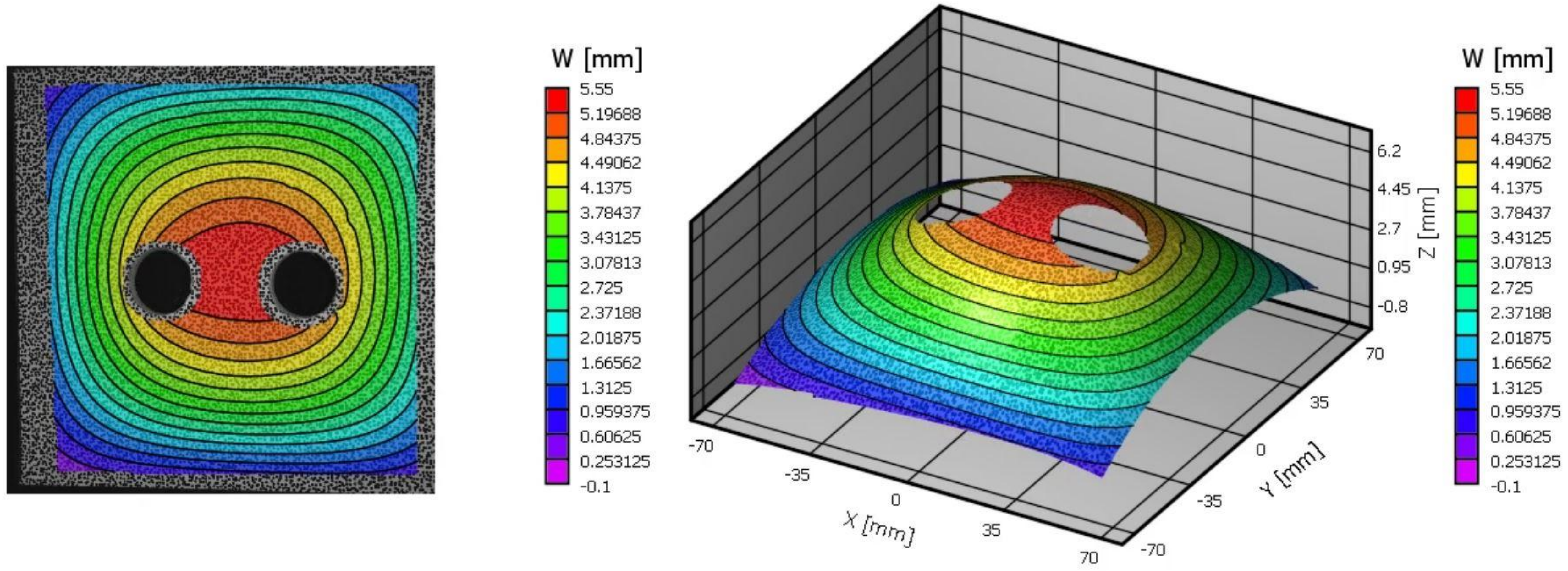
Solution:

Model this displacement transformation (called **subset shape function**) and use it to define the deformed subset.



correlated SOLUTIONS

Out-of-Plane Displacement

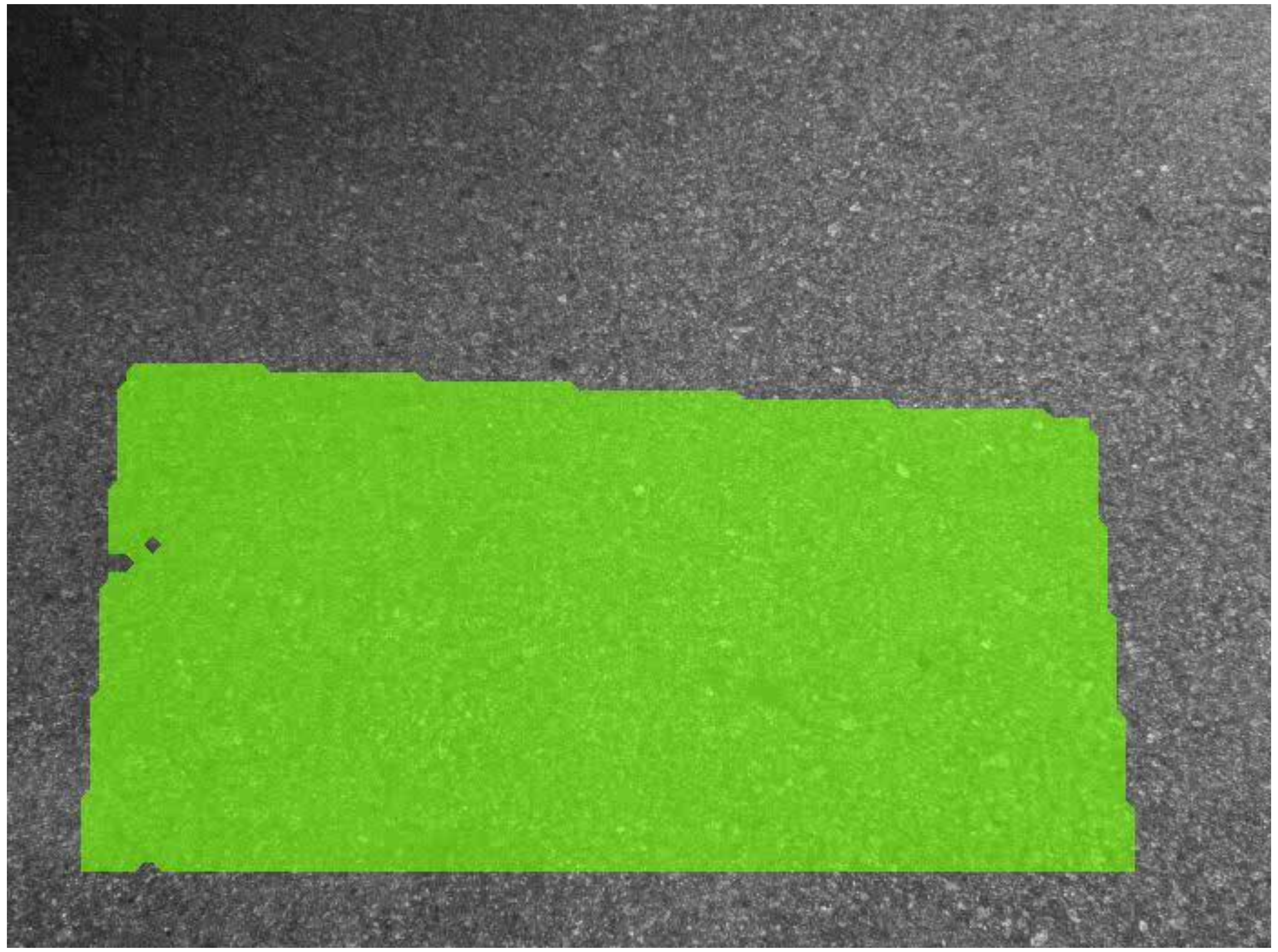


3-D Digital Image Correlation

Fundamentals

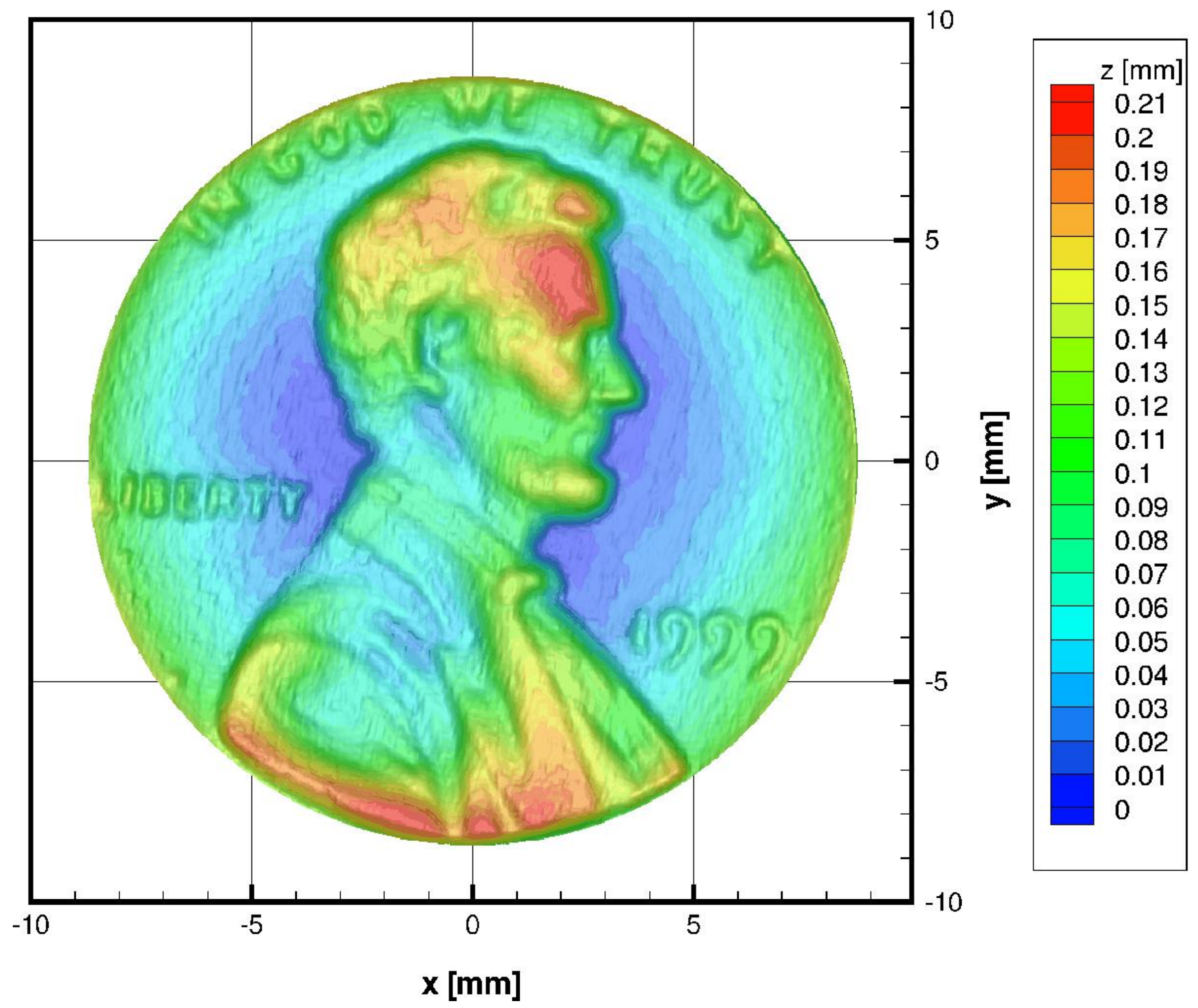
Purpose

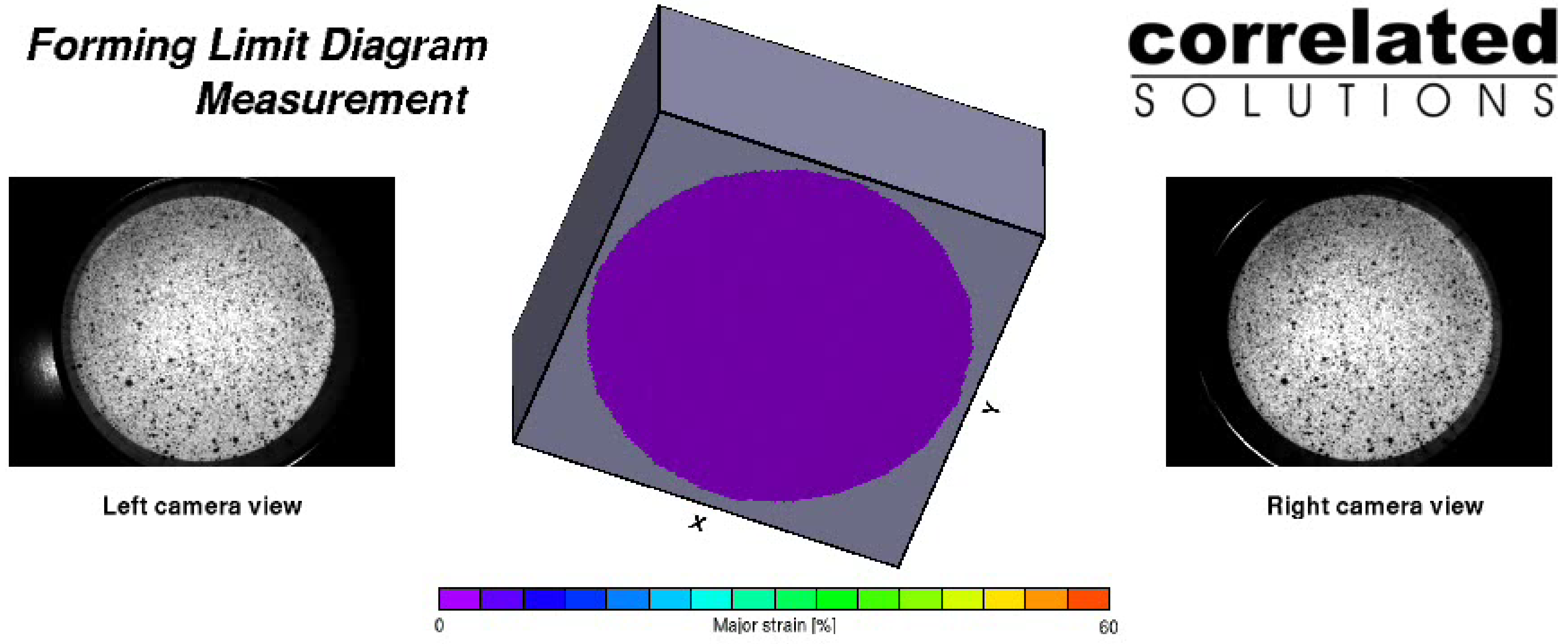
- 3-D shape
- Strain map
- Full-field measurement
- Non-intrusive
- **Any specimen shape**
- **Any motion**



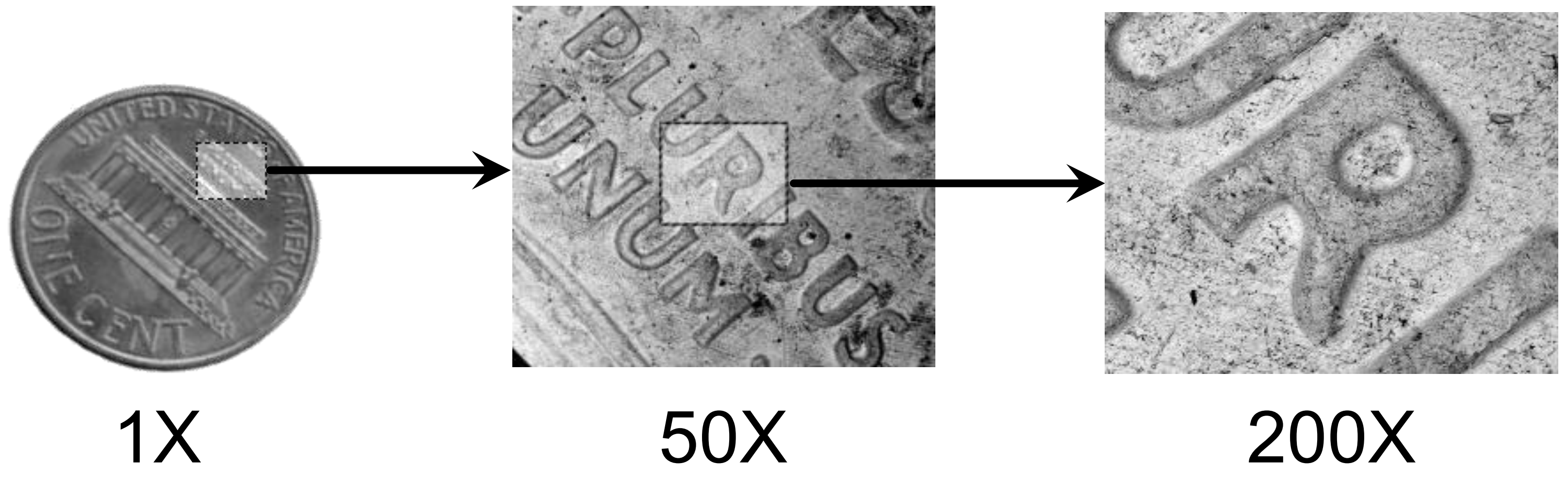
Purpose

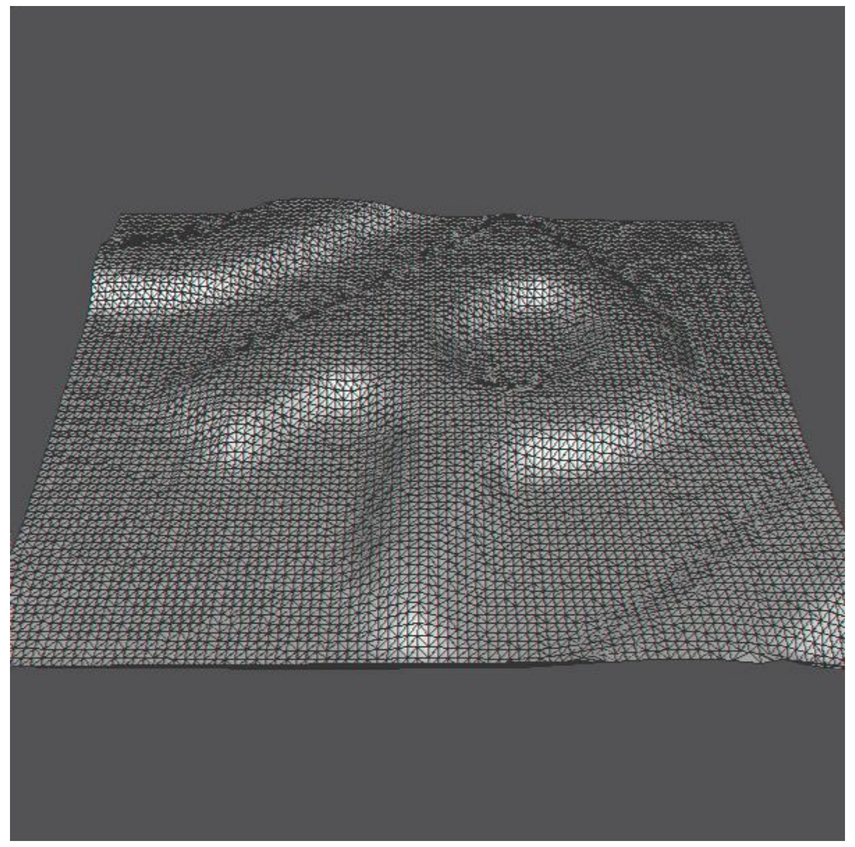
- 3-D shape
- Strain map
- Full-field measurement
- Non-intrusive
- **Any specimen shape**
- **Any motion**





Large range of size scales (10^{-9} to 10^{2} m)

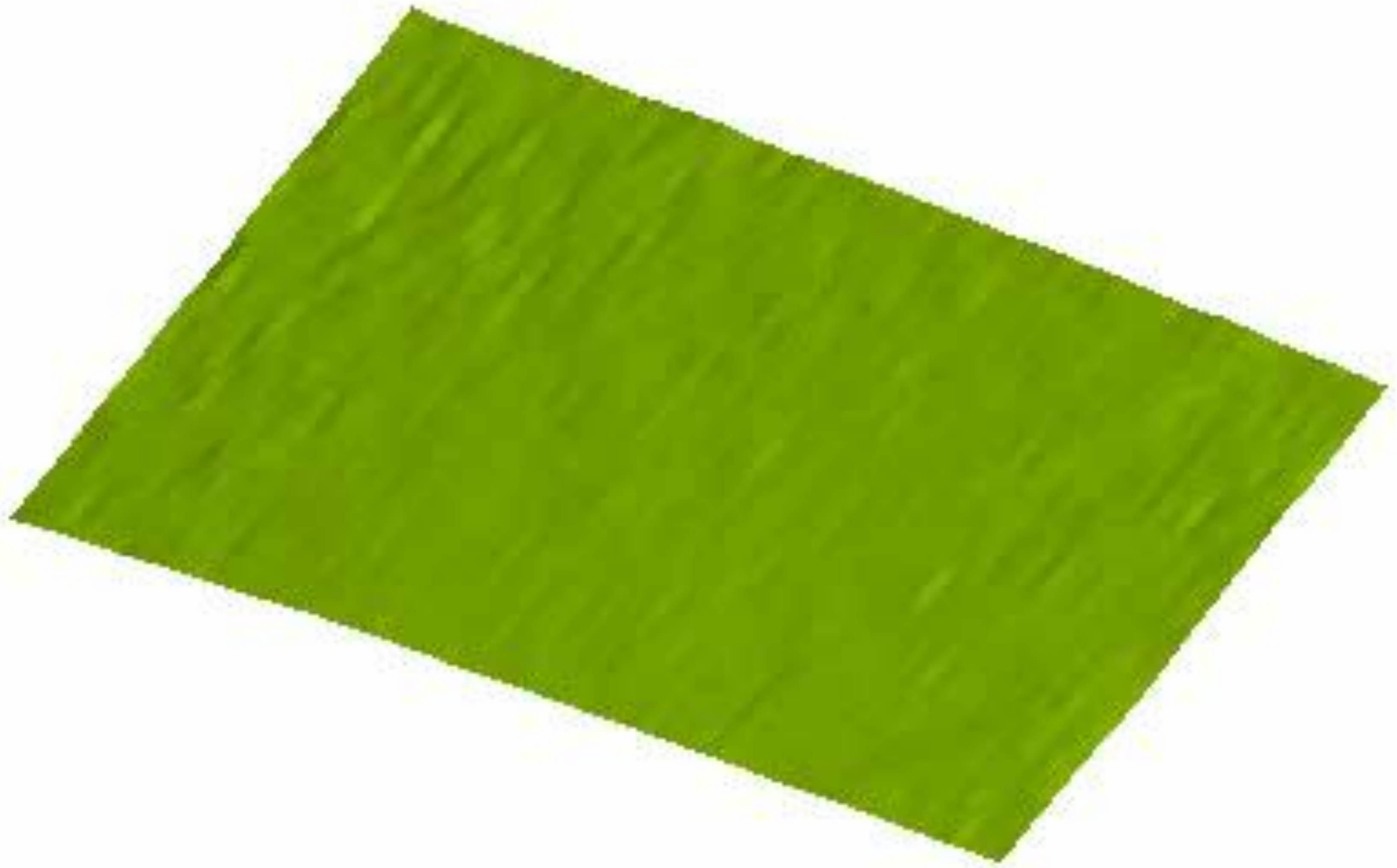




3D shape using Scanning Electron Microscope

28’ diameter test specimen

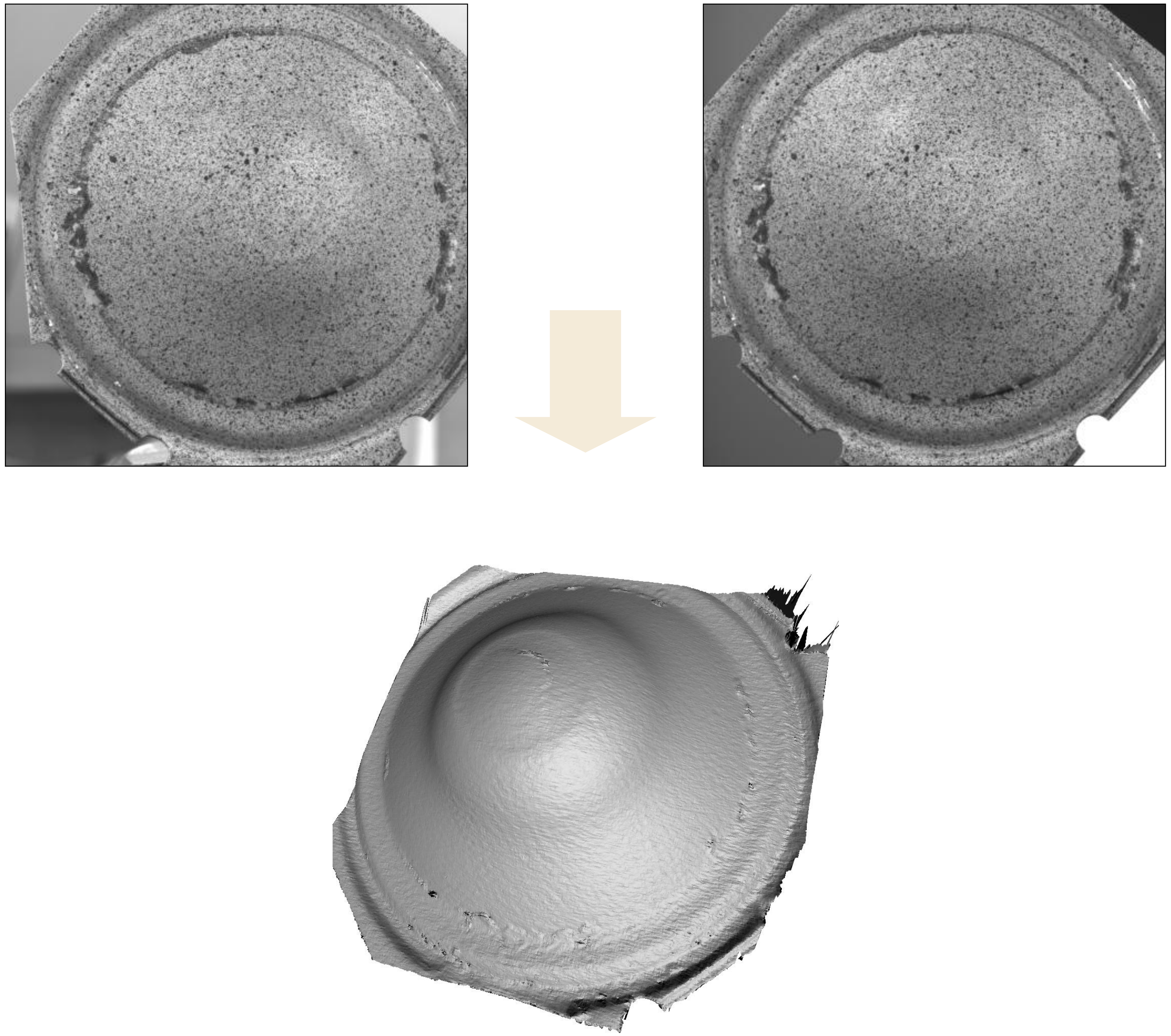
Large range of time scales (static to 5,000,000 fps)



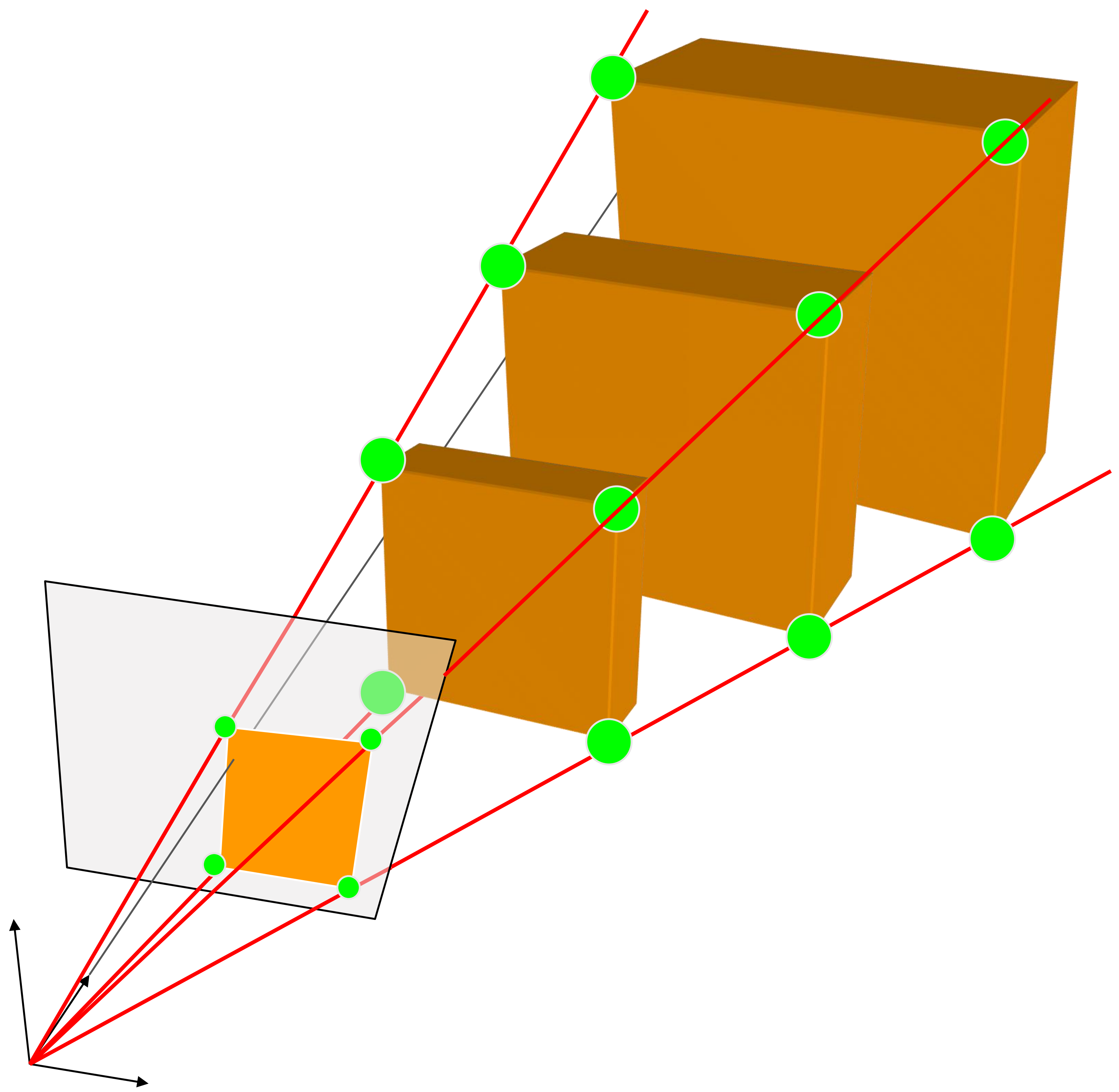
correlated SOLUTIONS

3D DIC Principle

Much like human vision, two imaging sensors provide enough information to perceive the environment in three-dimensions.

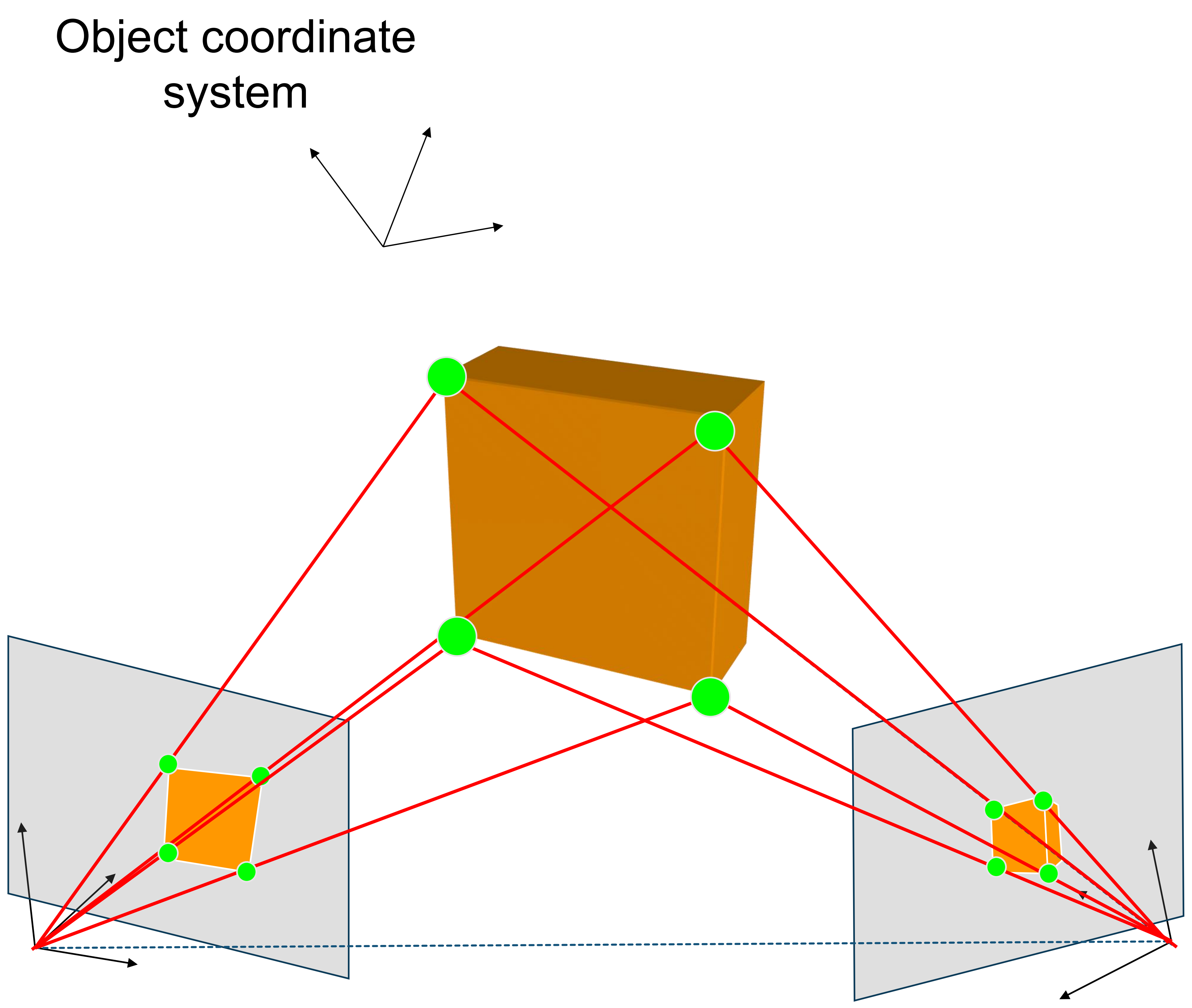


Monocular (cyclopean) vision cannot resolve for the scale of objects.



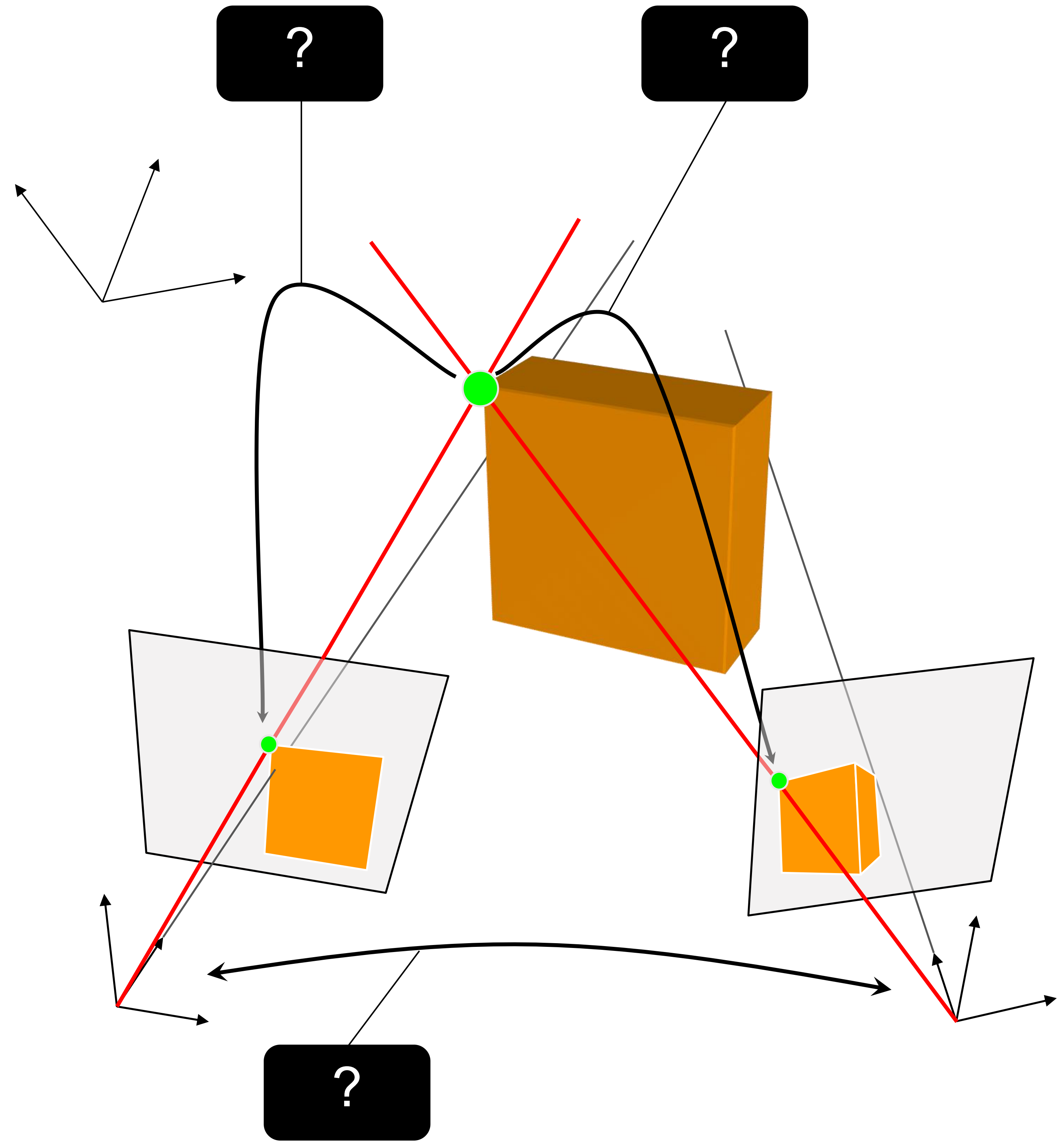
Recovering the three-dimensional structure of the environment using two imaging sensors is called **stereo-triangulation.**

Stereo-triangulation requires computing the intersection of two optical rays.



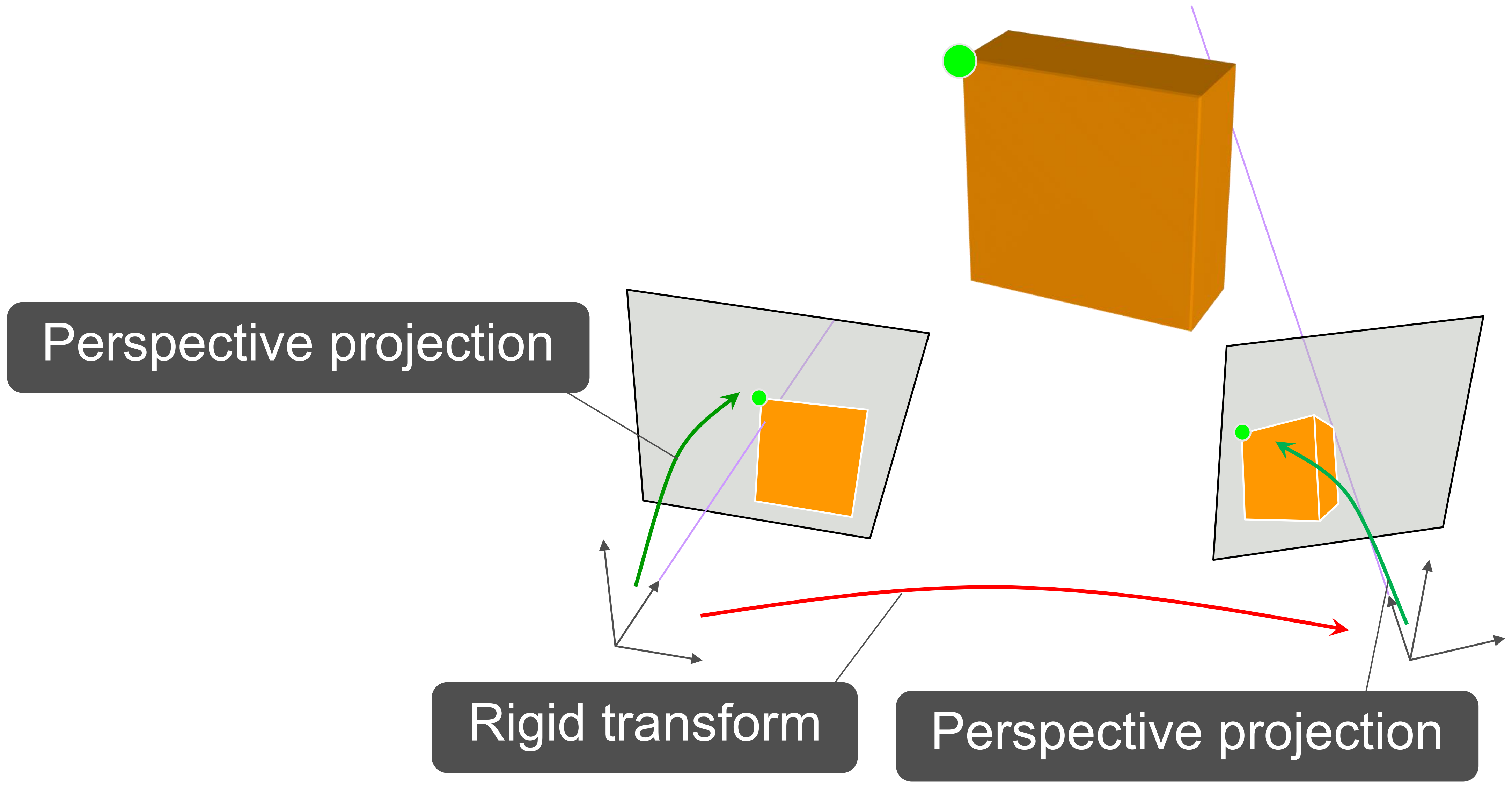
This is only feasible if these rays are formulated in a common coordinate system.

We need to **model** and **calibrate** the stereo-rig.



Camera Model

- One **extrinsic** rigid transformation
- Two **intrinsic** perspective projections



Camera Model

Extrinsic

The relative orientation of the stereo cameras has to be known for triangulation

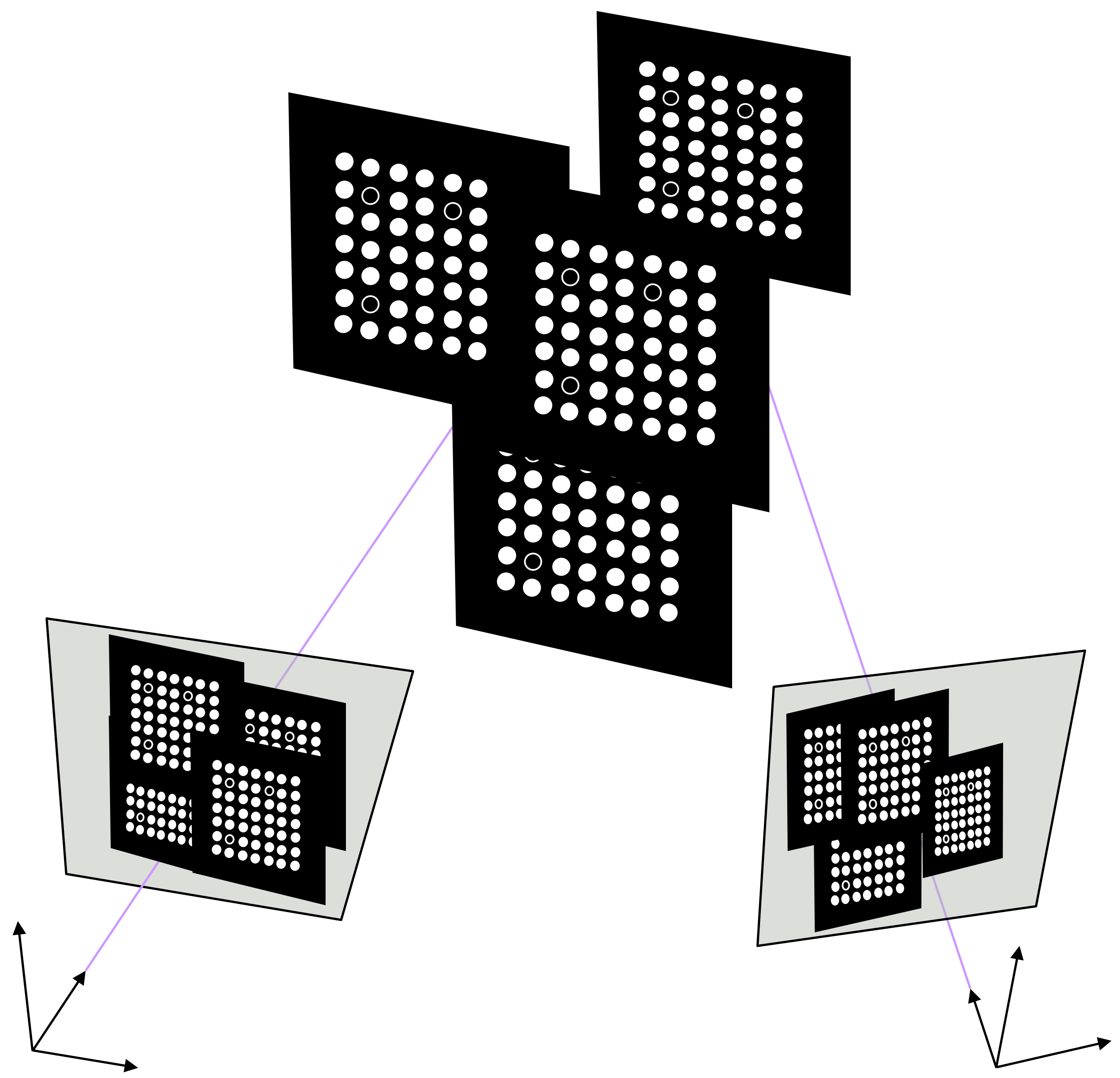
Intrinsic

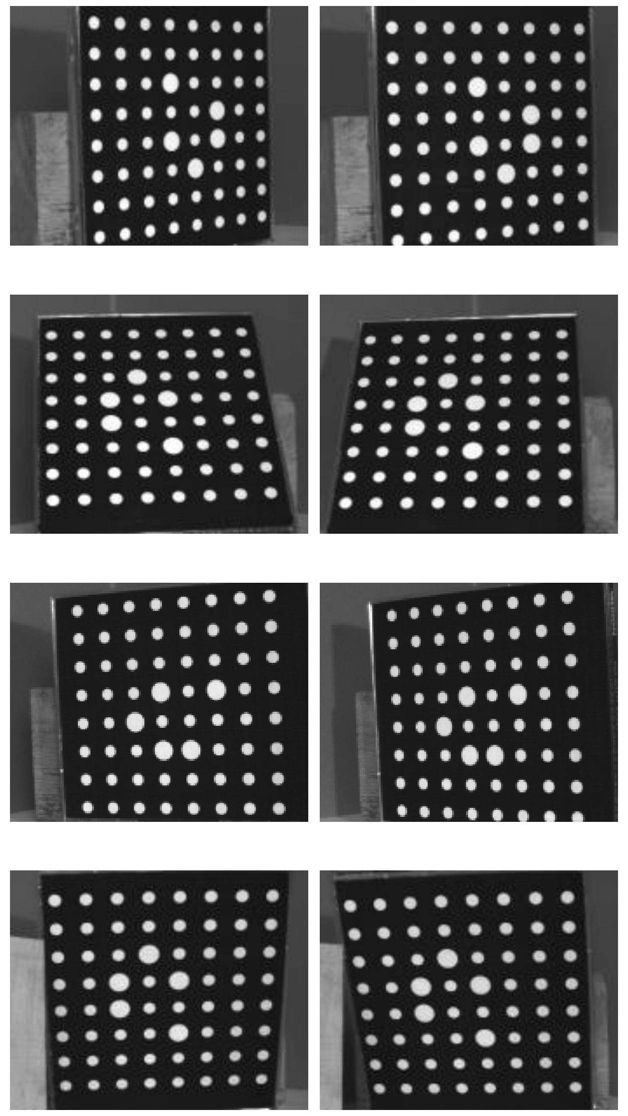
The internal camera parameters have to be calibrated (focal length, image center, distortions, skew)

Calibration Data Acquisition

Acquire pairs of images of a special target undergoing arbitrary motions.

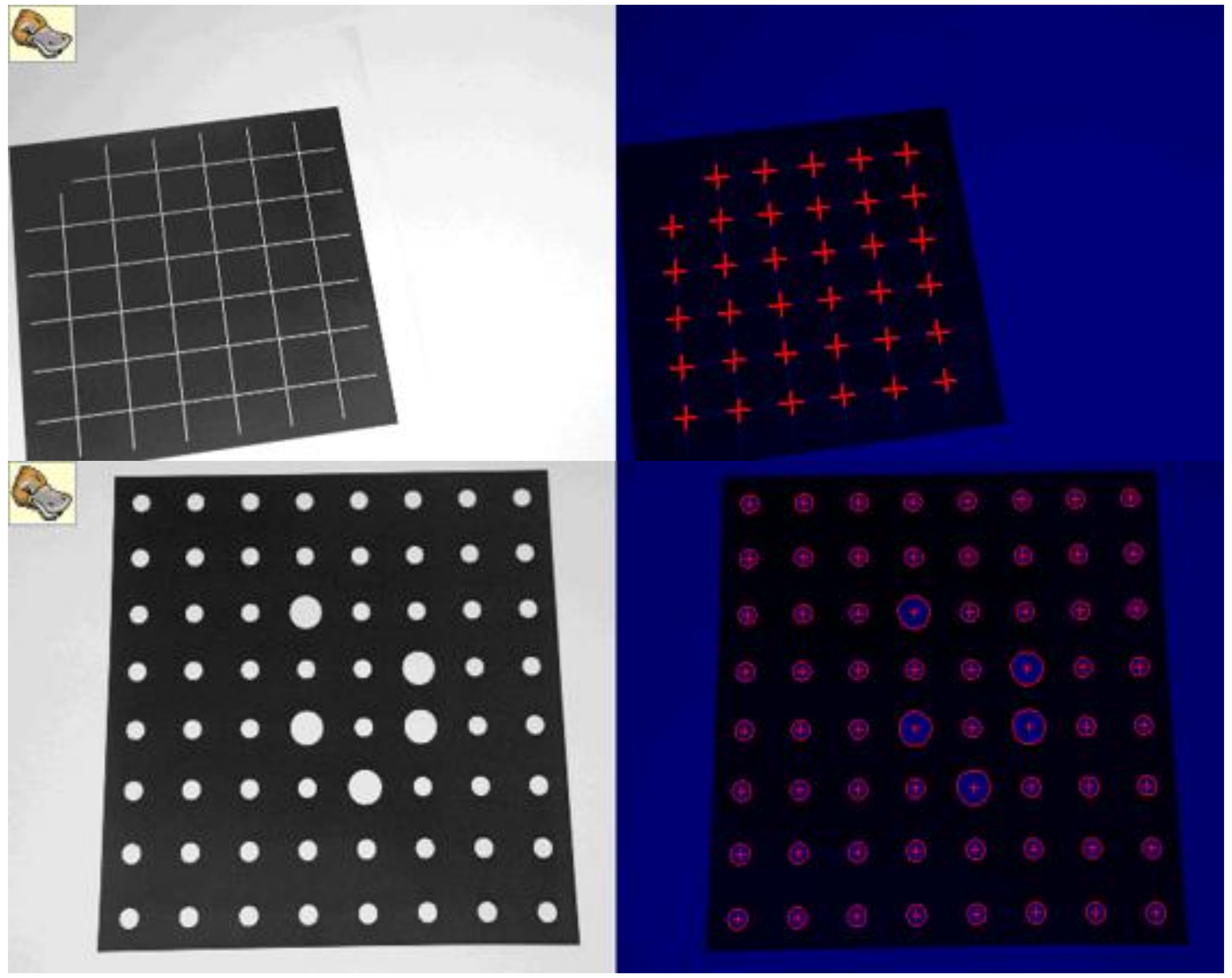
Calibration is shape measurement process (bundle-adjustment).





Parameter Estimation

Dedicated pattern recognition algorithm



Calibration target examples
Left: raw image, right: automatic pattern recognition

Identification of the **transfer function**

Parameter Estimation

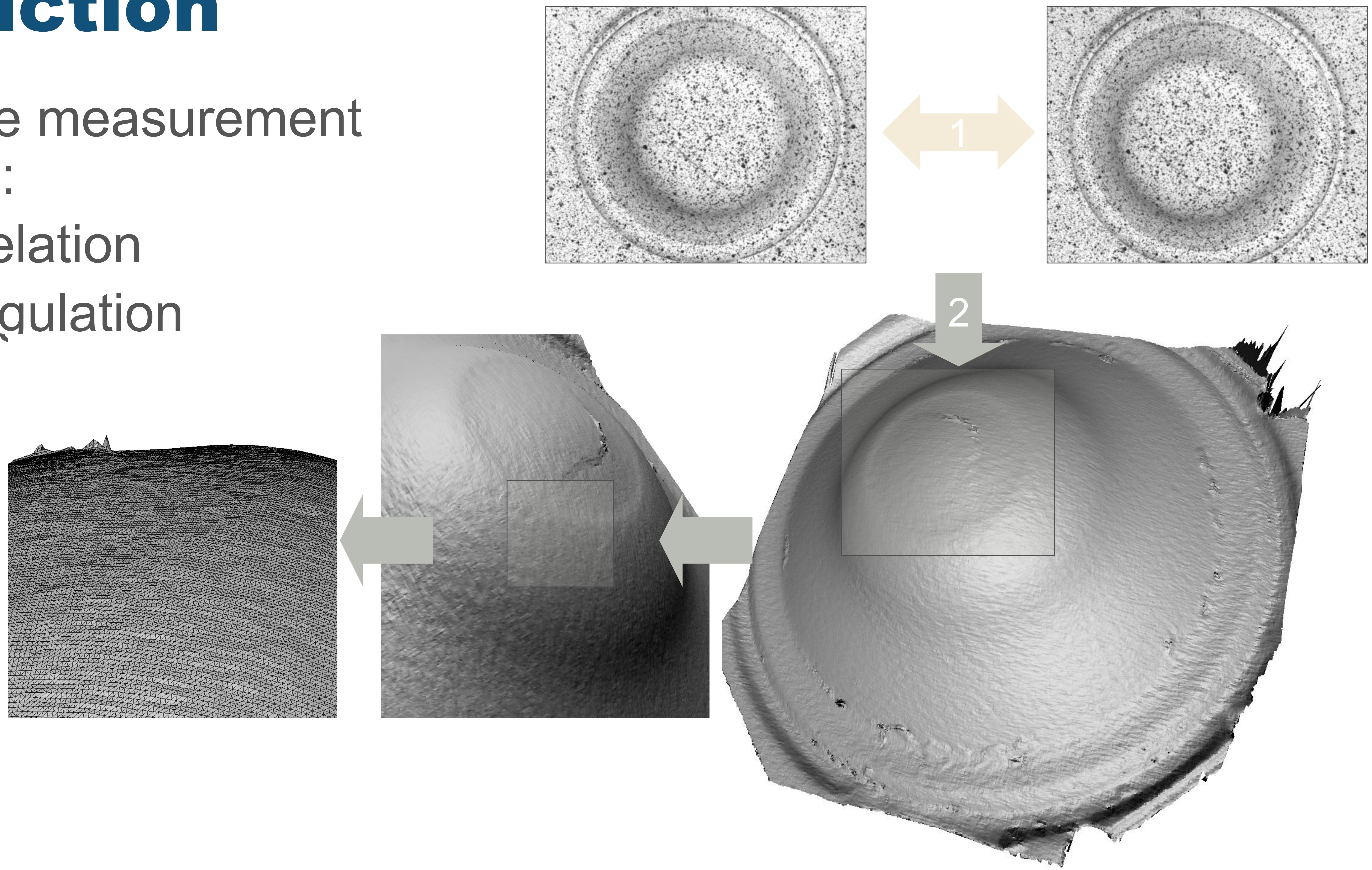
Bundle Adjustment

- No knowledge of calibration target required
- Shape of the target is measured during calibration.
  - Typically, a relatively flat target is used for initialization through a linear method.
- Generally regarded as **the optimal** method to calibrate cameras.
- Can provide confidence margins on all parameters estimated.

3D Reconstruction

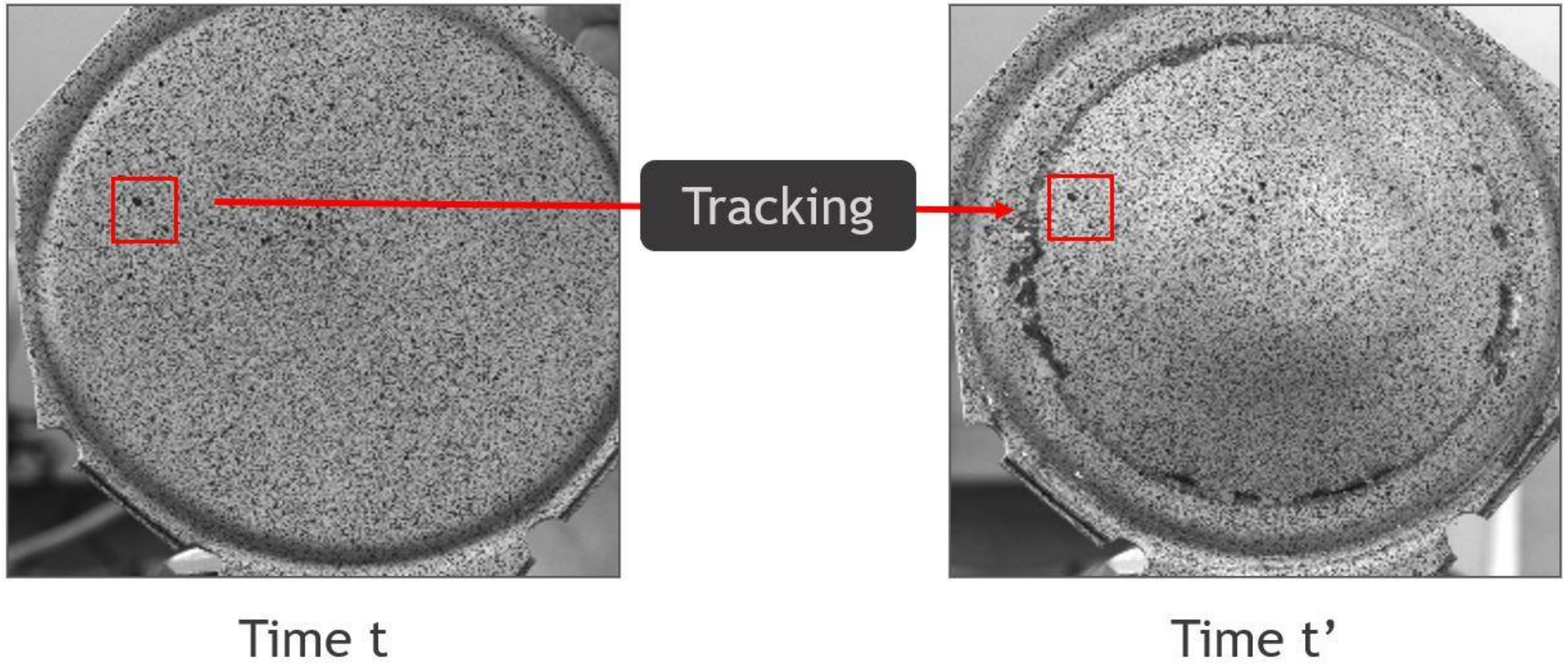
Two steps to 3D shape measurement given a pair of images:

1. Stereo-correlation
2. Stereo-triangulation



3D Tracking

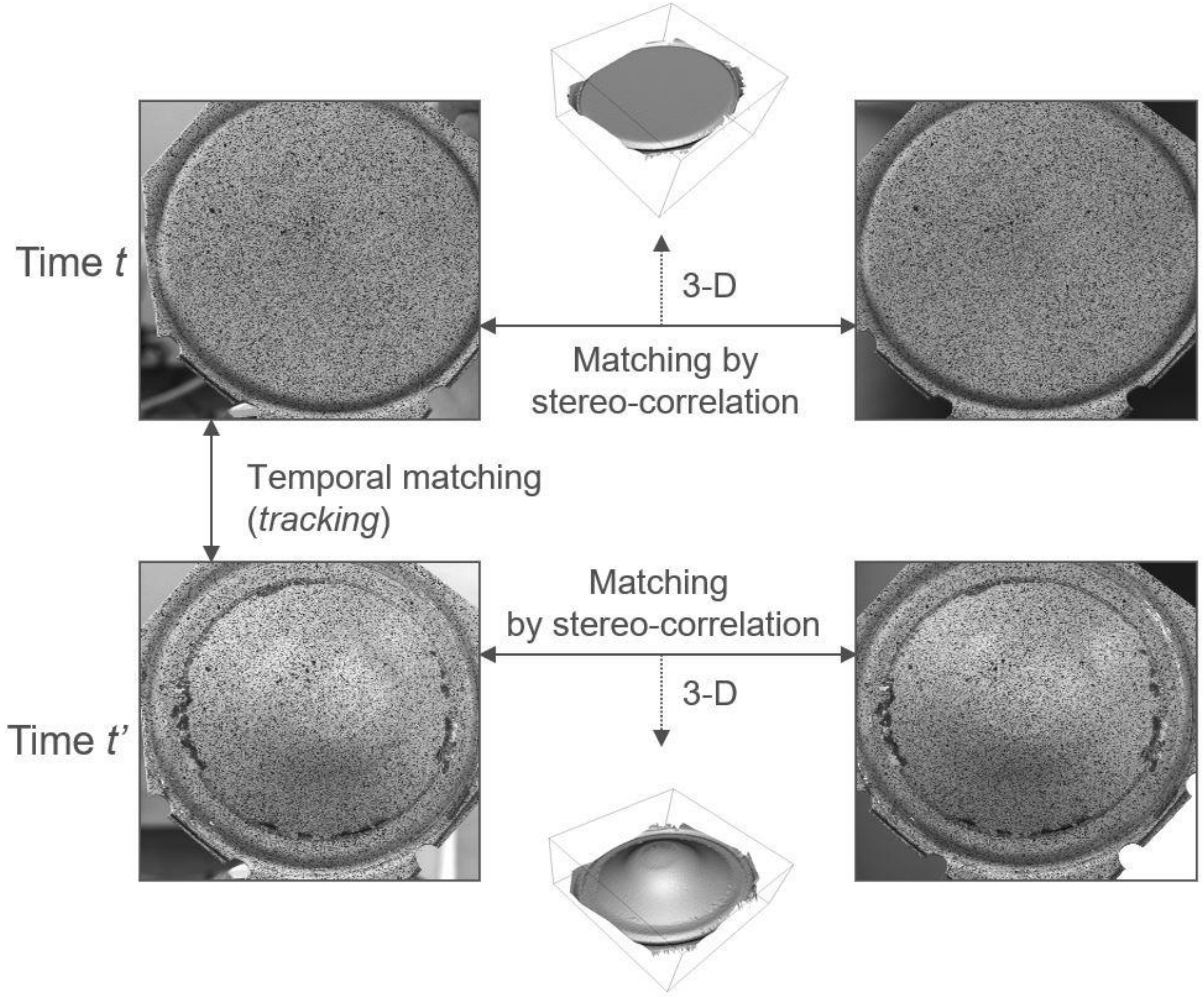
- Relate 3D shape through time
- Algorithms similar to 2D DIC



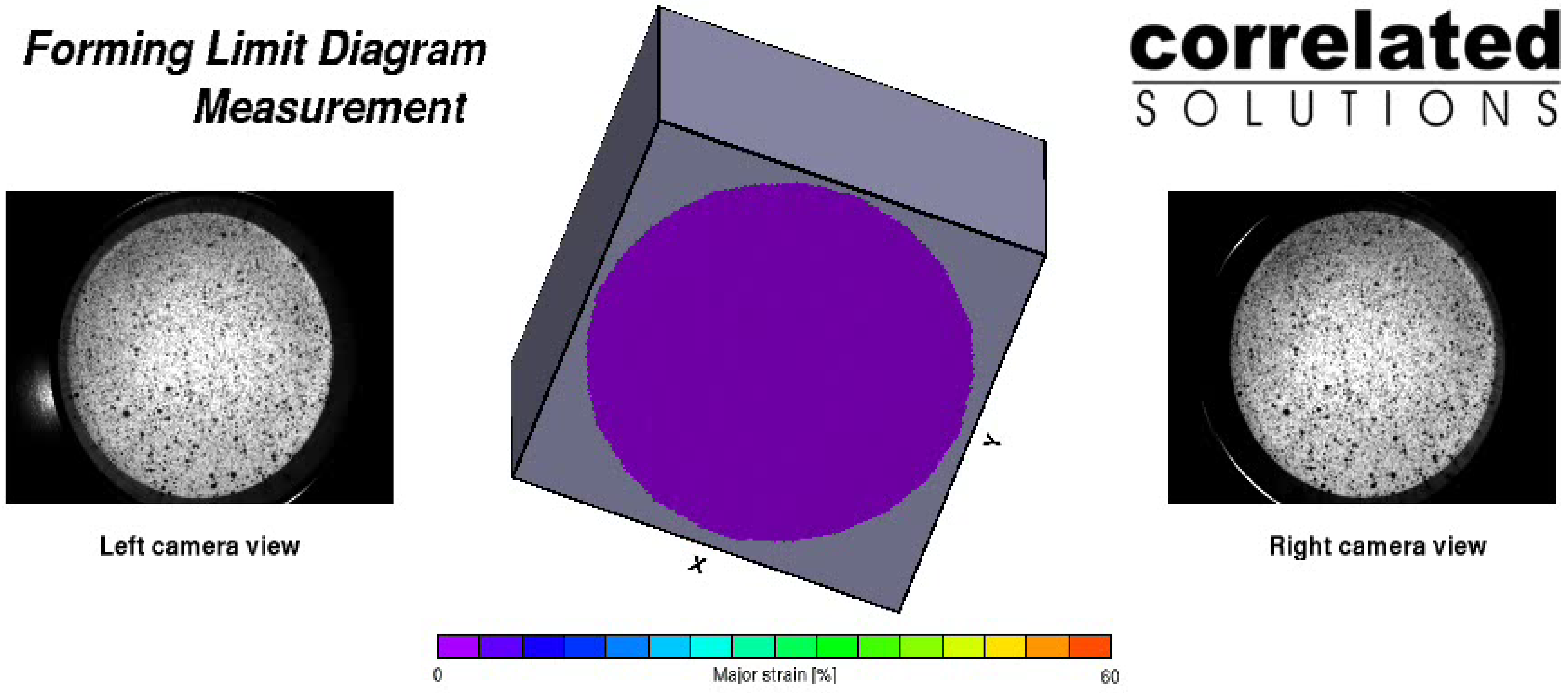
Combining Everything

The technology behind 3D DIC

- Stereo-correlation
- Tracking by correlation
- Stereo-triangulation (needs calibration)

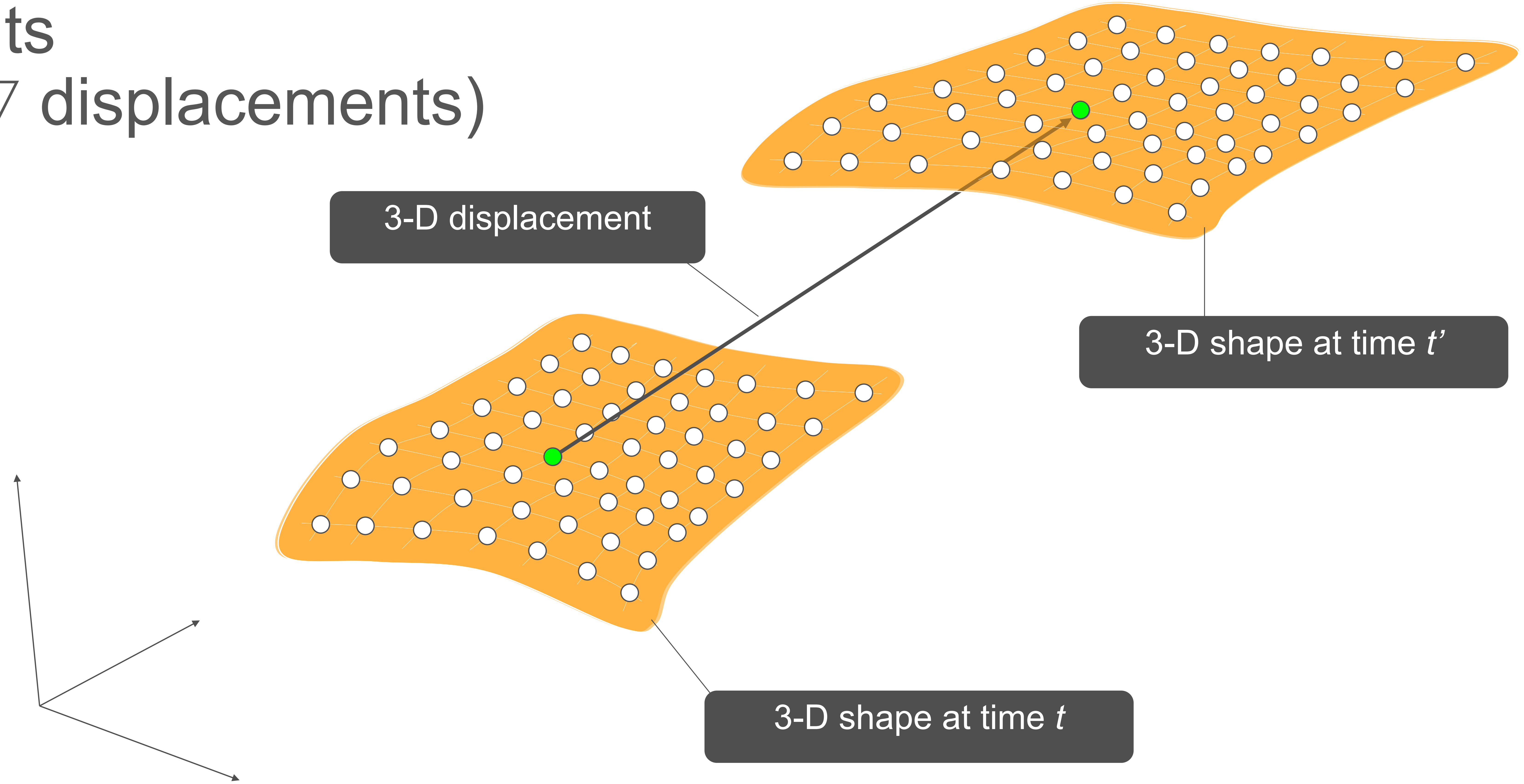


Combining Everything



Strain Computation

Strains are computed from the measured displacements of object points
(strains $\cong \nabla$ displacements)



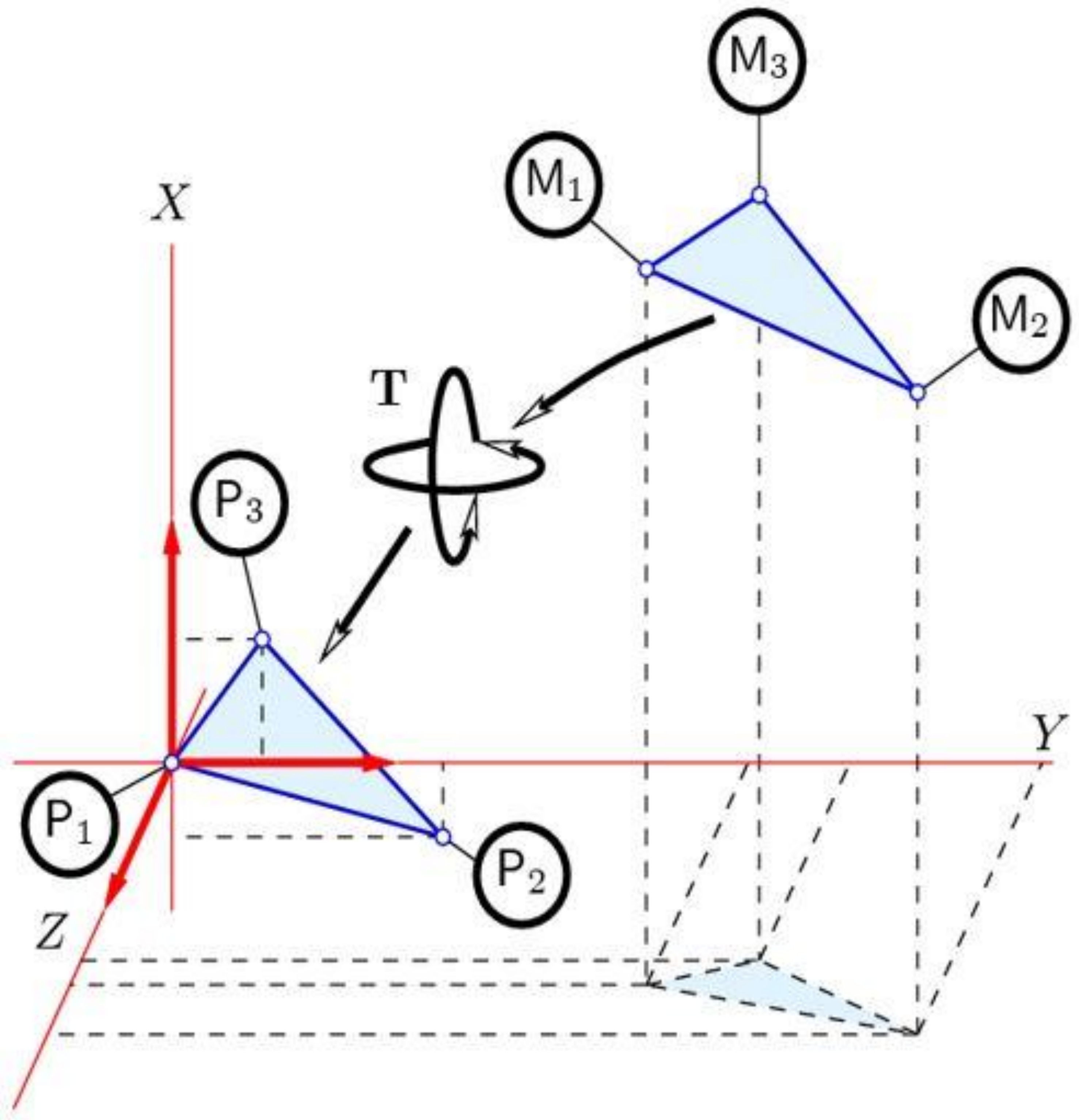
Strain Computation

Strains are only defined in the tangential plane of the surface.

The DIC data can be converted to a triangular mesh.

Since triangles are planar, it is simple to compute the strain on each triangle.

Same equations as found in FEM.



Strain Computation

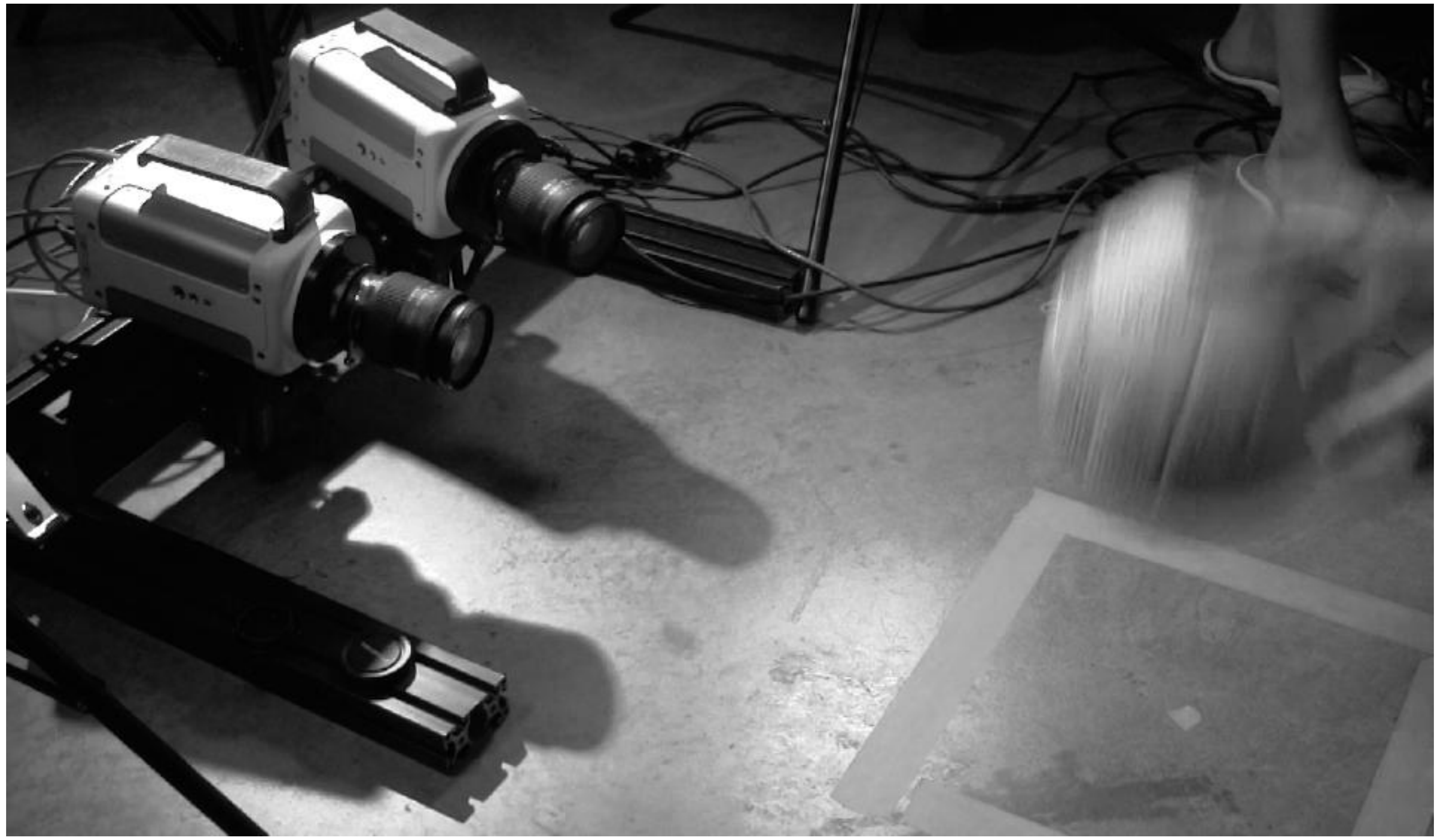
Smoothing

The strains computed on each triangle are noisy, unless the triangles are fairly large.

The strains are normally smoothed using low-pass filters.

Low-pass filtering decreases spatial resolution.

correlated SOLUTIONS



3-D Digital Image Correlation

Procedures & Practicalities

Camera Selection

- **Cameras available for different time scales**
  - Quasi-static (10-30 fps)
  - Medium speed (500 fps)
  - High-speed (50,000 fps)
  - Ultra-high speed (5,000,000 fps)
- **Choose sensitive, monochrome cameras**
- **Pixel size**
- **CCD vs. CMOS**

Camera Synchronization

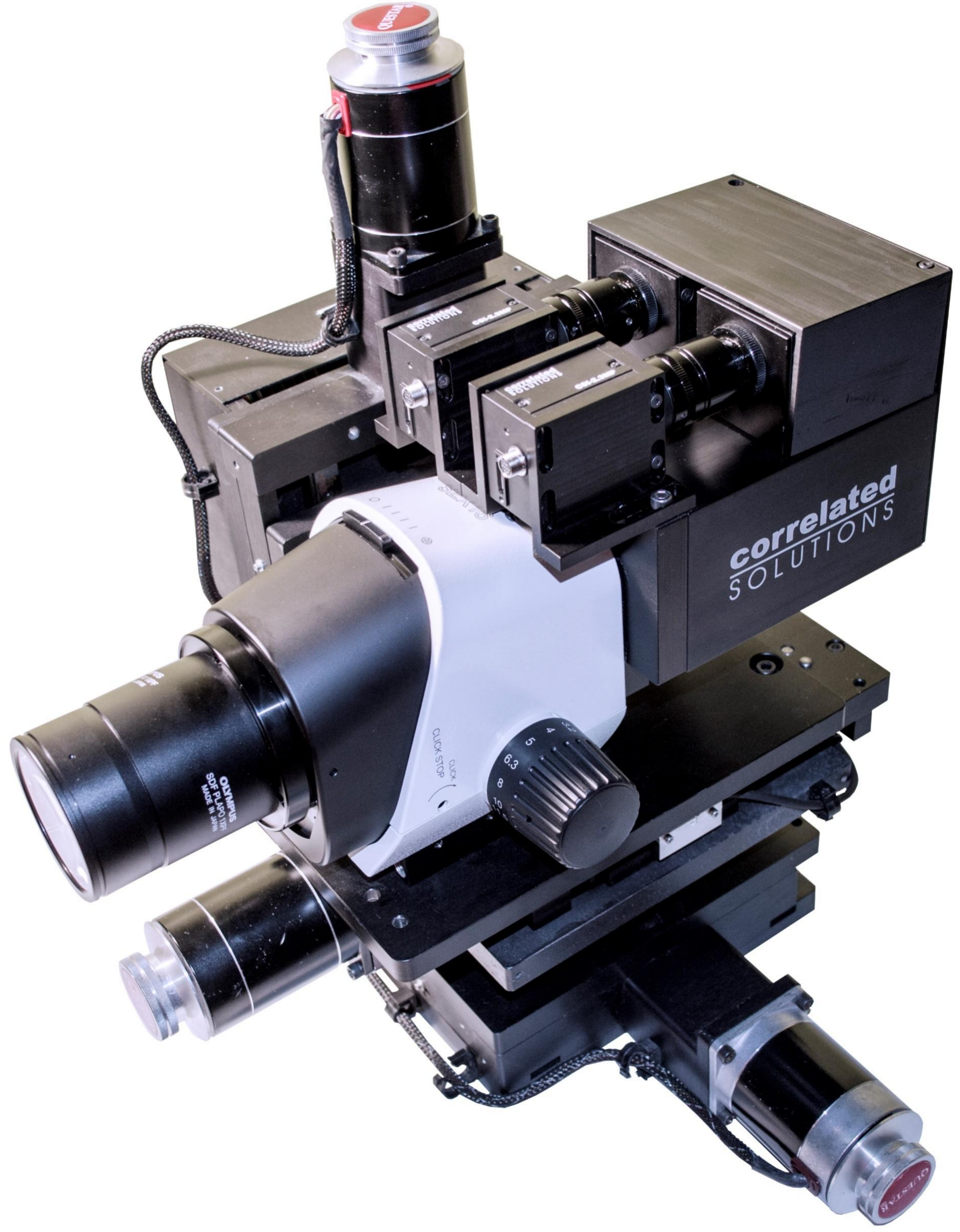
- Stereo cameras must be synchronized
- Required accuracy depends on speed of event
- Synchronization accuracy should be small fraction of exposure time

Camera Setup

- **Cameras must not move relative to each other**
- **Tolerable camera motion depends on magnification**
- **Example:**
  - 1:1 magnification
  - 5 micron pixel size
  - Detectable motion 0.01 pixel
  - 50 nanometer relative camera motion is detectable!!!
- **For high magnifications, a rigid camera setup is paramount**

Camera Setup

- Mount cameras on rigid support
- Tie down camera cables
- Use vibration isolation for high magnification work



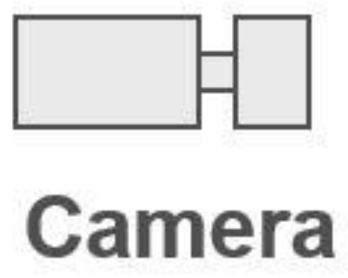
Camera Setup

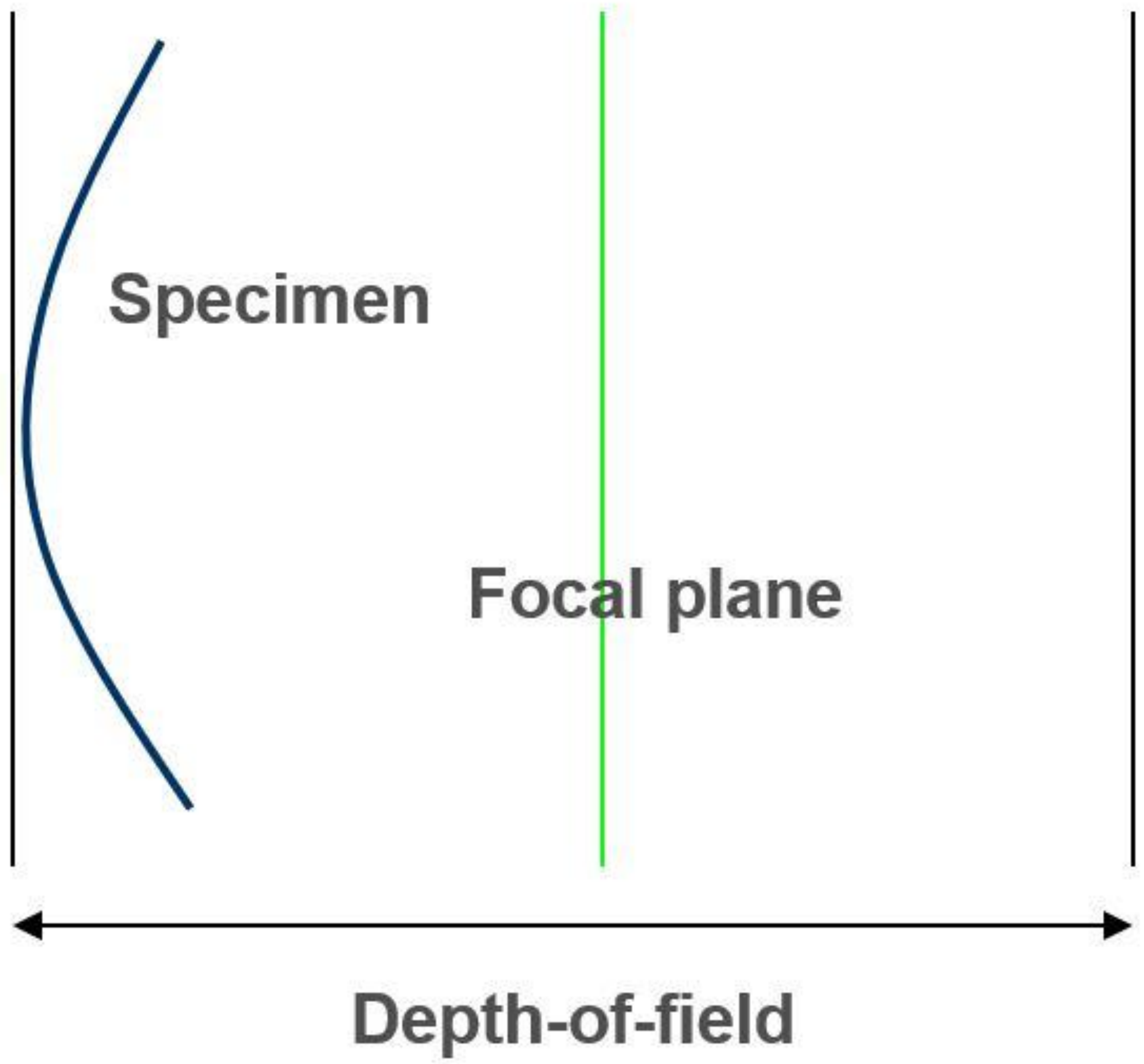
- For short lenses (8 mm, 12 mm), use a stereo angle of at least 35º
- With longer lenses (35 mm, 70 mm), use at least 10-15º
- If you must use small stereo angles, keep the AOI to the center of the images

Focusing Camera

- The entire sample should be focused during the entire test
- It can be difficult to focus a camera correctly when the depth-of-field is large

Small aperture (high f-number):

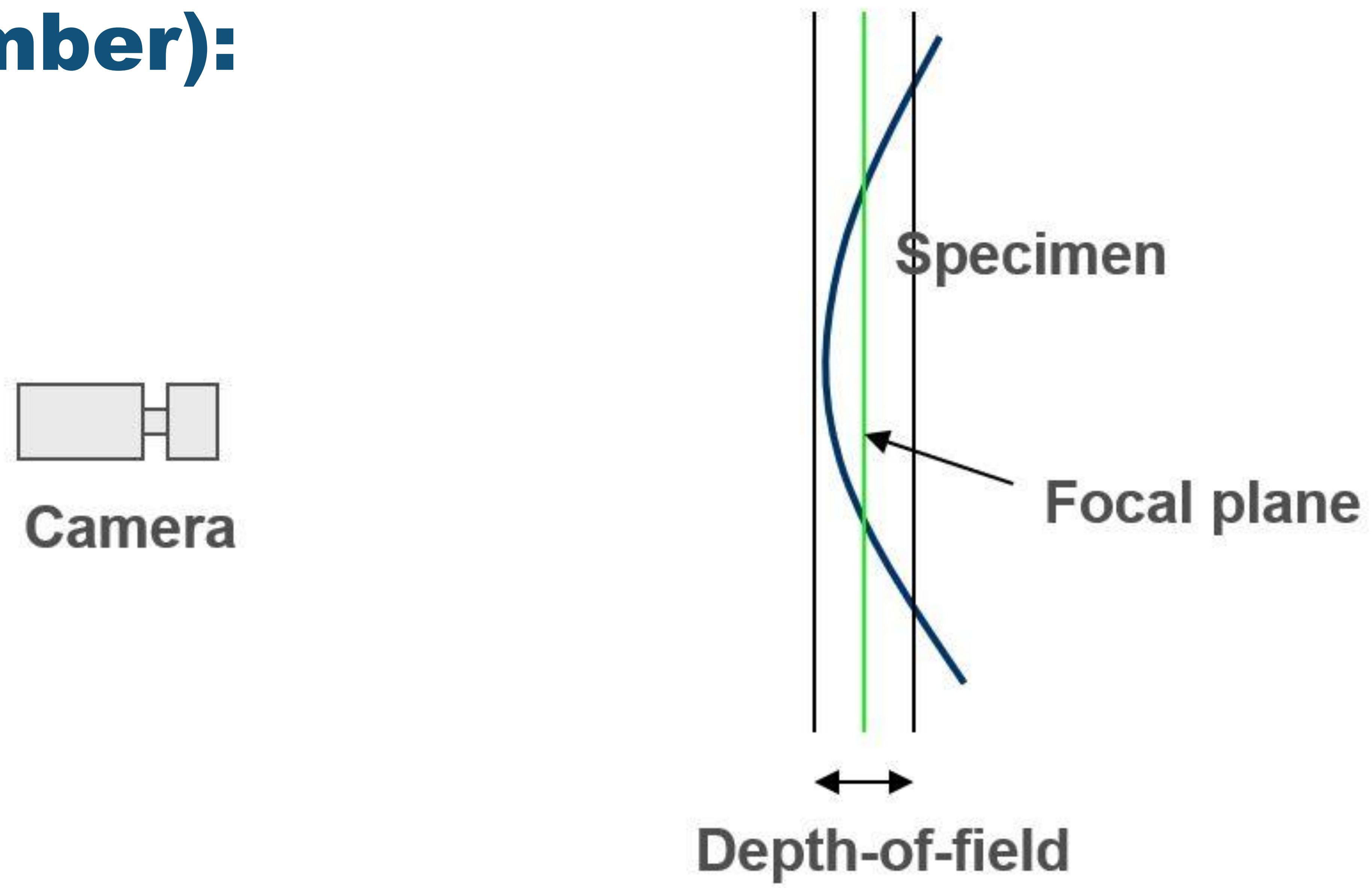




Focusing Camera

- The entire sample should be focused during the entire test
- It can be difficult to focus a camera correctly when the depth-of-field is large

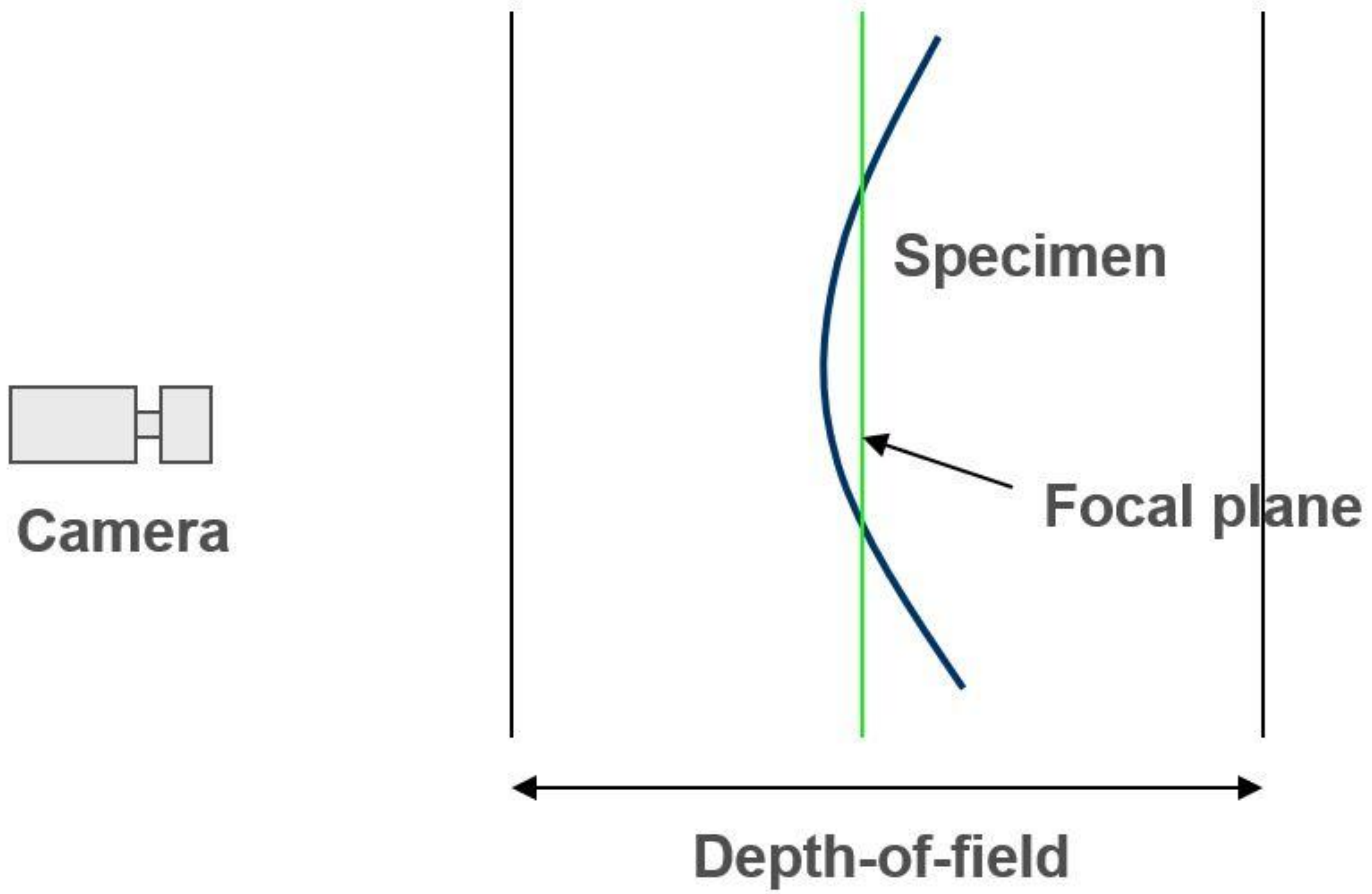
Large aperture (small f-number):



Focusing Camera

- Focus with open aperture
- Close aperture after focusi

After closing aperture:



Aperture, Exposure, Lighting

- Use a short exposure to freeze any motion
  - Calibration is frequently the bottleneck
- Apertures in the middle are best
  - DOF concerns
  - Diffraction limit & pixel size
- Difficult cases
  - Wet/shiny specimen
  - Metal & glare
  - Transparent/translucent
  - 3D and textures

Specimen Preparation Methods

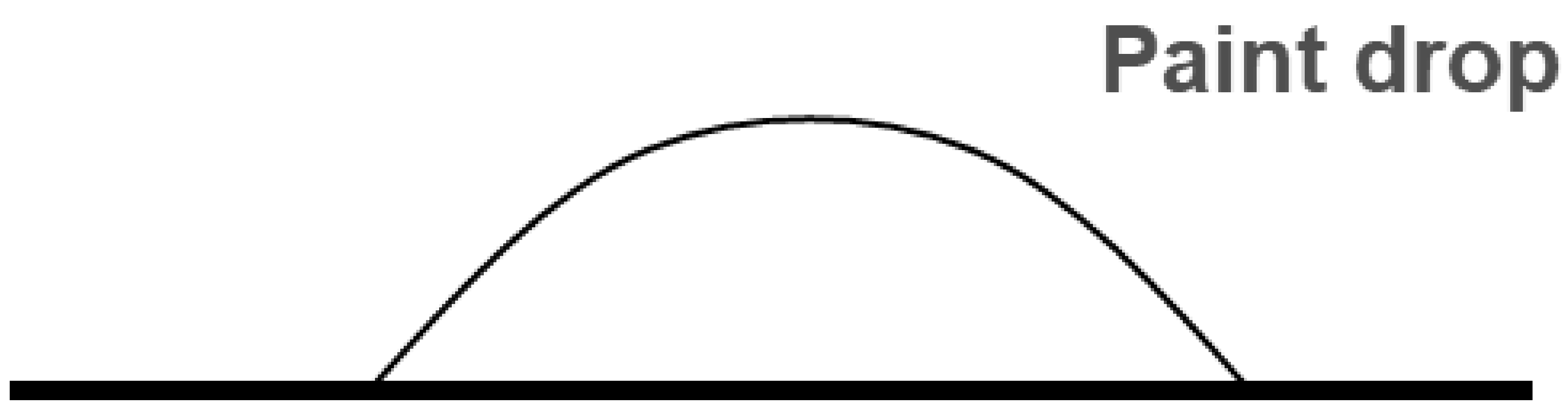
- Uniform random pattern must be applied
- Large range of application methods:
  - Spray painting
  - Lithography and vapor deposition
  - Toner powder on paint
  - Stencils
  - Stamps
  - Screen printing
  - Adhesive-backed vinyl
  - …

Basic Pattern Requirements

- Pattern must deform with sample
  - No slip for stick-on patterns
  - Dye sample for large deformations (100%-800%)
  - Must hold up to testing conditions (temperature, moisture, acceleration etc.)
- Pattern must not reinforce sample
  - Use dye penetrant developer for measurements on very thin metal foils

Basic Pattern Requirements

- It is critical to avoid specular reflections
  - If sensor is saturated, the signal is chopped off
  - Accurate matching no longer possible
  - Large artificial spikes in strain
- Use matte paints
- Whenever possible, use back lighting for transparent or semi-transparent samples
- Avoid thick paint drops
- Use diffuse lighting



Basic Pattern Requirements

- Small speckles approximately 3-5 pixels in size
  - Permits analysis with small subset
  - High spatial resolution
- No preferred orientation
- Uniform (check histogram)
- Matte
- No big paint blobs or uncovered areas

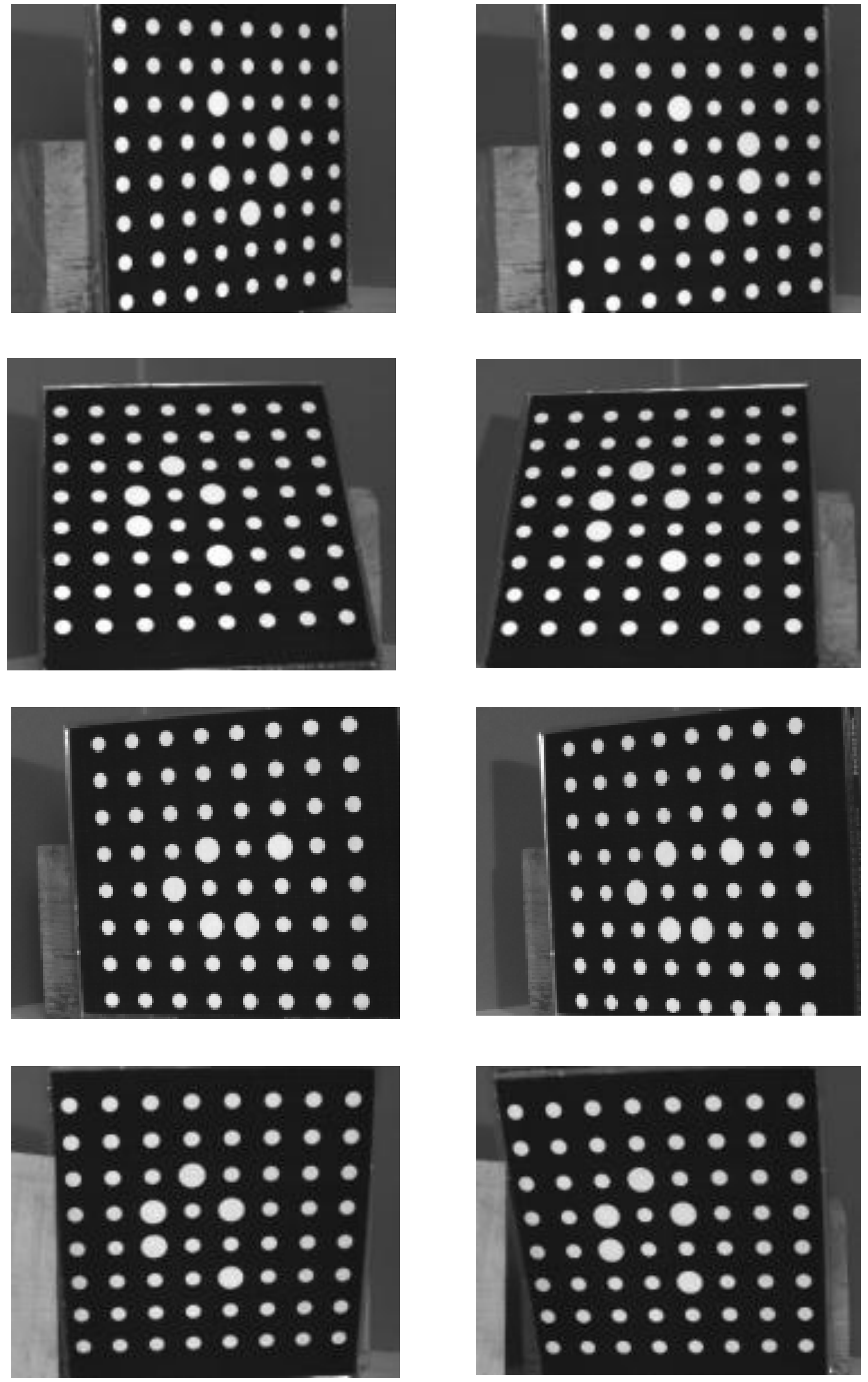
Calibration Procedure

- The internal camera parameters have to be calibrated (focal length, image center, distortions, skew).
- The relative orientation of the stereo cameras has to be known for triangulation.
- Typically, all parameters are calibrated at the same time using a calibration target.

Calibration Procedure

A good calibration needs **30 good image pairs** and:

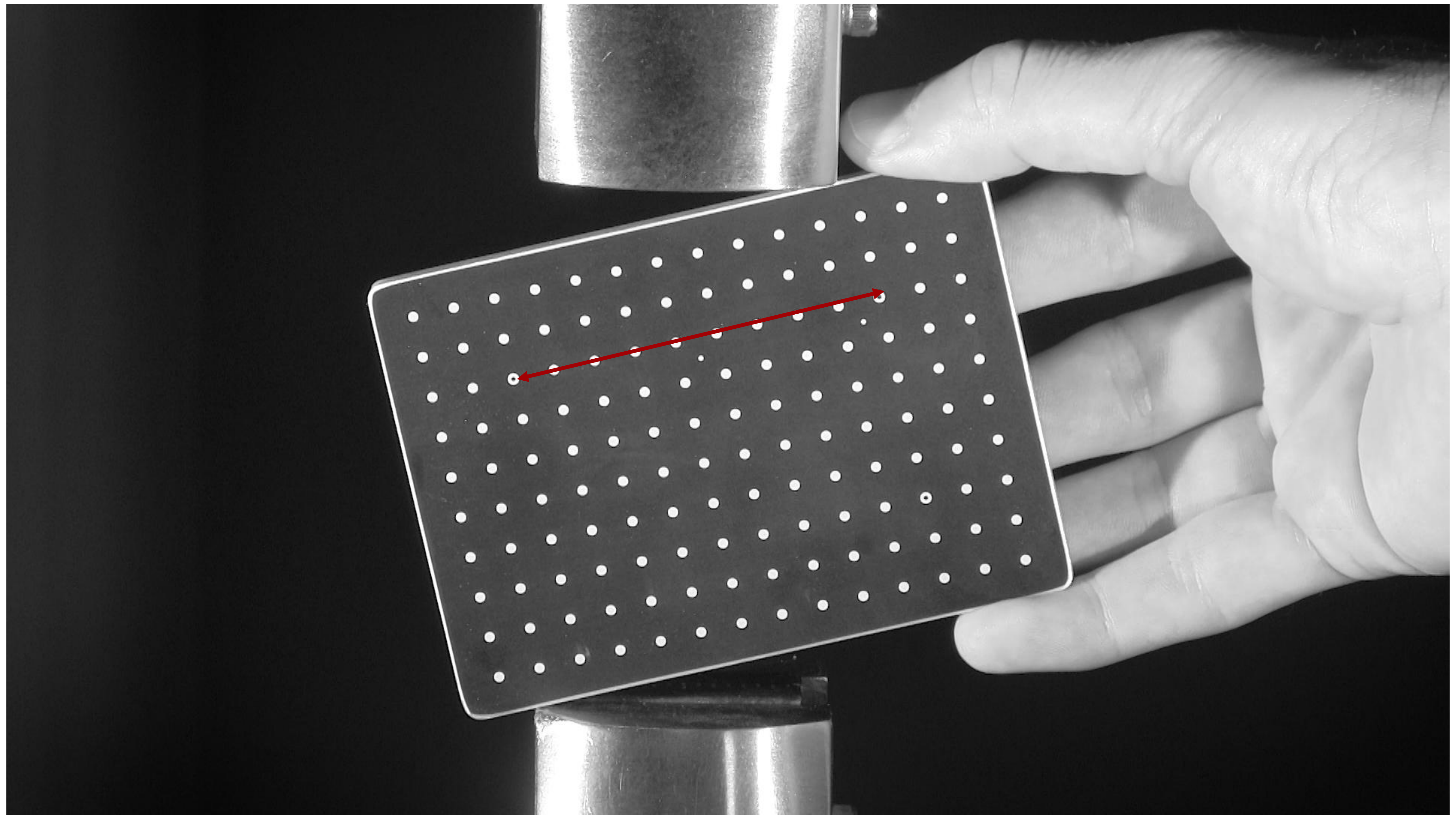
- AS MUCH OUT-OF-PLANE TILT as the DOF allows
- Tilt various degrees about the horizontal and vertical axes
- Just 1 or 2 in-plane rotation necessary
- Grid should fill at least 75% of the field of view
- The grid must be rigid; it cannot deform during calibration
- Camera calibration is a shape measurement of the calibration target!



Calibration Procedure

Does one need a precision calibration target to calibrate a stereo system?

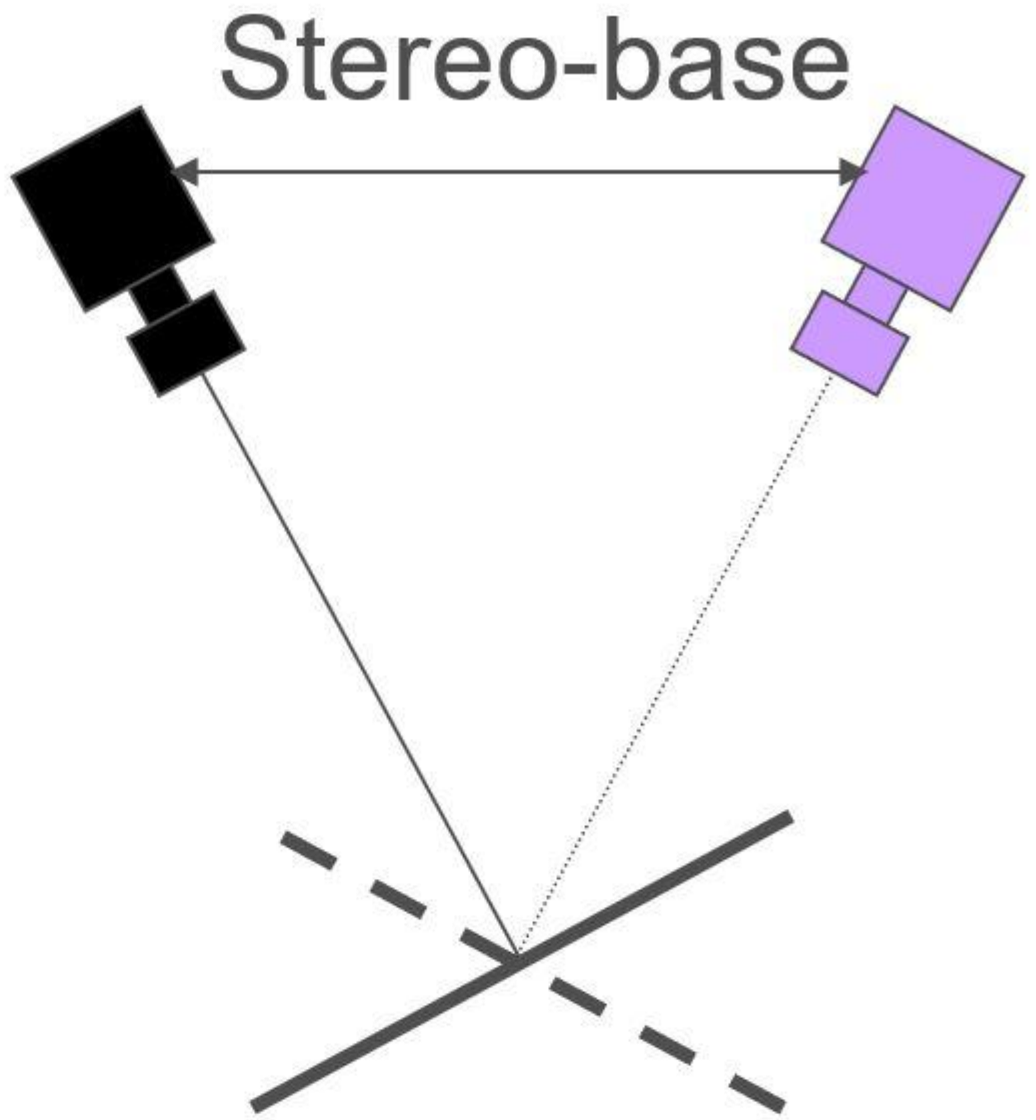
- Internal camera parameters can be calibrated from a completely arbitrary calibration target (only constraint: target must be rigid).
- Rotation and direction vector between cameras can also be calibrated from arbitrary target.
- A distance between two fiducial points has to be known accurately to recover the absolute scale.



Calibration Procedure

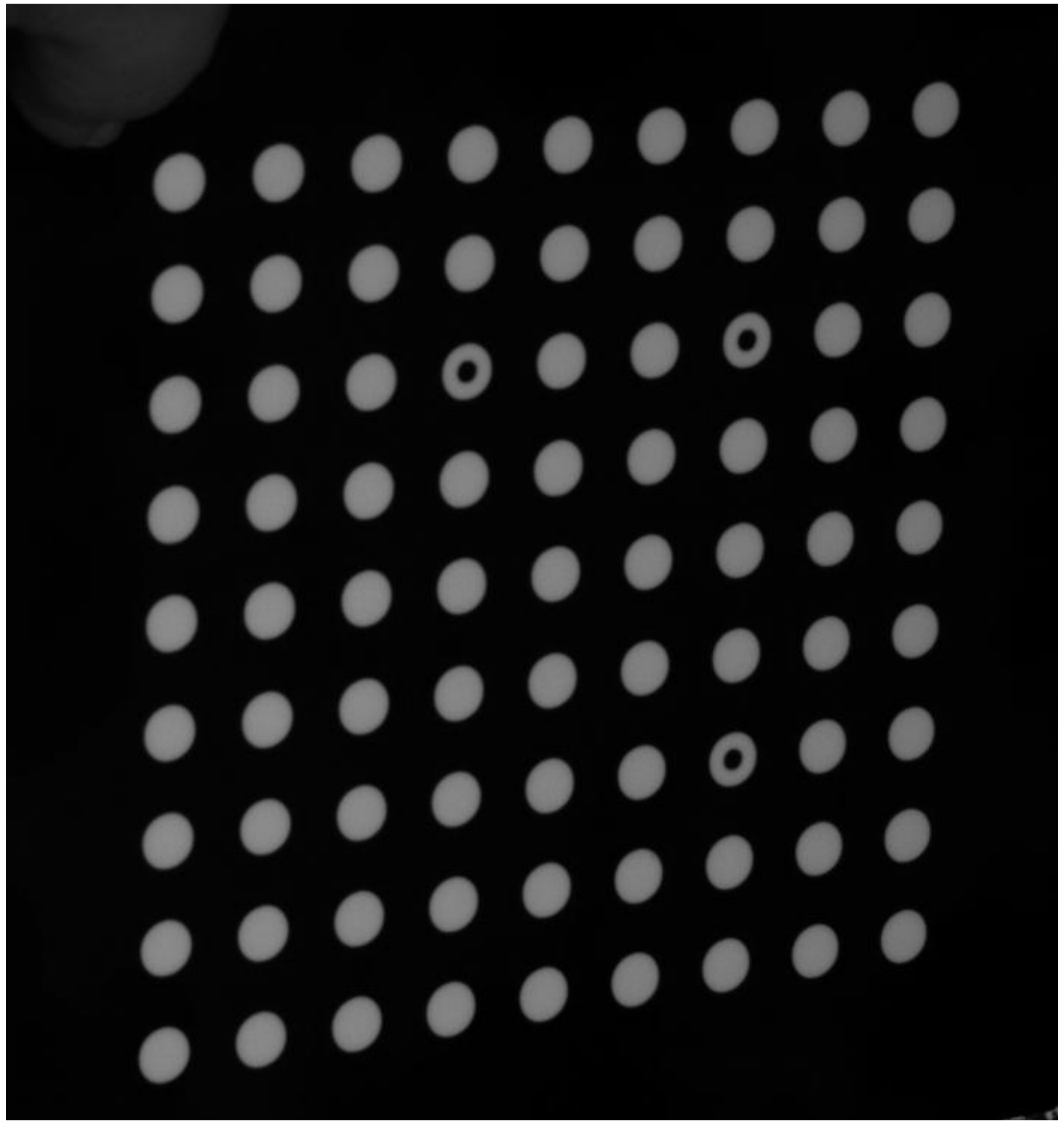
Importance of Rotations

- Calibration equivalent to shape measurement
- Reliable shape measurement only possible for large stereo-baseline
- Rotations serve to increase baseline



Calibration Procedure

- Coded targets are used for automatic extraction
  - Coded markers must be visible in all views
- Avoid glare
- Use short exposure times to freeze target motion
  - rule of thumb: 1/focal length seconds
  - Ex. 30 mm lens=1/30 seconds=33 ms

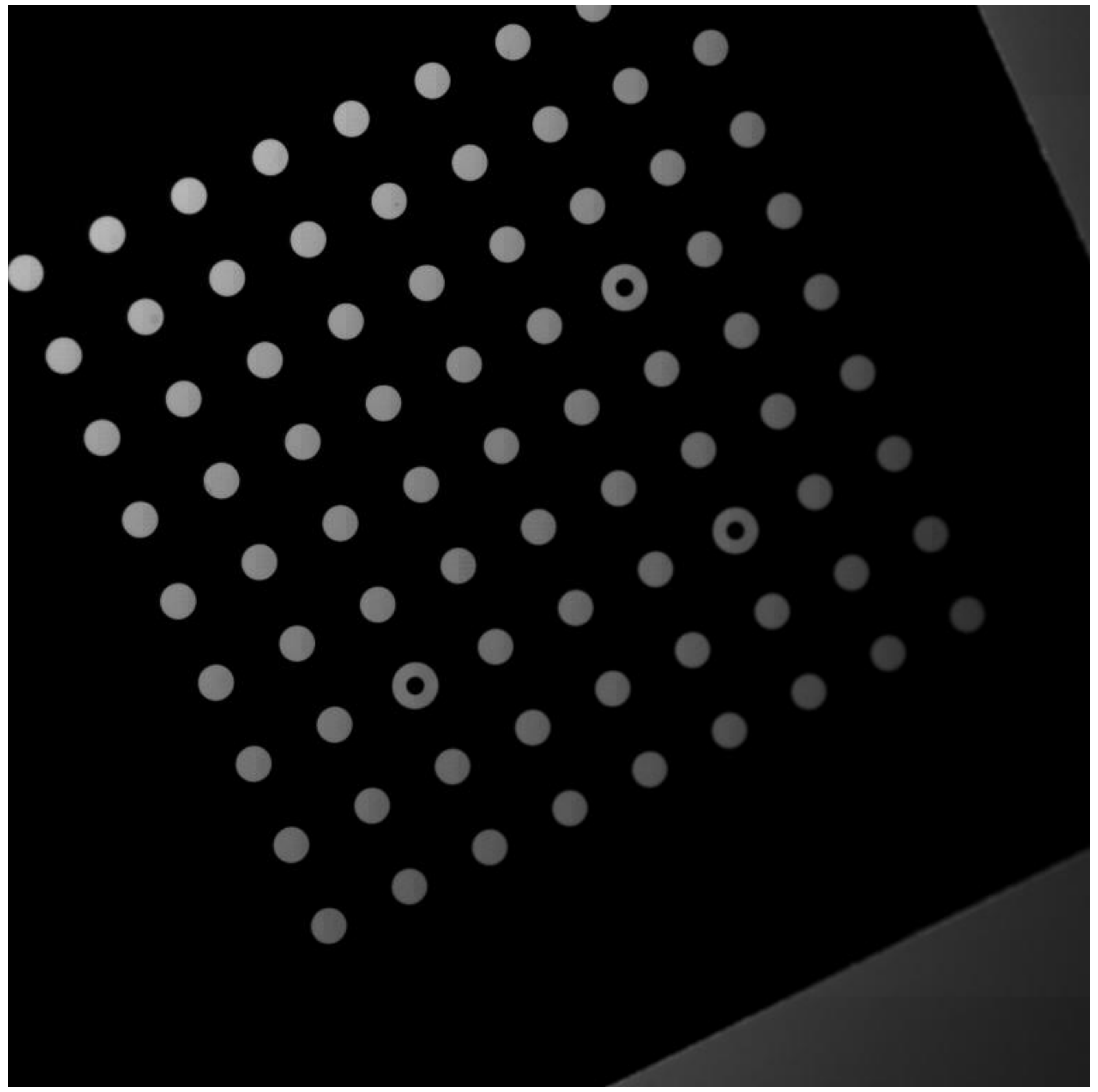


Calibration Image Distortions

- Distortions are described by high-order polynomials in the distance from the image center
  - Distortions are normally small in central image area
  - Distortions rapidly increase at image boundaries
- It is critical that the calibration grid covers the entire image, particularly close to the boundaries, to accurately calibrate lens distortions
- Short focal-length (and inexpensive) lenses require higher-order polynomials and can only be calibrated with a large number of images

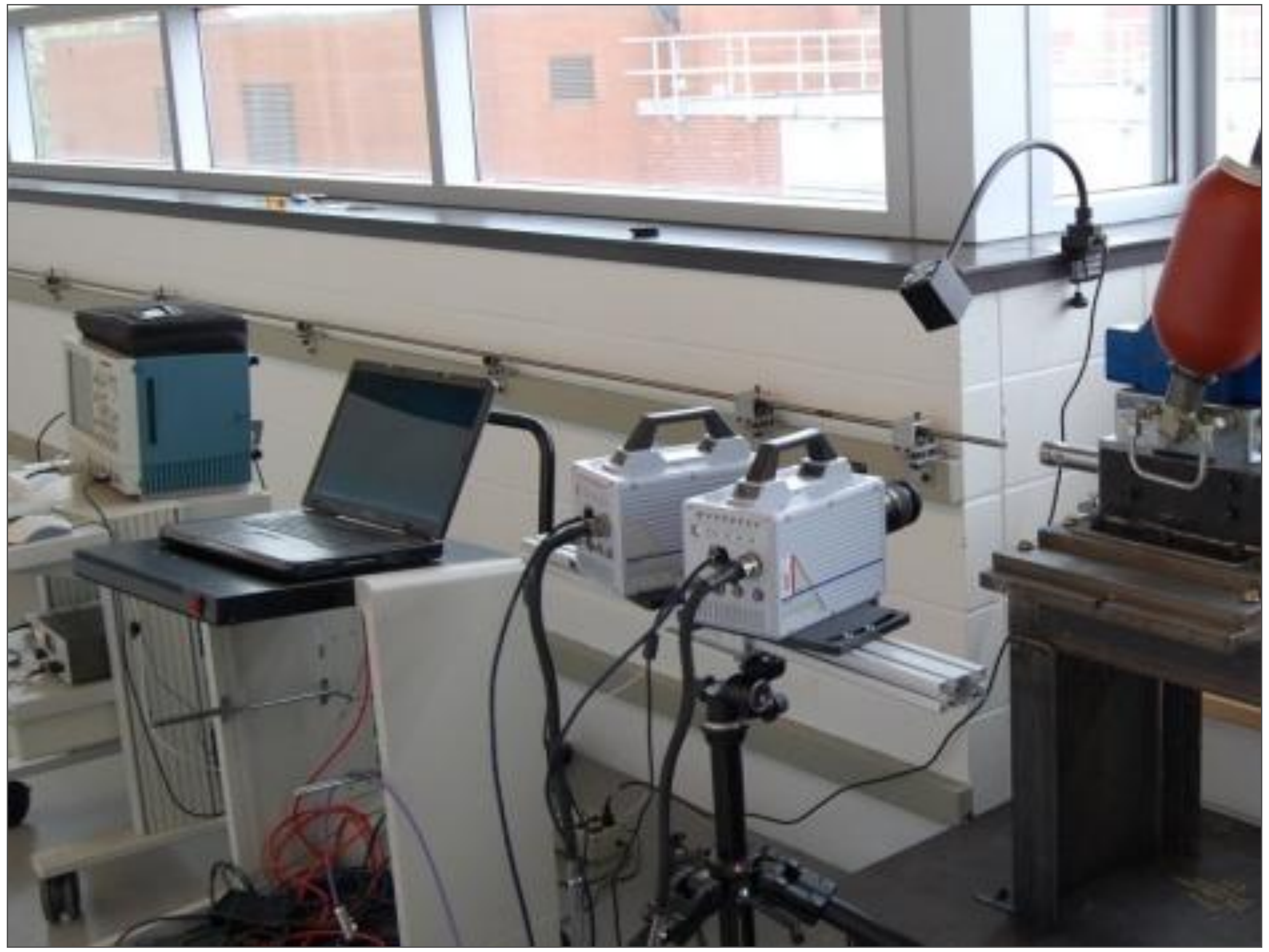
Calibration Image Distortions

- For high magnifications, glass grids are used
  - Background lighting
  - Positioning
- Strong tilt becomes very difficult at smaller FOV's
  - "High-magnification" options
- DOF concerns
  - Calibrating in front may be impossible



High-Speed Calibration

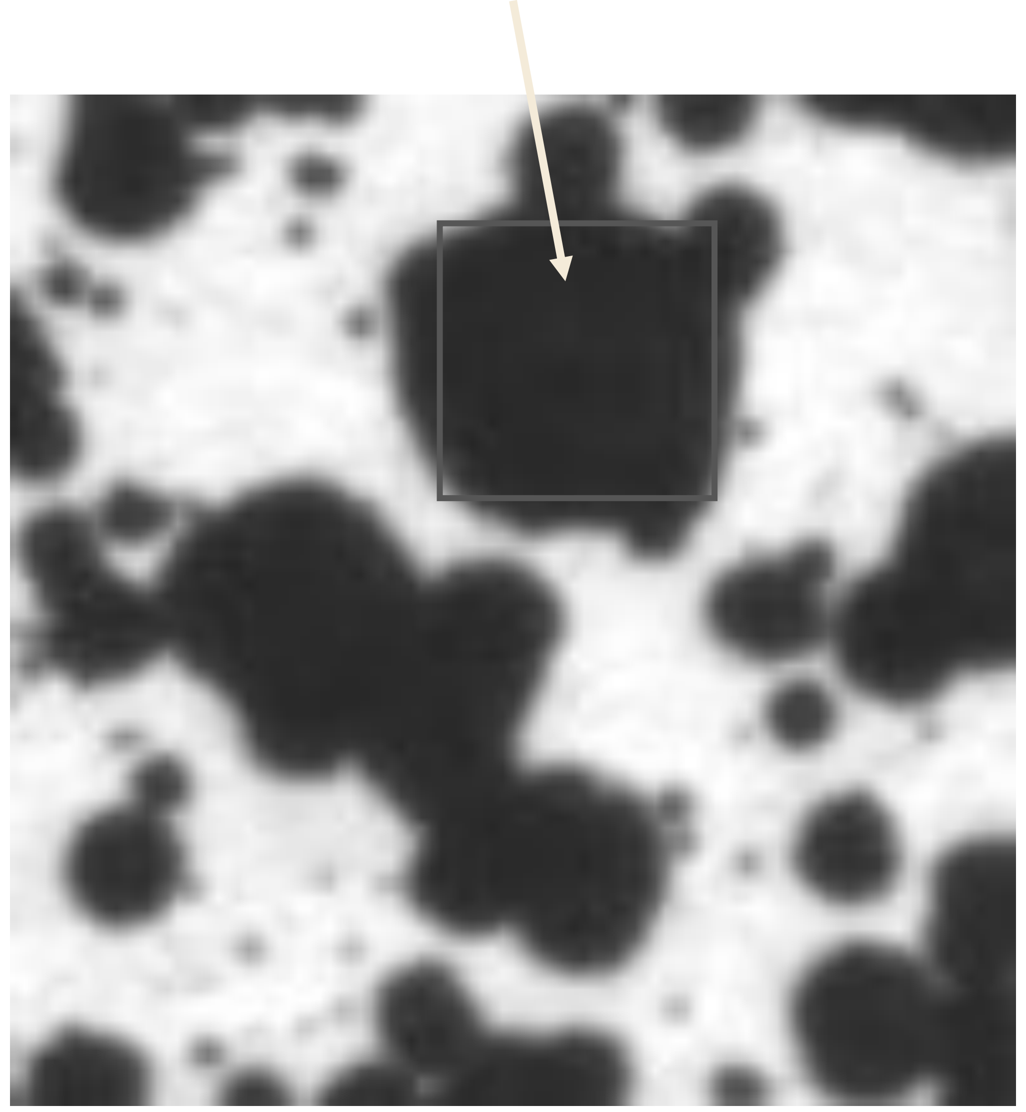
- Full resolution calibration
  - Crop adjustment
- DOF concerns
  - Calibrating in front may be impossible



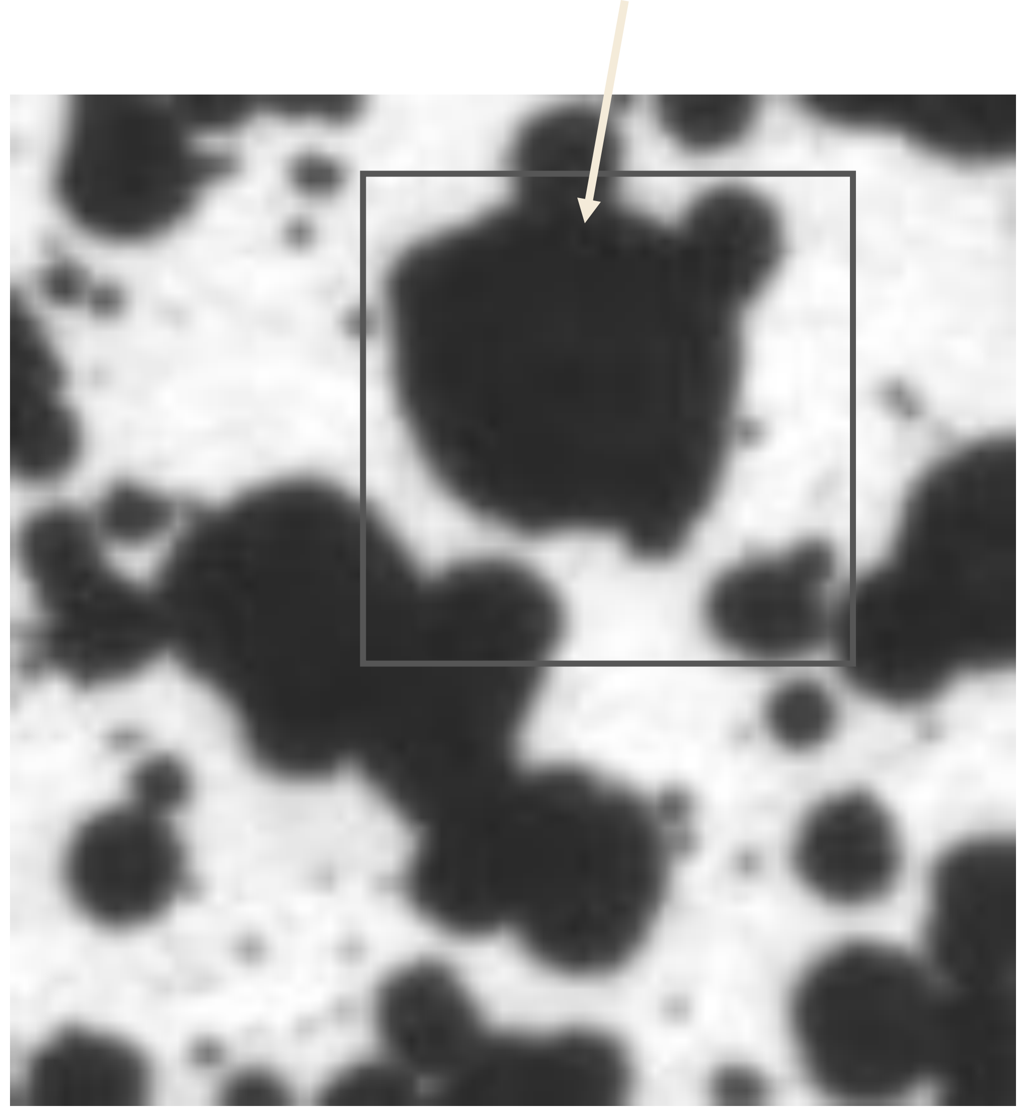
Subset Size

- Subsets must contain enough speckle information to be unique.
- Use subset bigger than largest speckle.
- Larger subset size provides higher confidence at cost of resolution and speed.

Subset contains no information



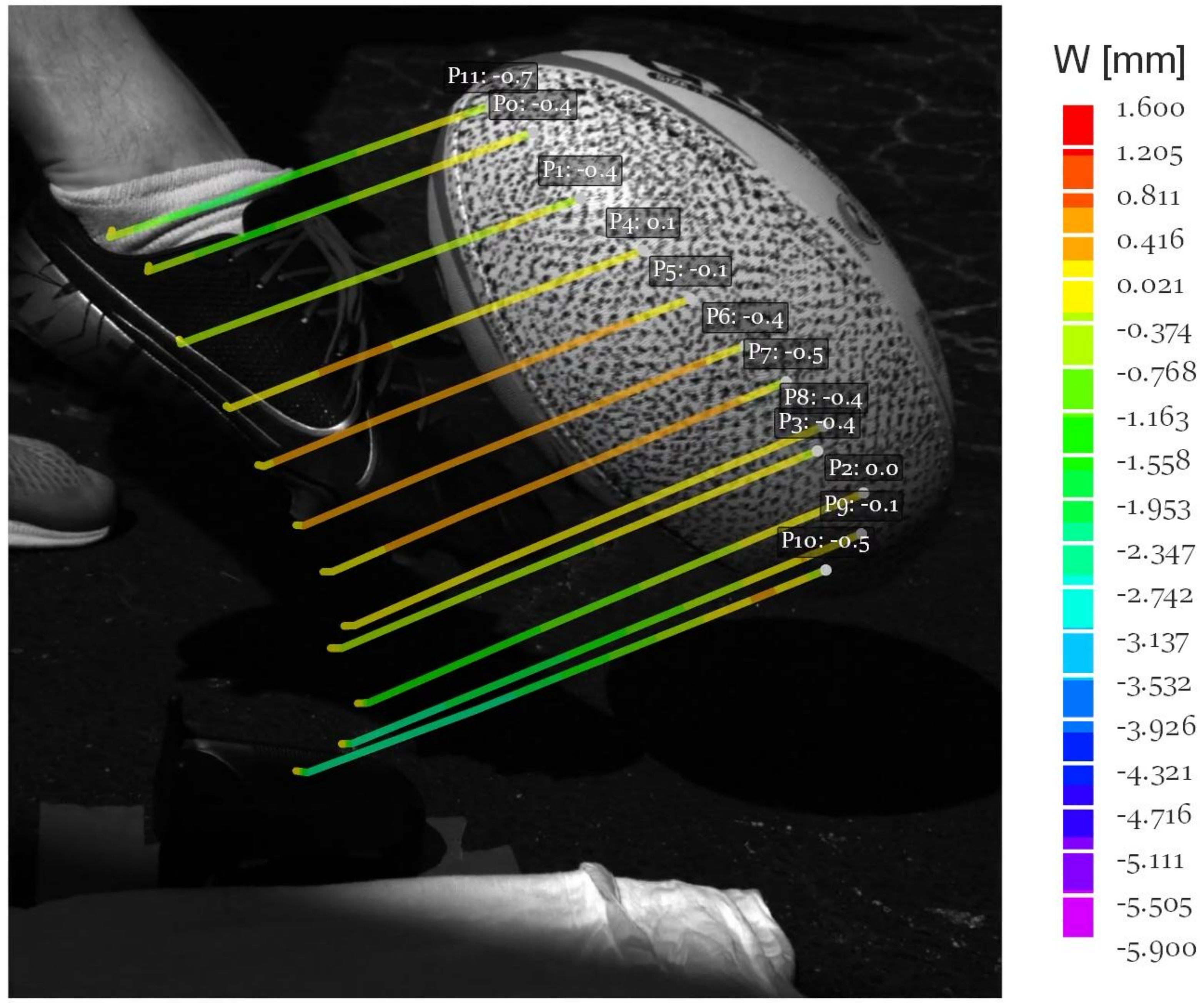
Larger subset needed



Step Size

- Step size dictates the spacing between each data point
  - Lower step size = more data points
- Overlapping subsets will not be independent
- For non-repetitive data, use step size ¼ of subset size

correlated SOLUTIONS



3-D Digital Image Correlation

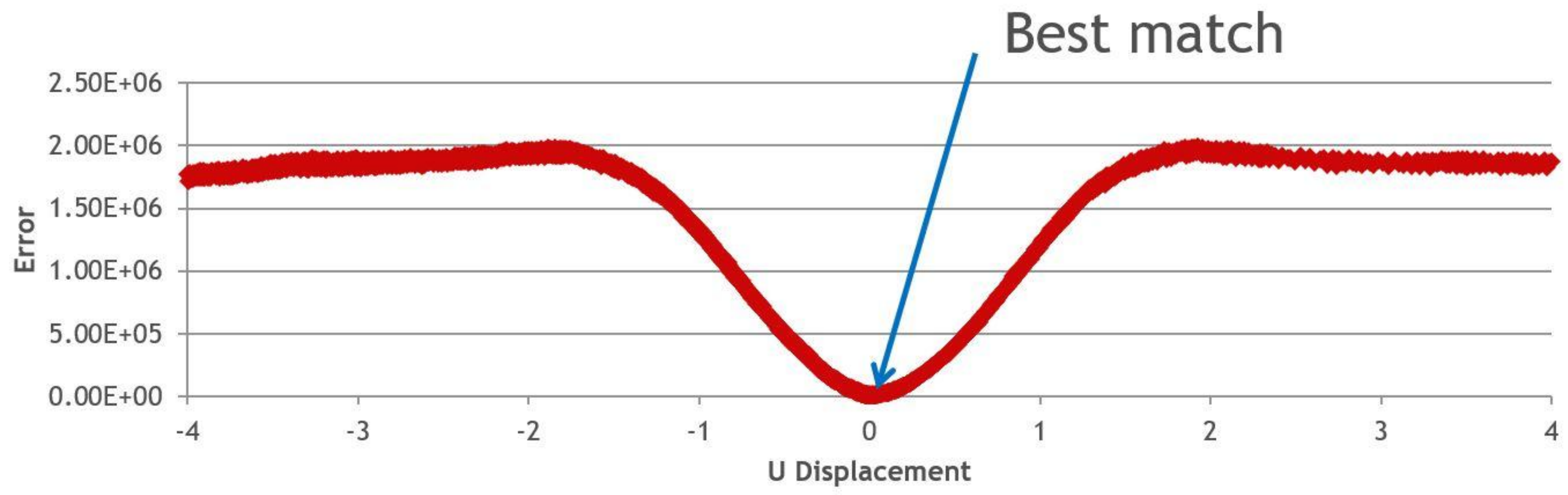
Minimizing Noise & Bias

Noise in DIC

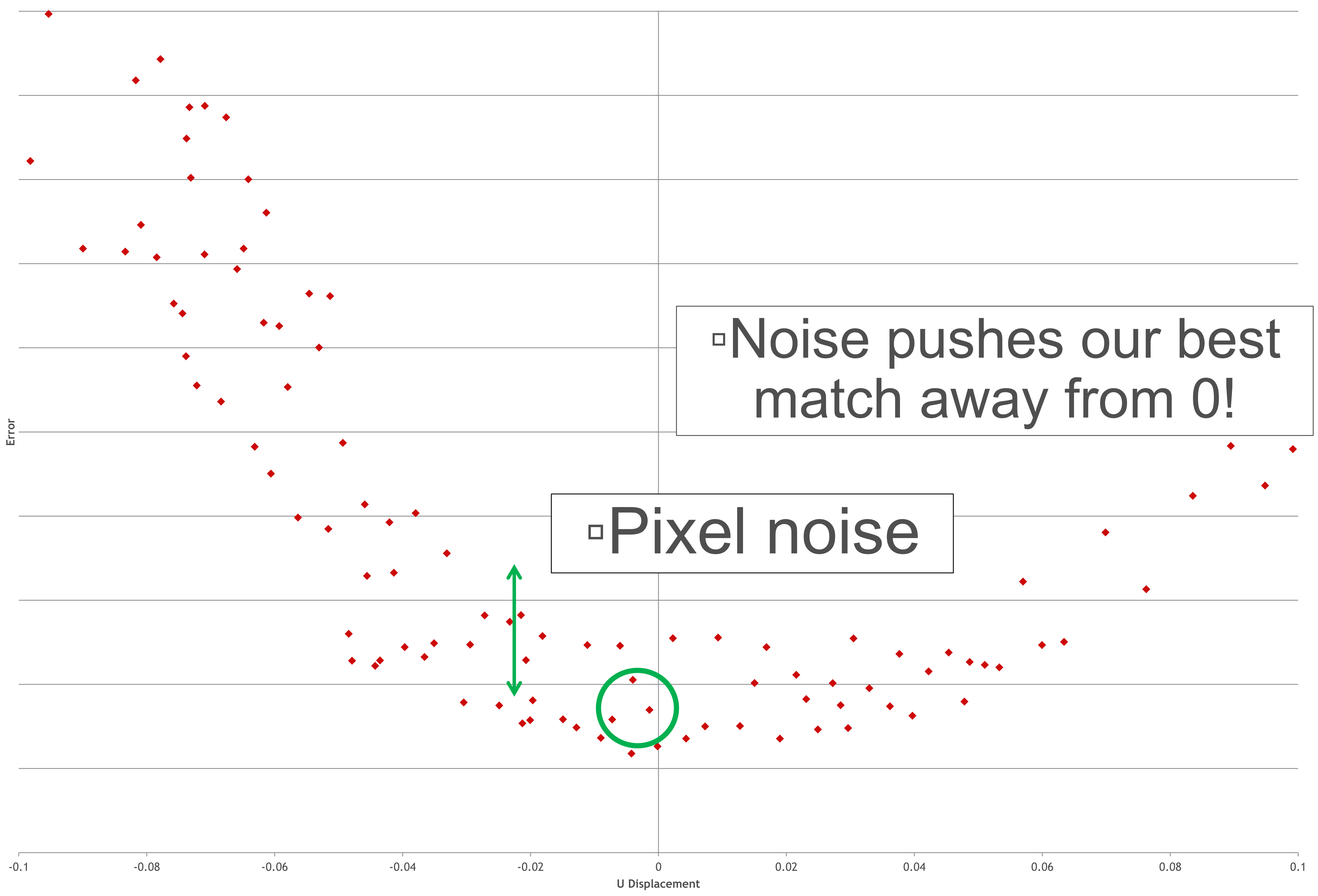
- Noise: random, zero-mean deviations from the correct result
- Noise is unavoidable, but can be minimized with careful setup
- Largely attributed to image quality and test setup – pay attention to parameters than may affect this:
  - Focus
  - Contrast/Lighting
  - Glare
  - Aperture/F-stop
  - Stereo-Angle/Lens selection
  - **Speckle pattern**

Noise in DIC

- Noise causes grey level values of pixels to have some amount of deviation between images
- The correlation (SSD) function will likely never be 0 for a perfect match
- Consider simple case: optimization for U displacement only
- Typical error curve from correlation function:



Noise in DIC


Noise pushes our best match away from 0!
Pixel noise
Error
U Displacement
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1

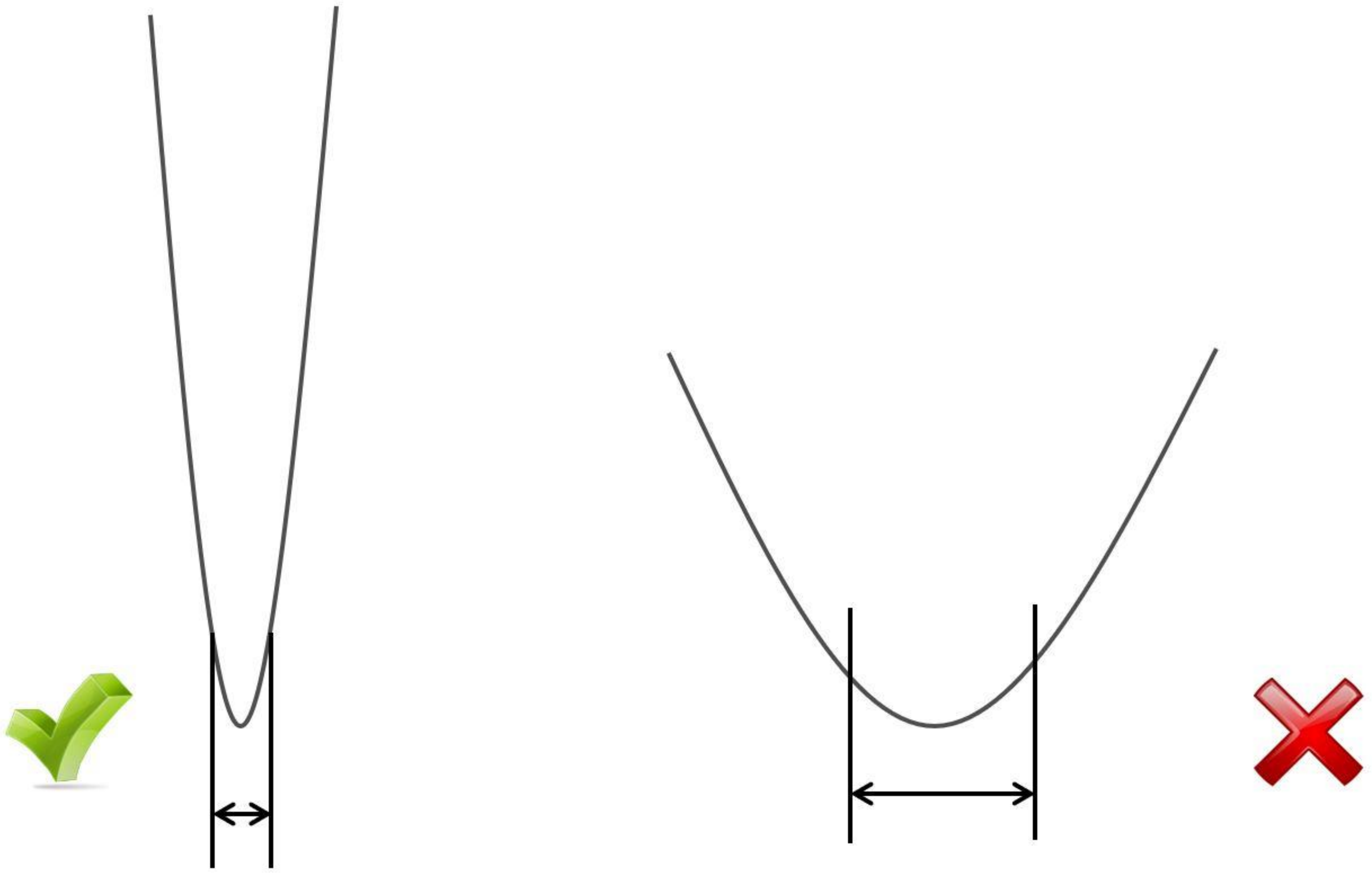
Noise in DIC

How do we reduce the effect of displacement noise?

- Reduce camera noise
  - Limited options
- Increase subset size
  - Loss of spatial resolution
- Optimize speckle pattern and test setup
  - This is our best and most important option

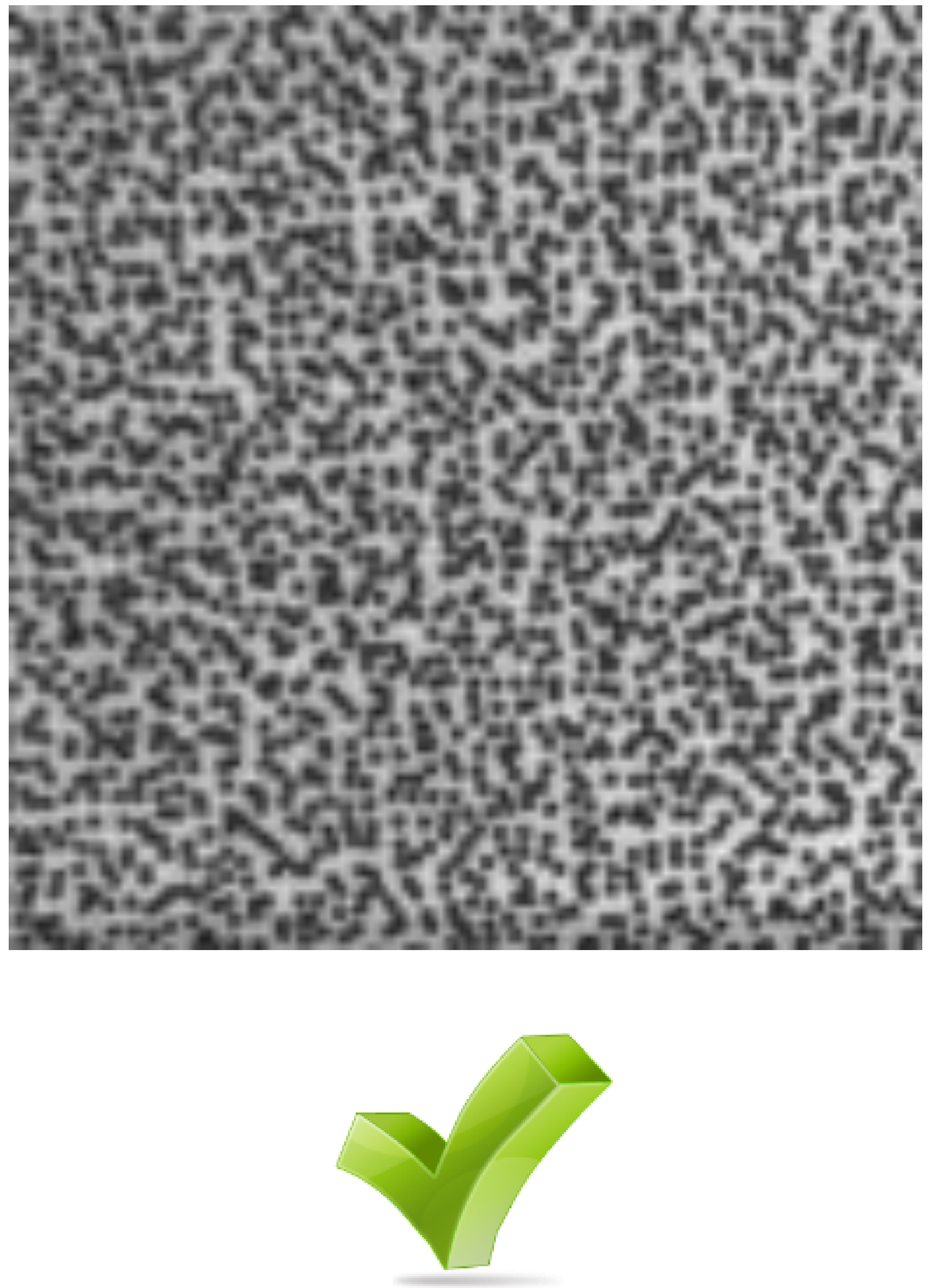
Noise in DIC

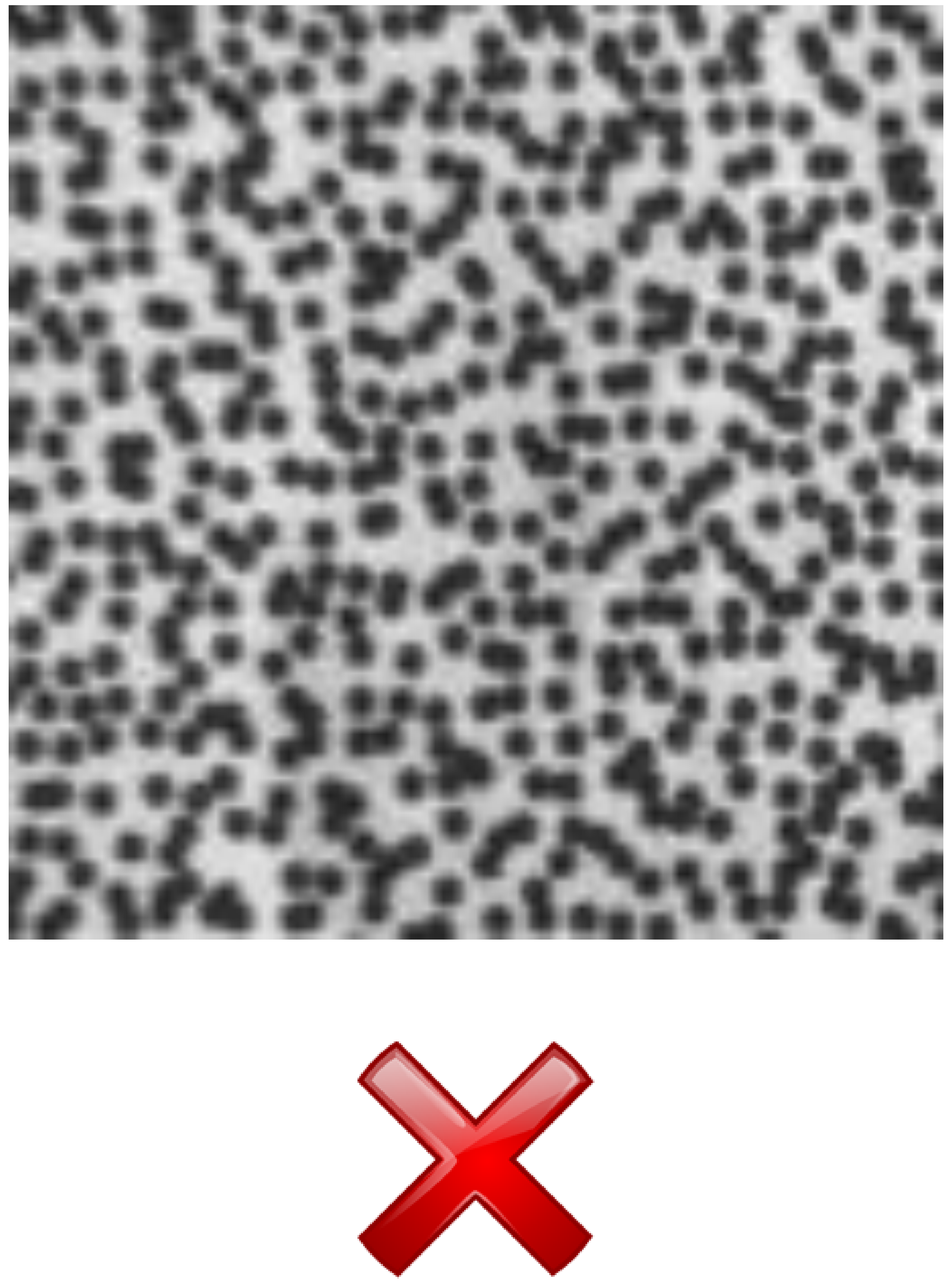
- Noise normally **cannot** be controlled
- We must increase the **signal**
- Steeper drop = better confidence



How to make the bowl deep?

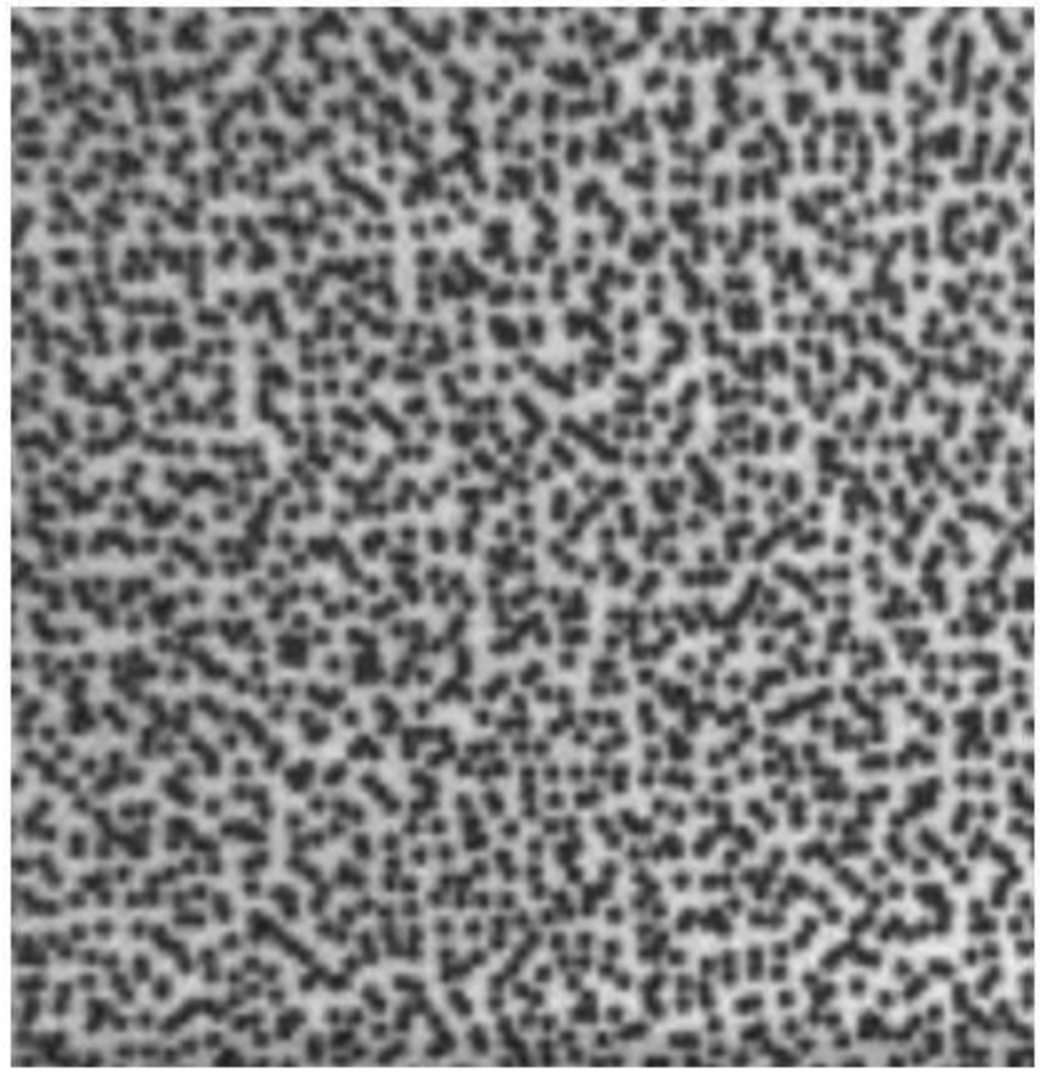
- Good Contrast
- Good Speckle Size

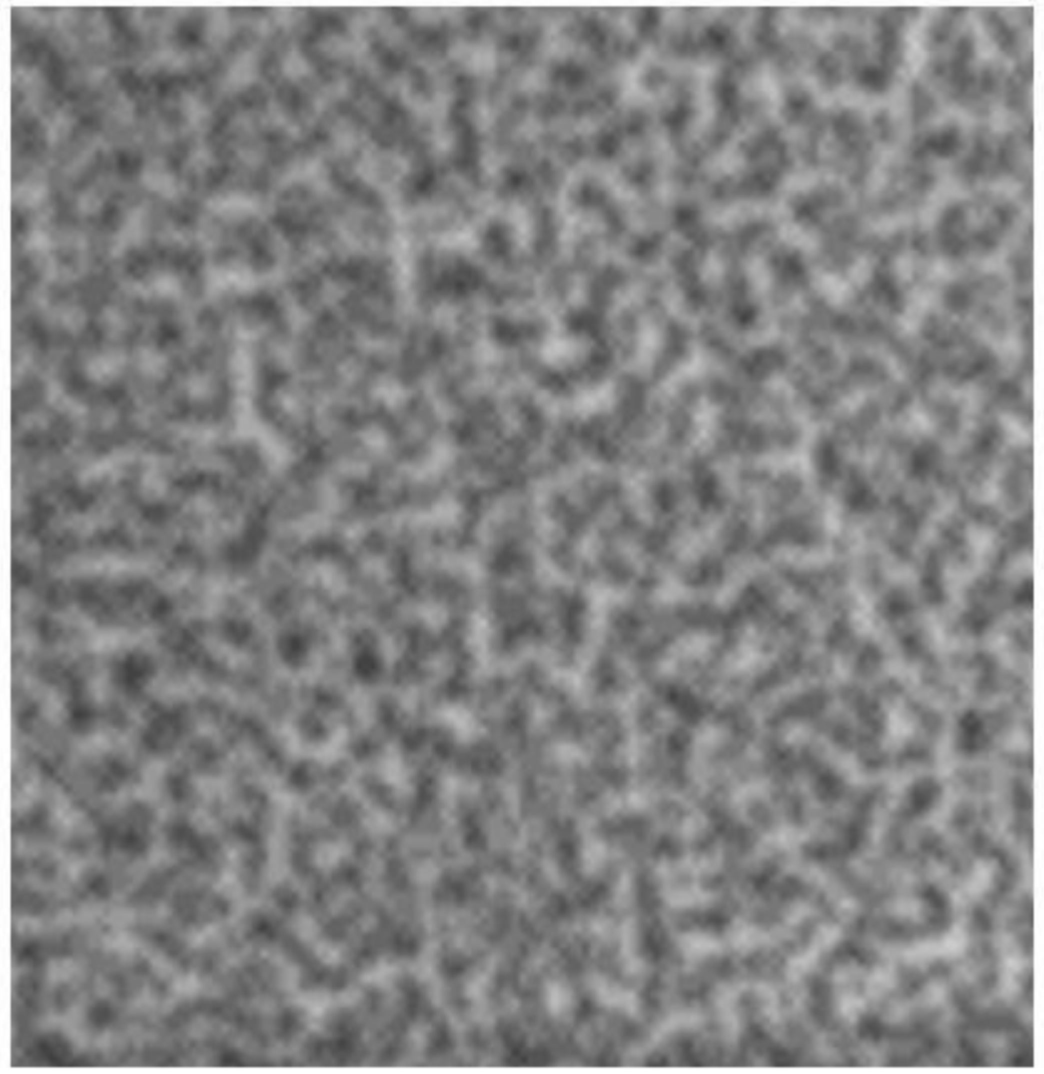




How to make the bowl narrow?

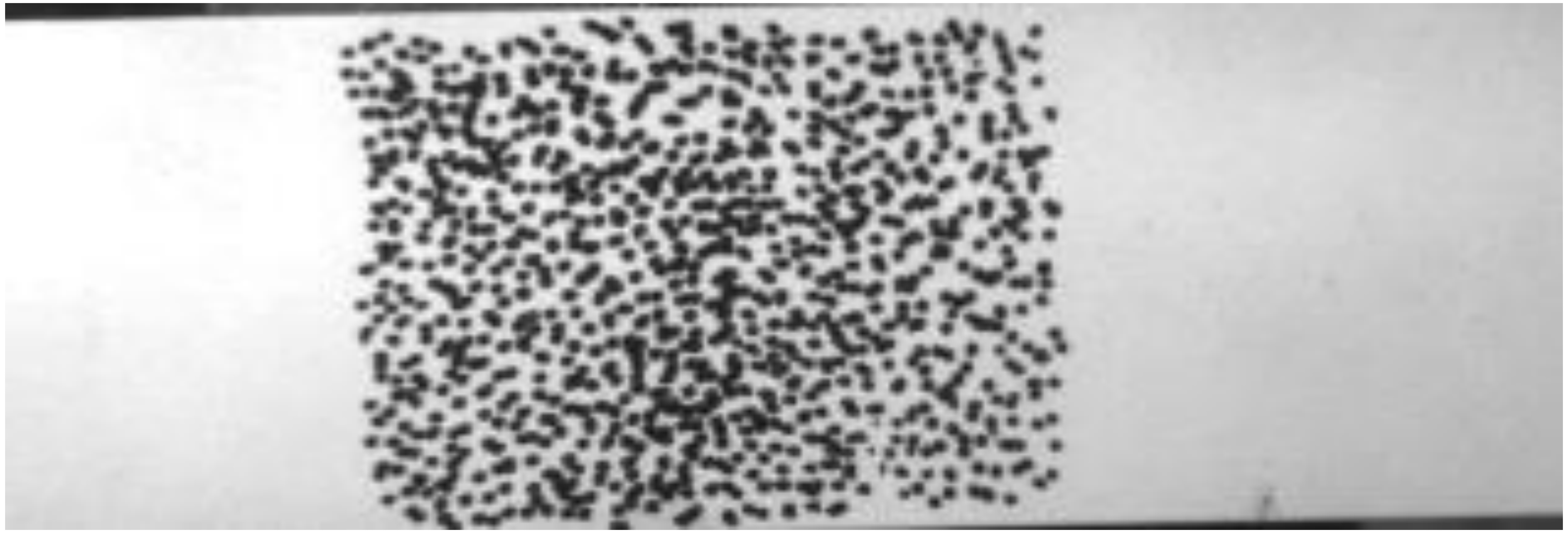
- Sharp edges
- Good focus
- Proper F-stop



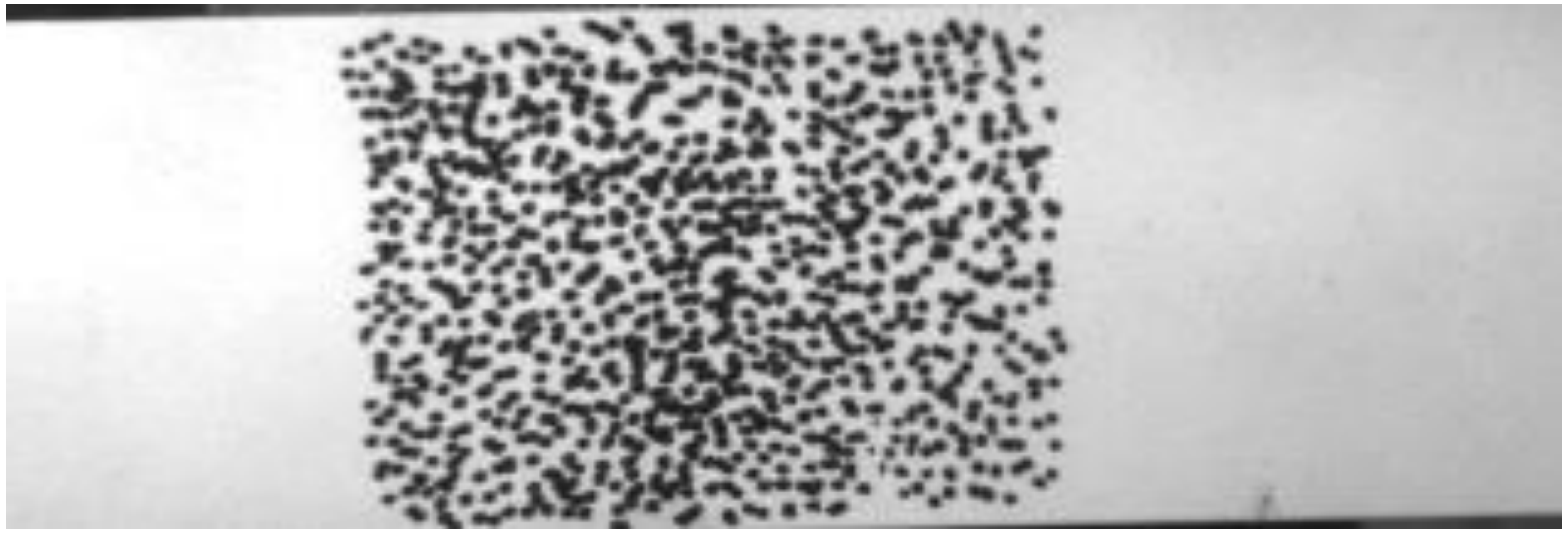


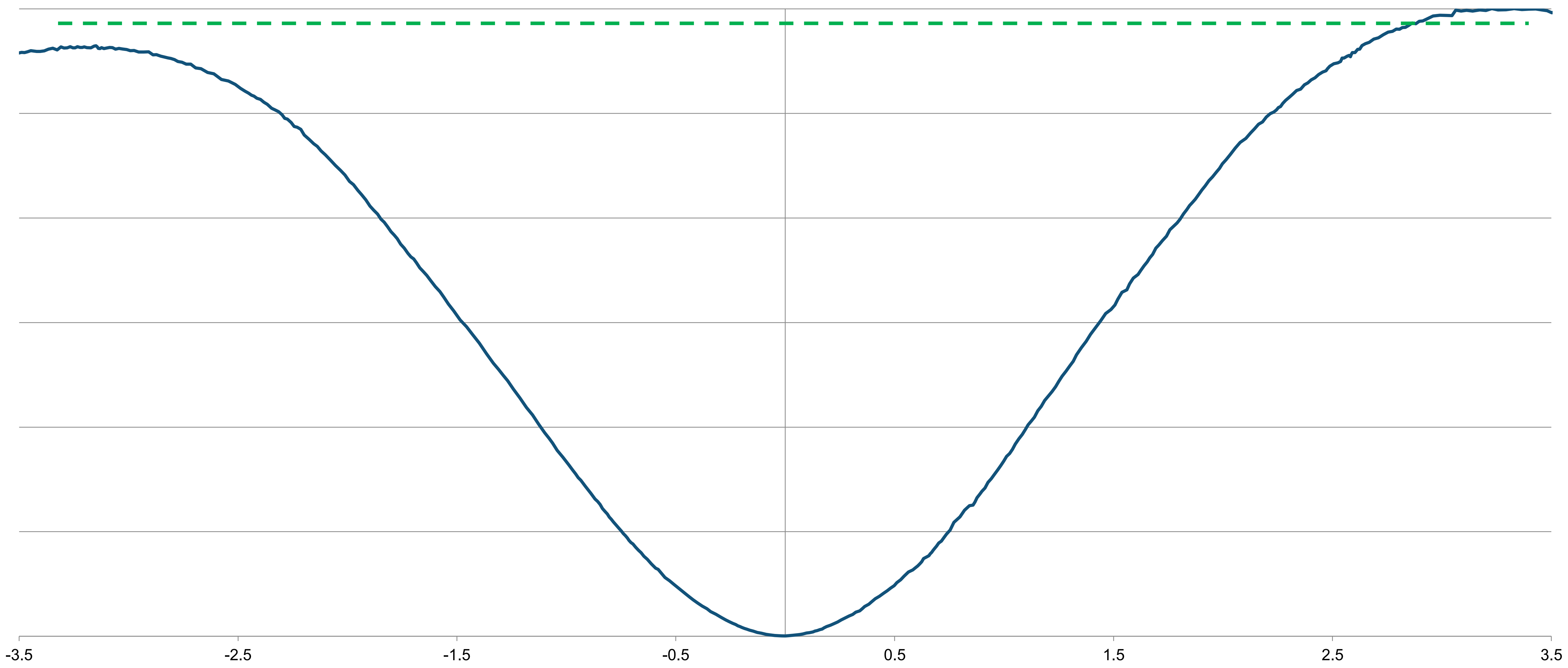
Great Pattern Example

- Sharpie marker on white paint
- Bright whites
- Dark blacks
- Hard edges
- Consistent speckle size



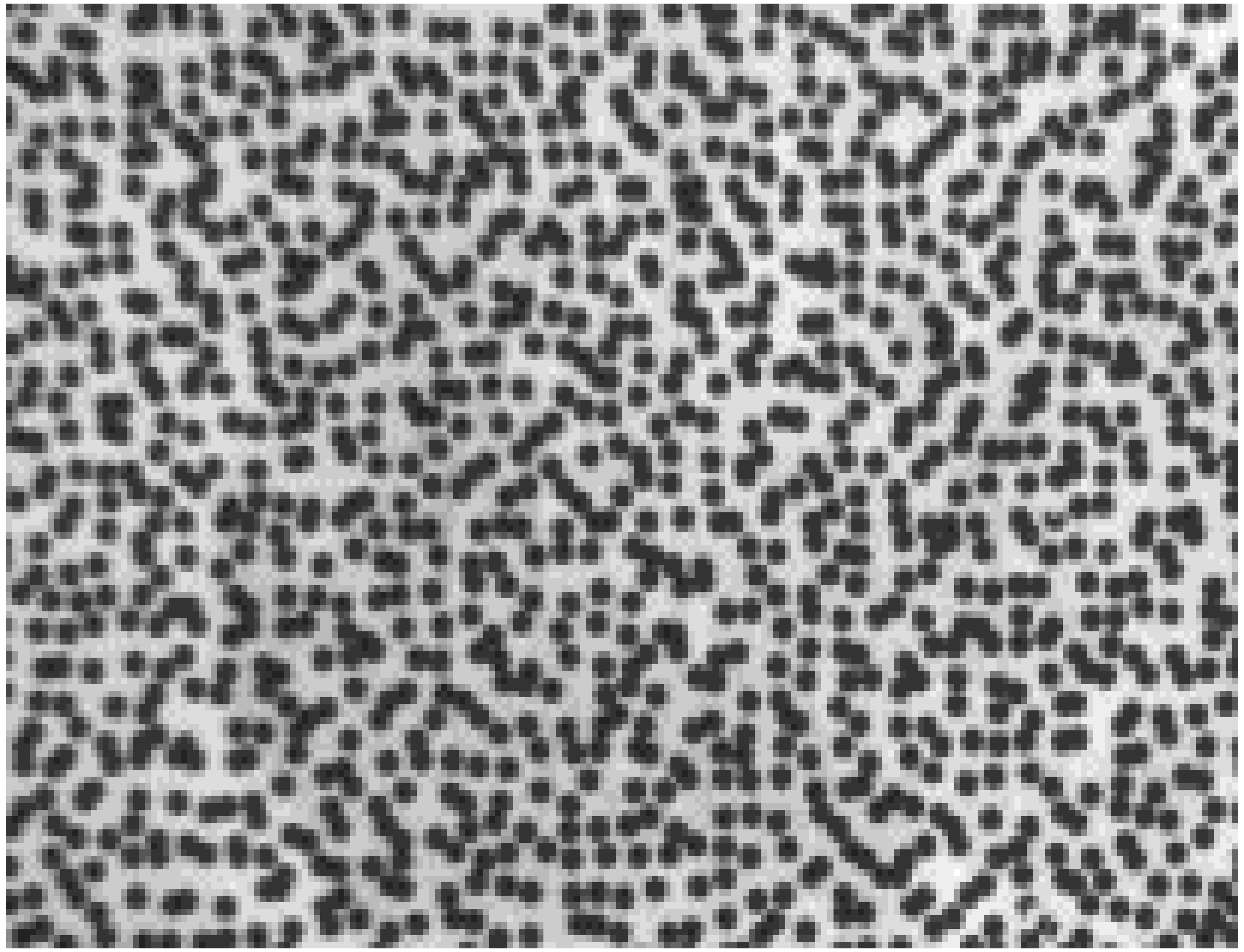
Great Pattern Example



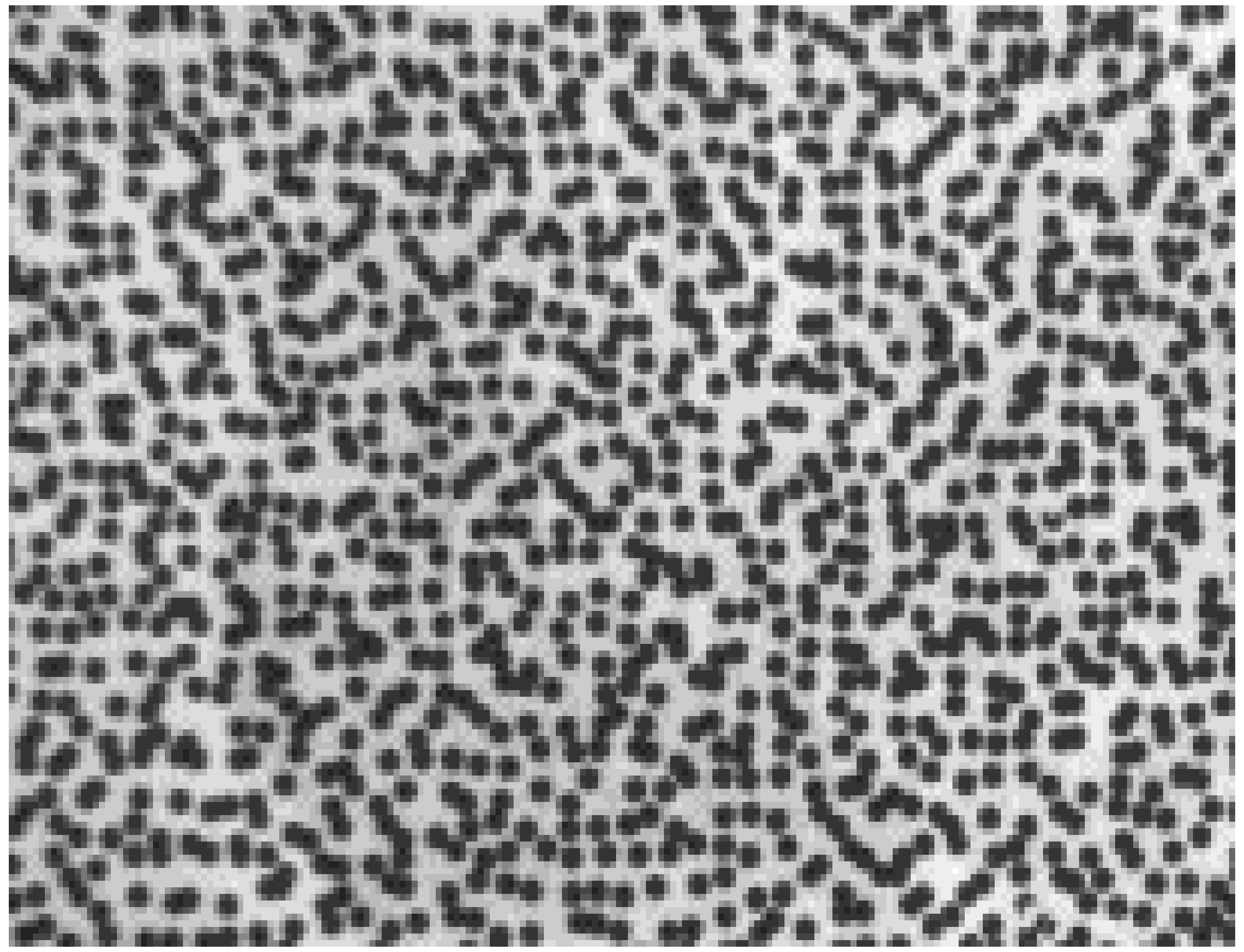


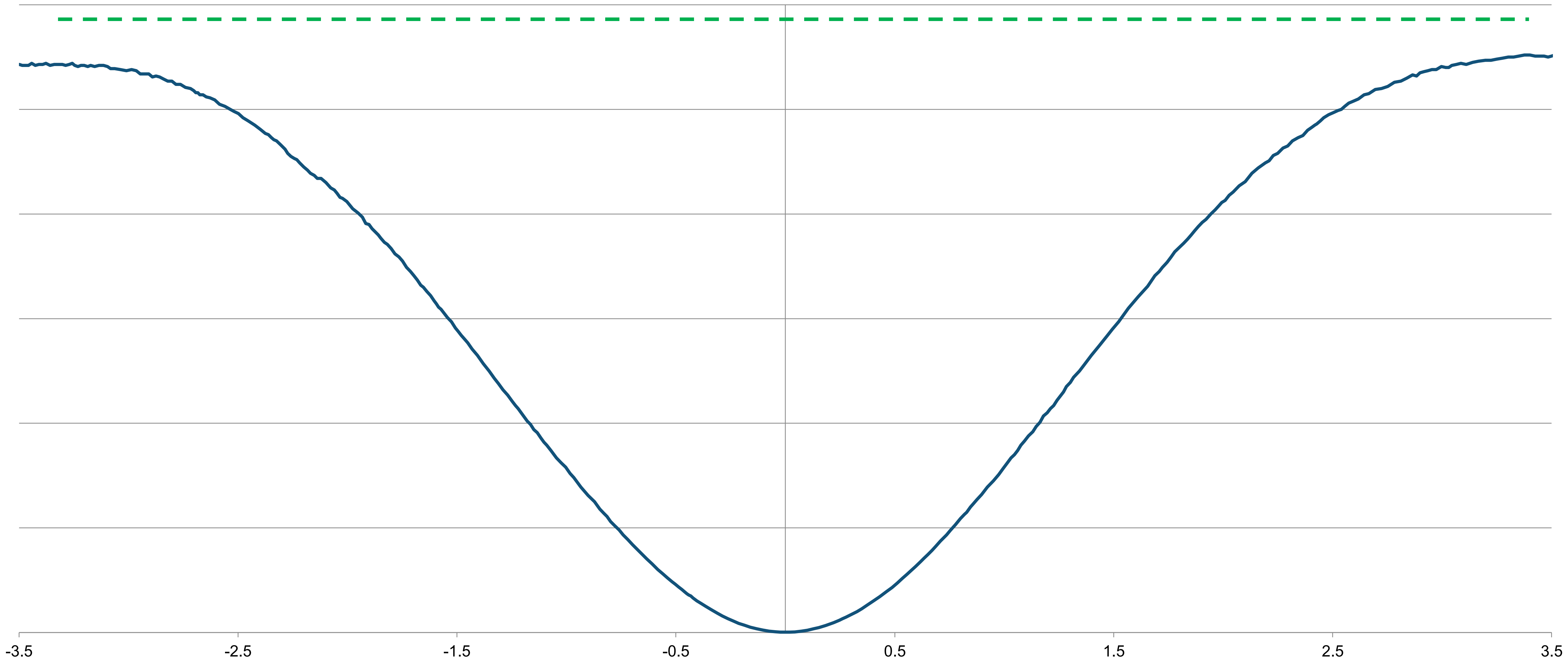
High Contrast Printed Pattern

- Laser printer
- CSI target generator
- Good contrast
- Consistent size



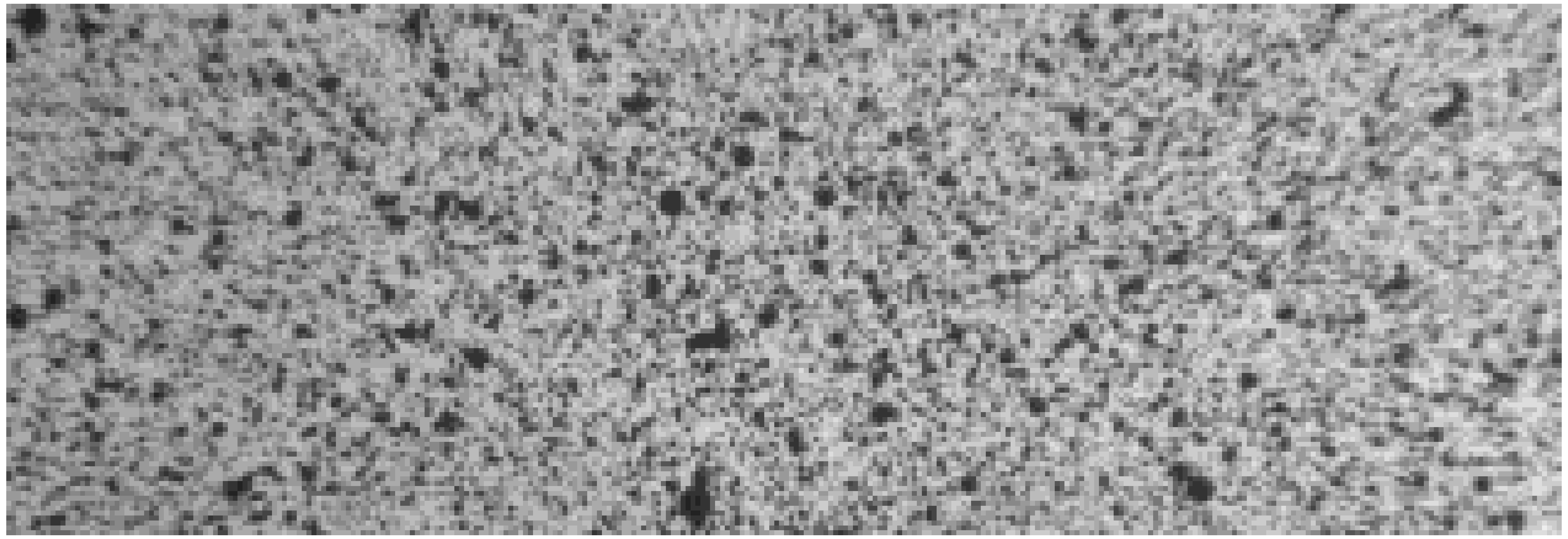
High Contrast Printed Pattern



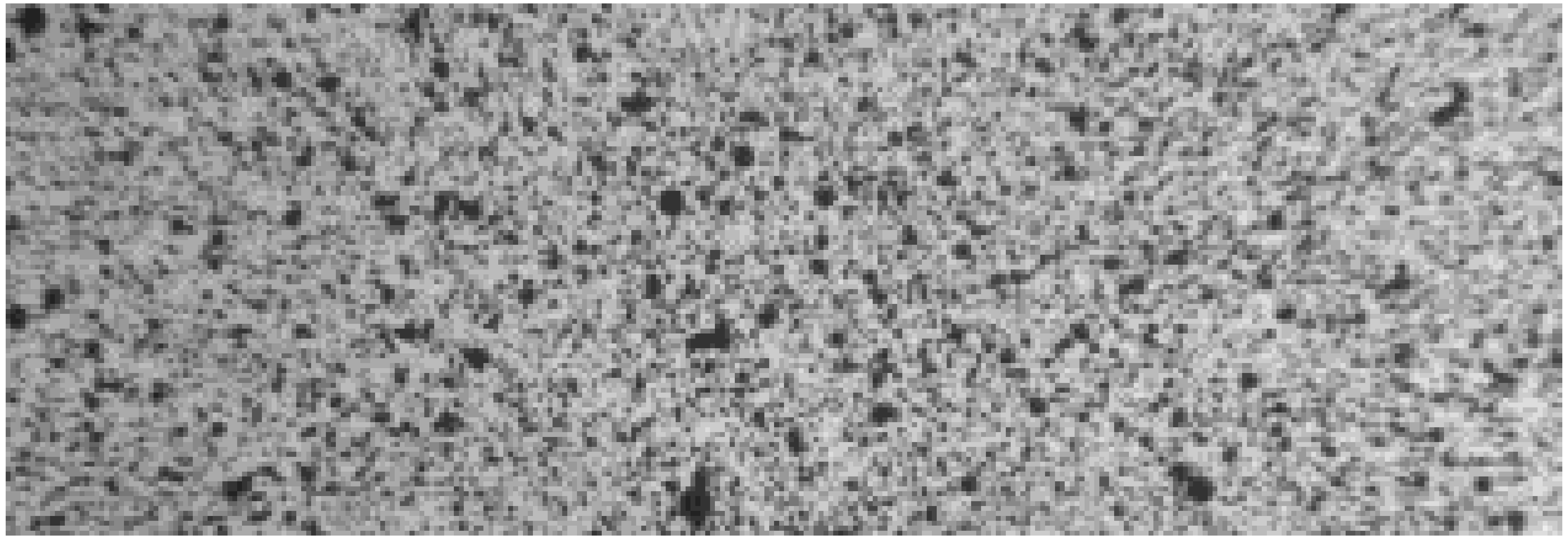


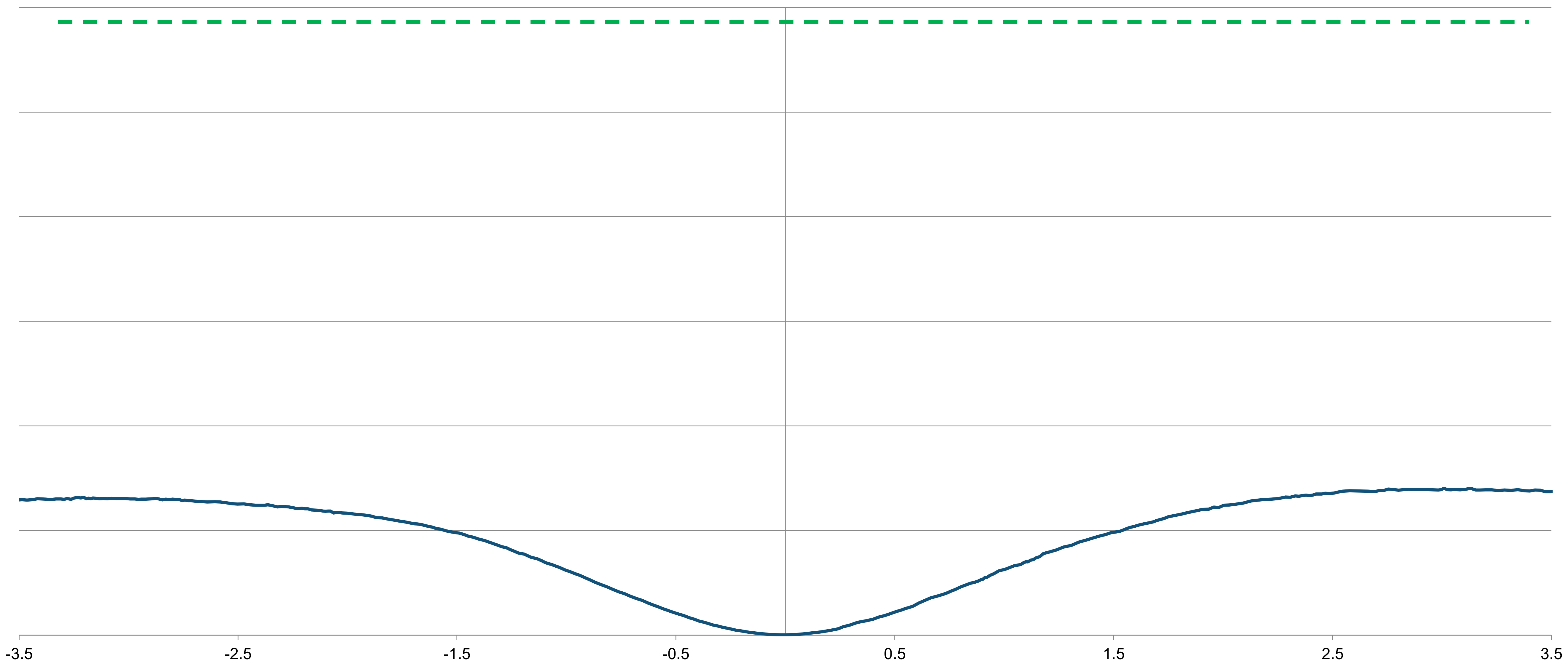
Typical Painted Pattern

- Inconsistent size
- No bright white areas
- Soft edges

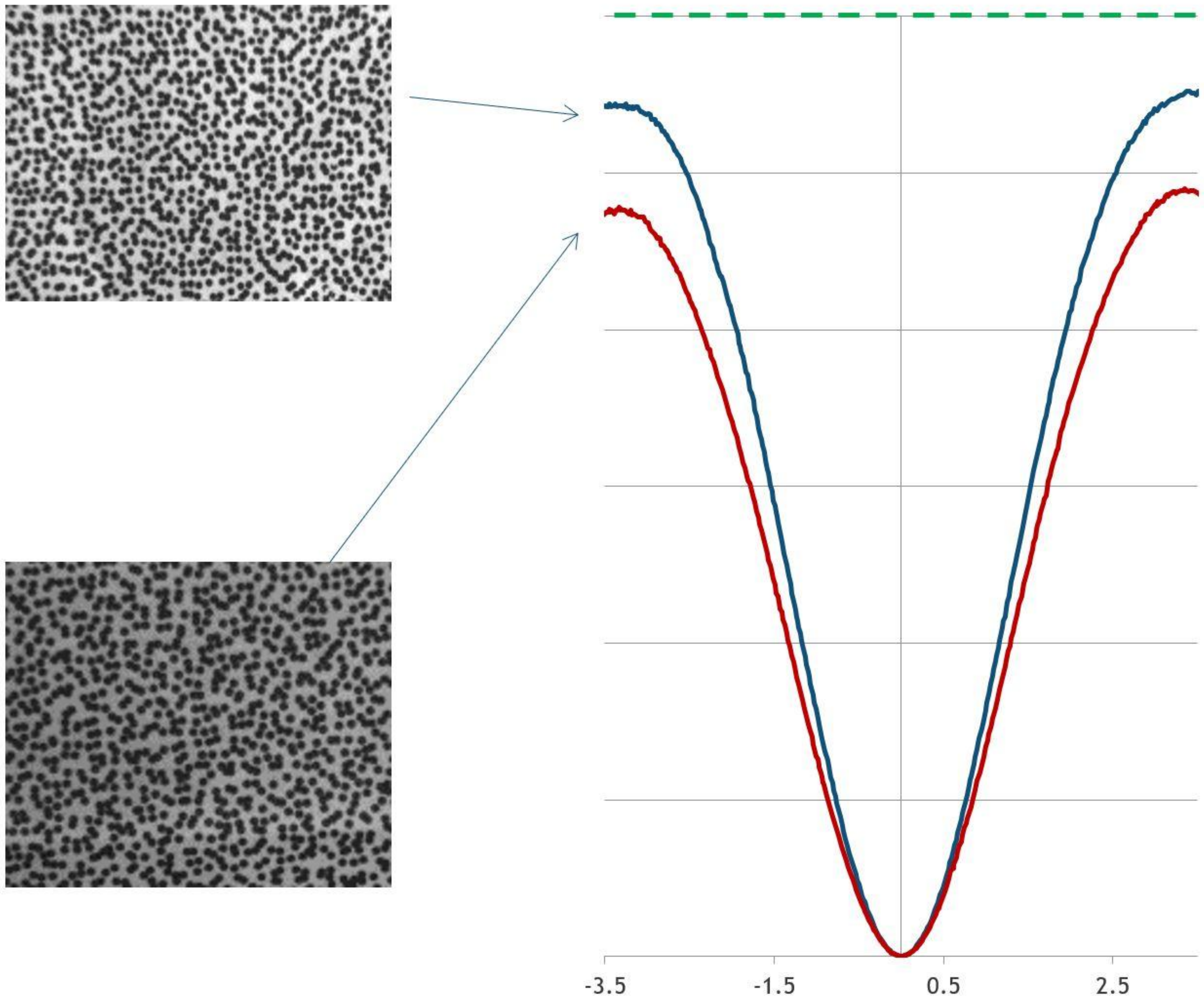


Typical Painted Pattern

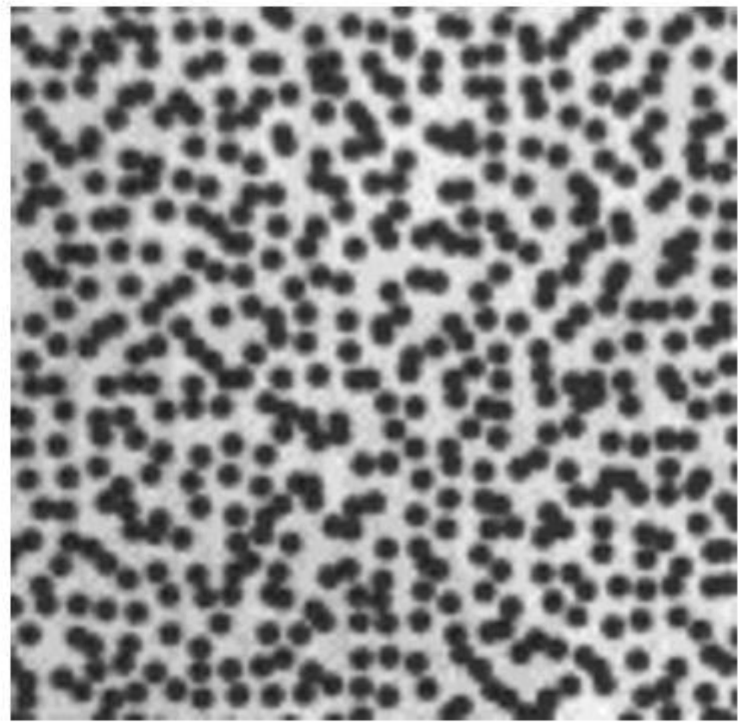


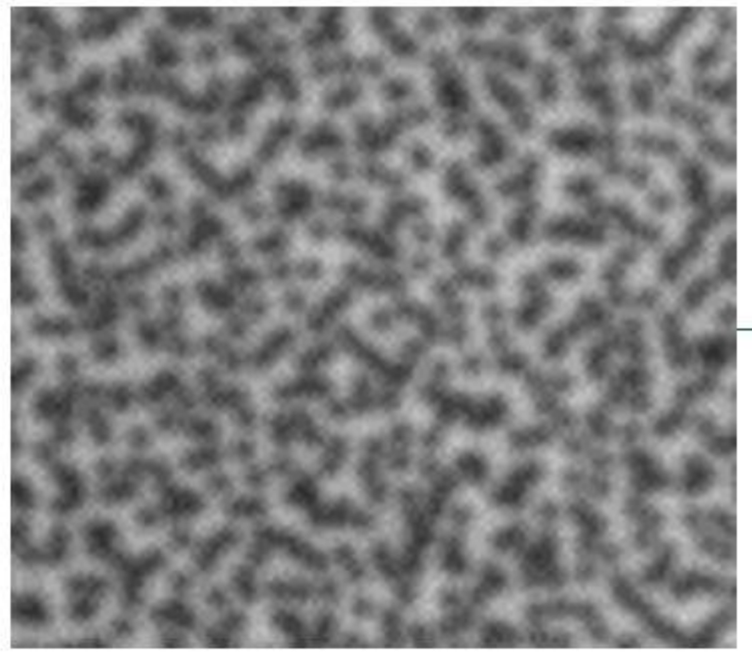


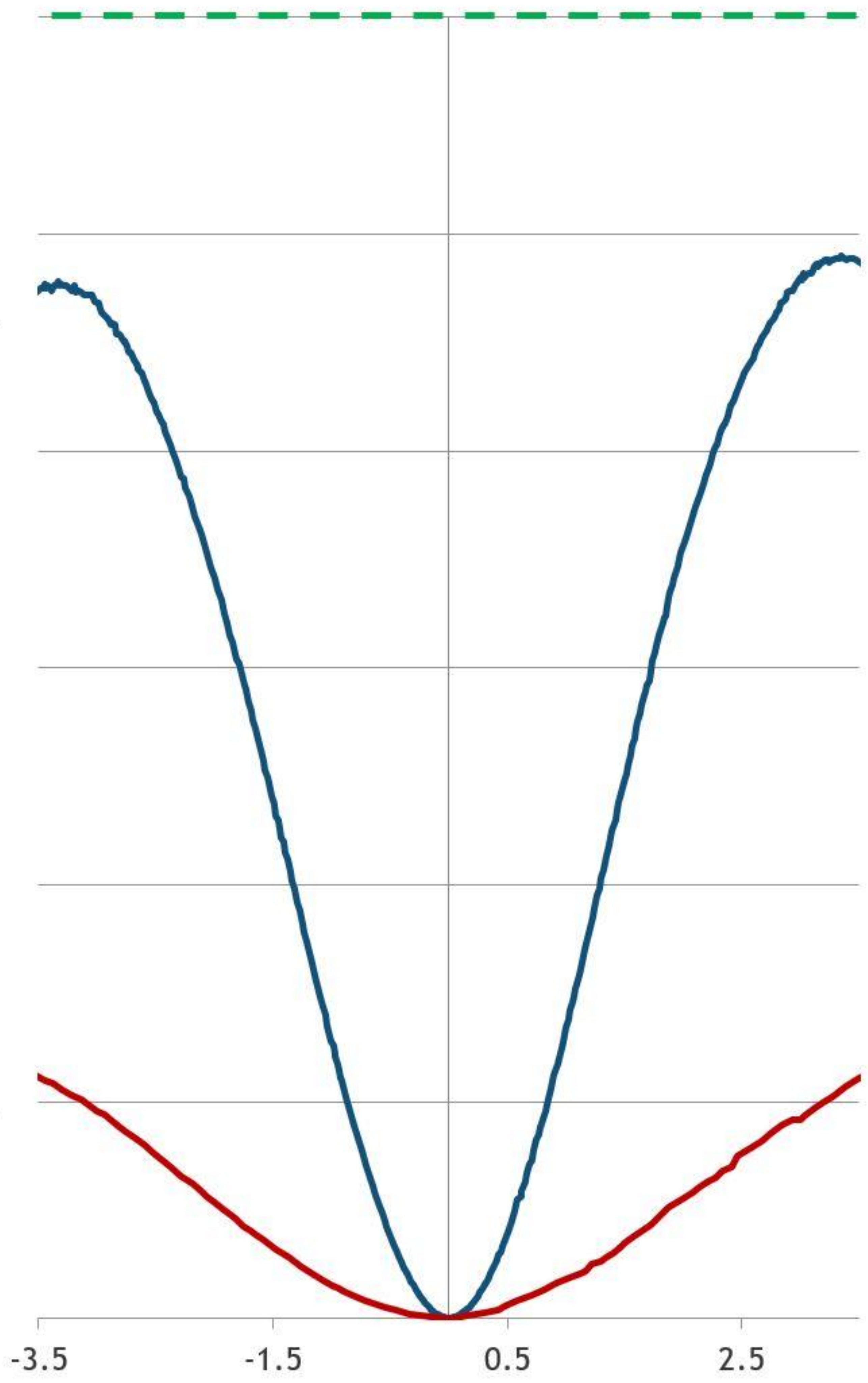
Effect of Reduced Contrast



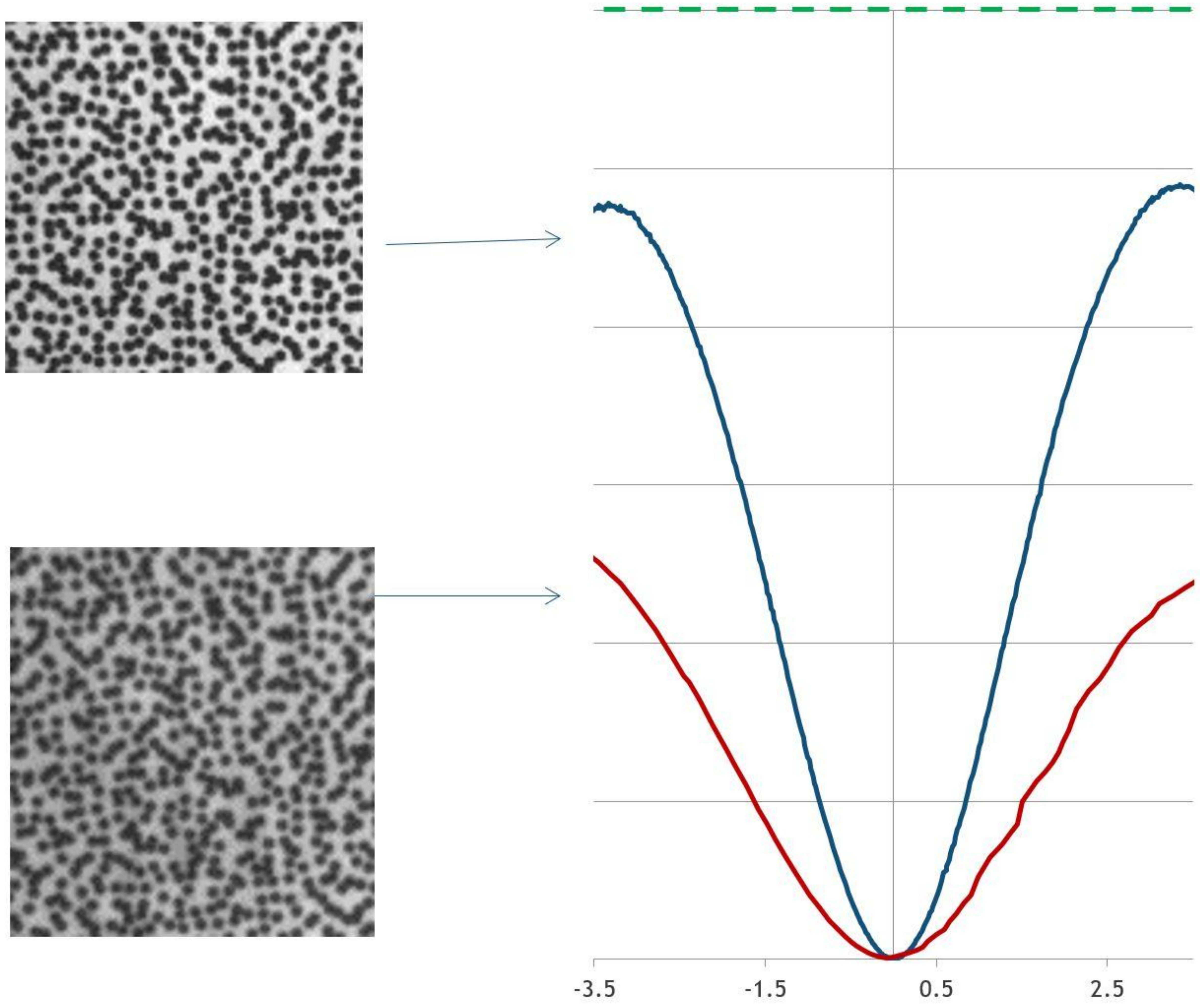
Effect of Reduced Focus



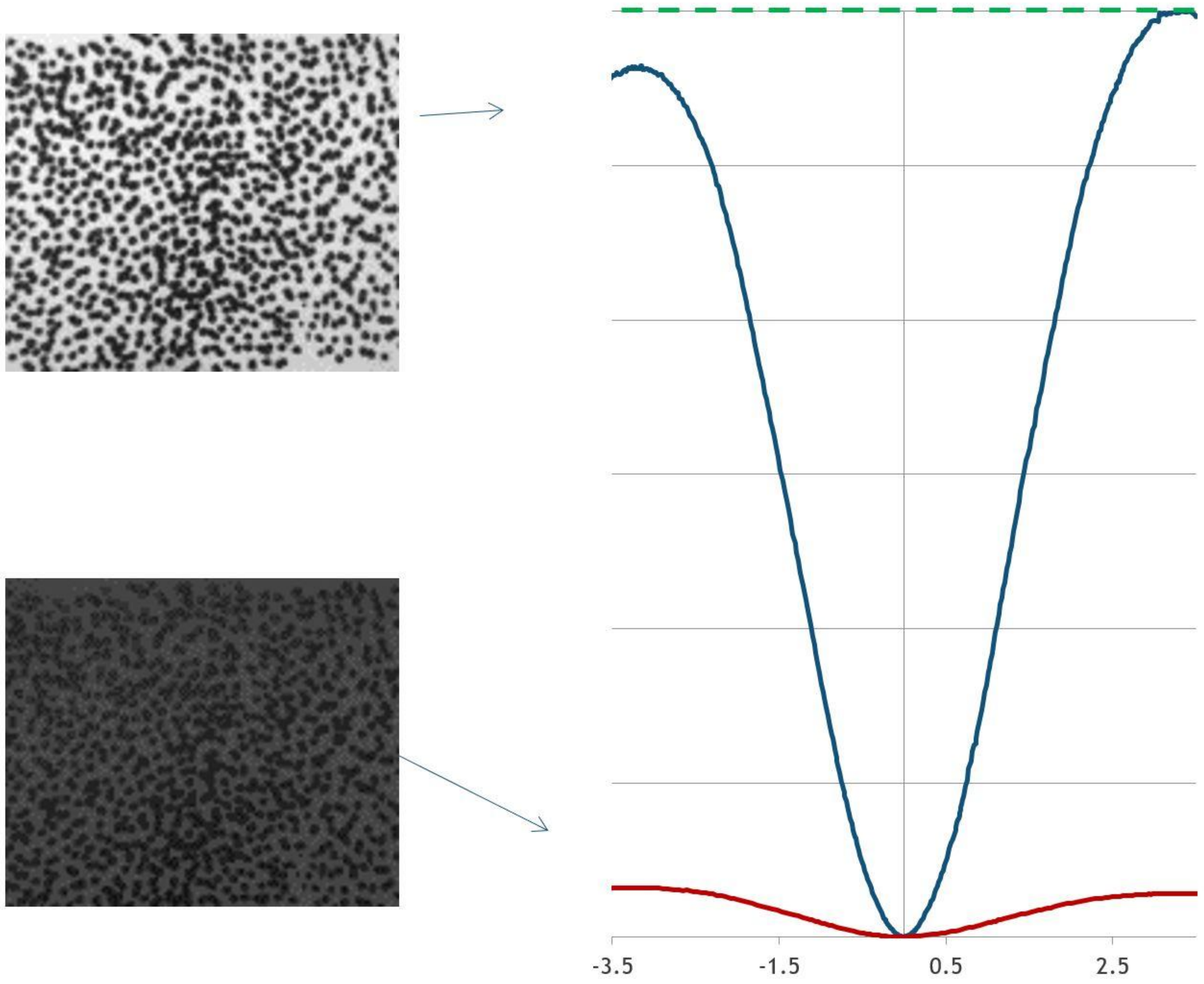




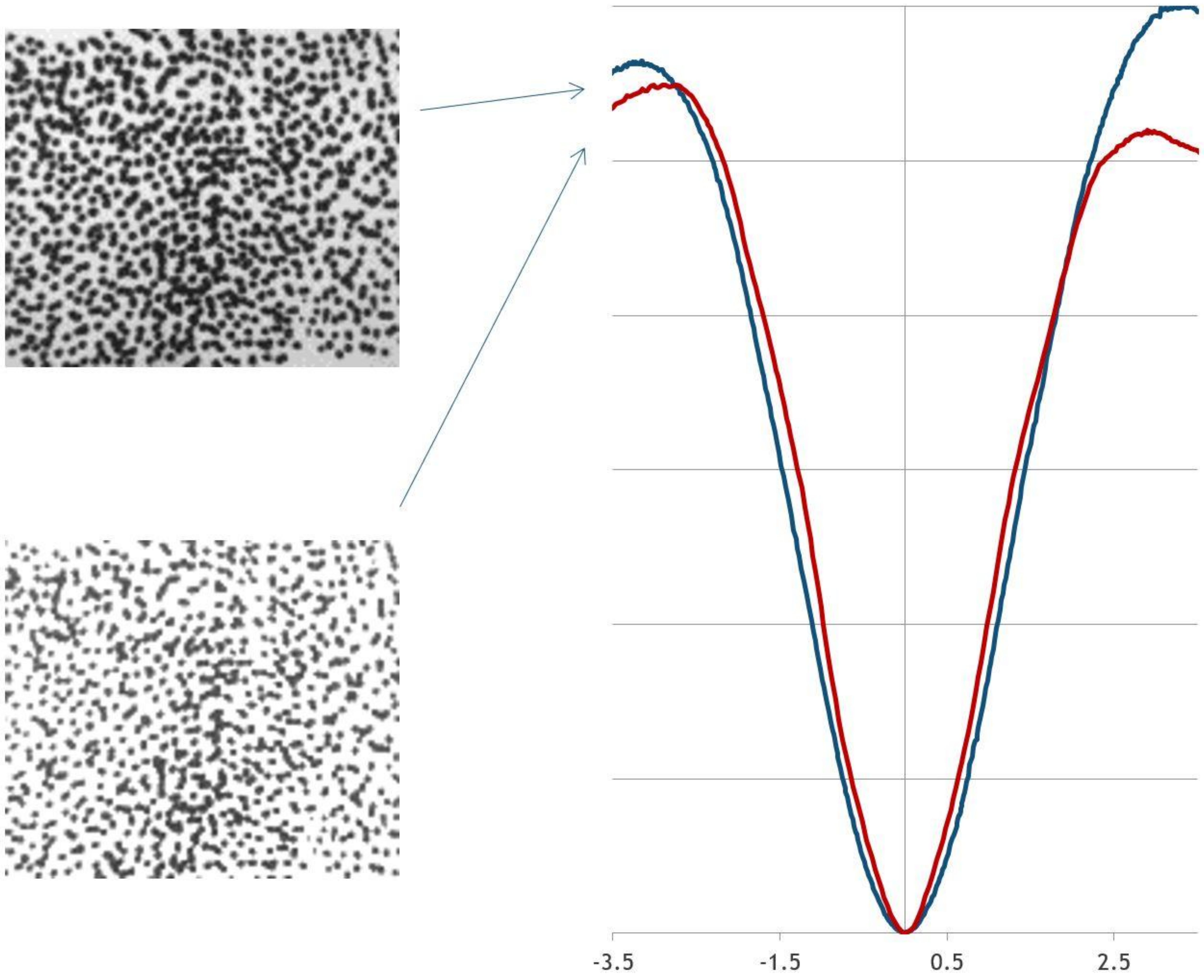
Aperture too small



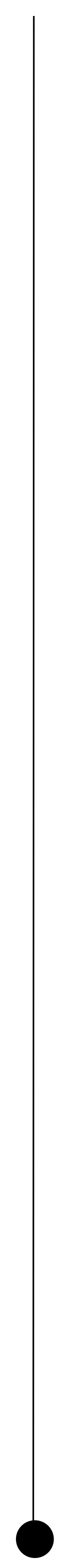
Effect of low light



Effect of too much light

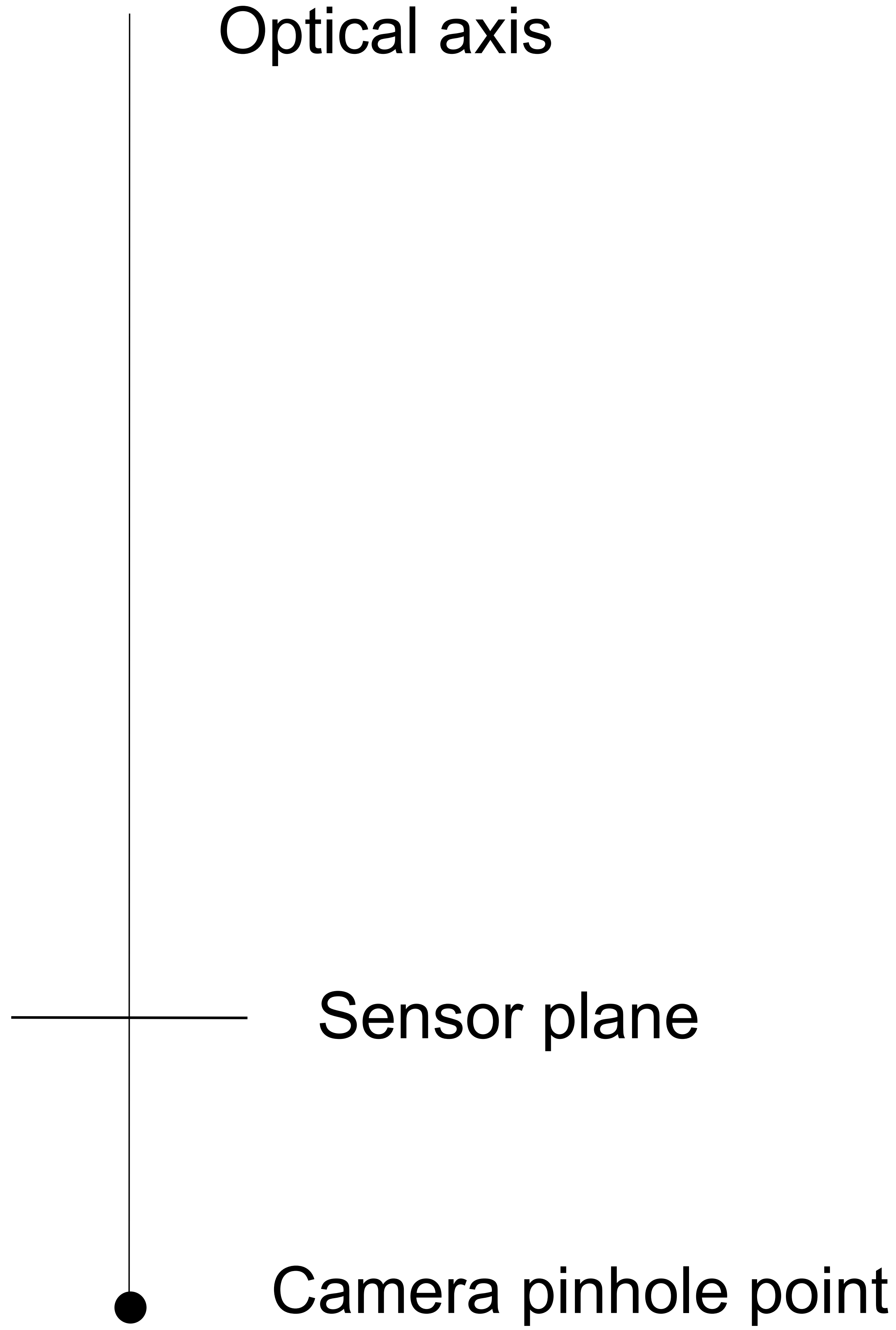


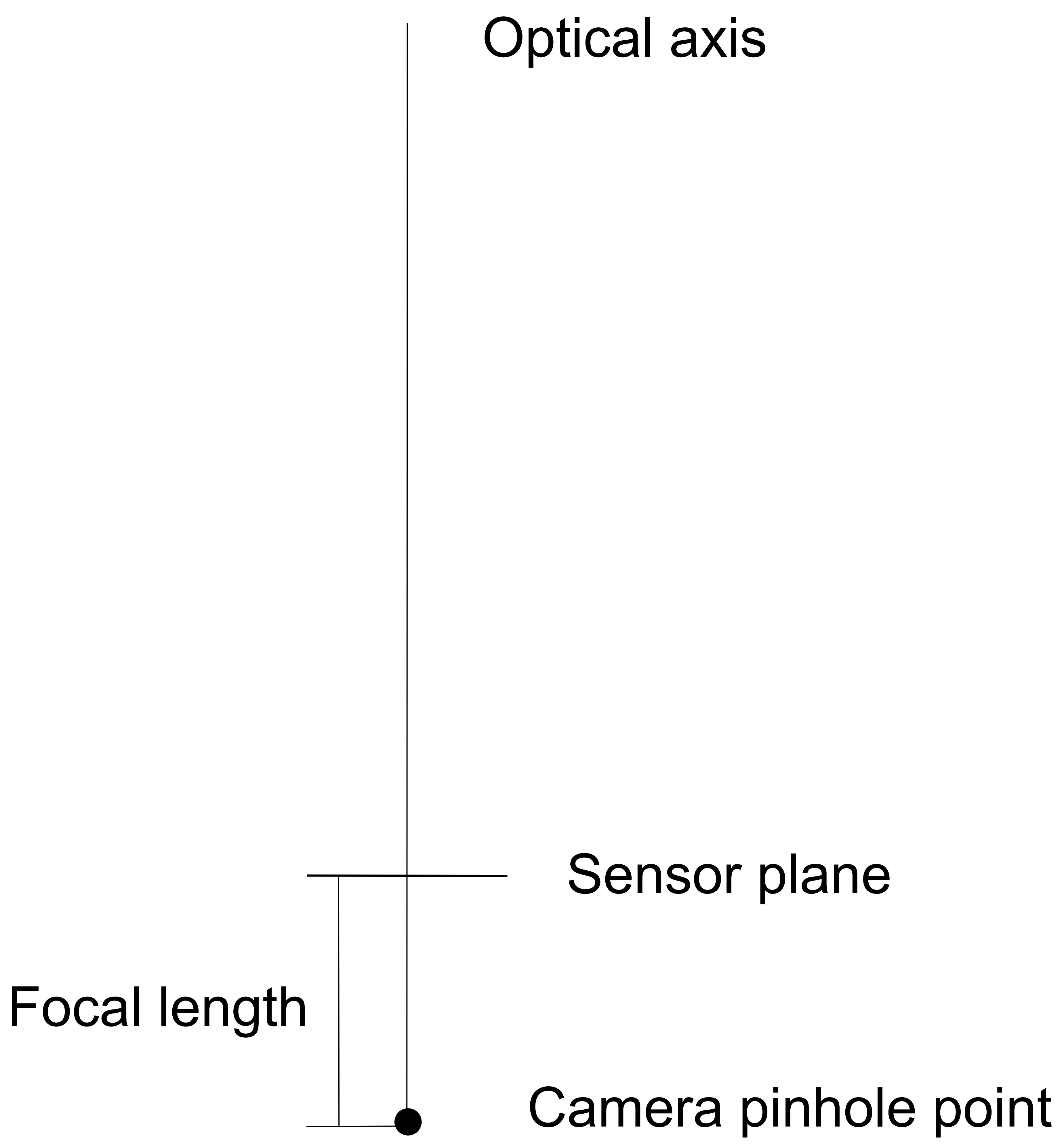
Confidence Margins in 3D



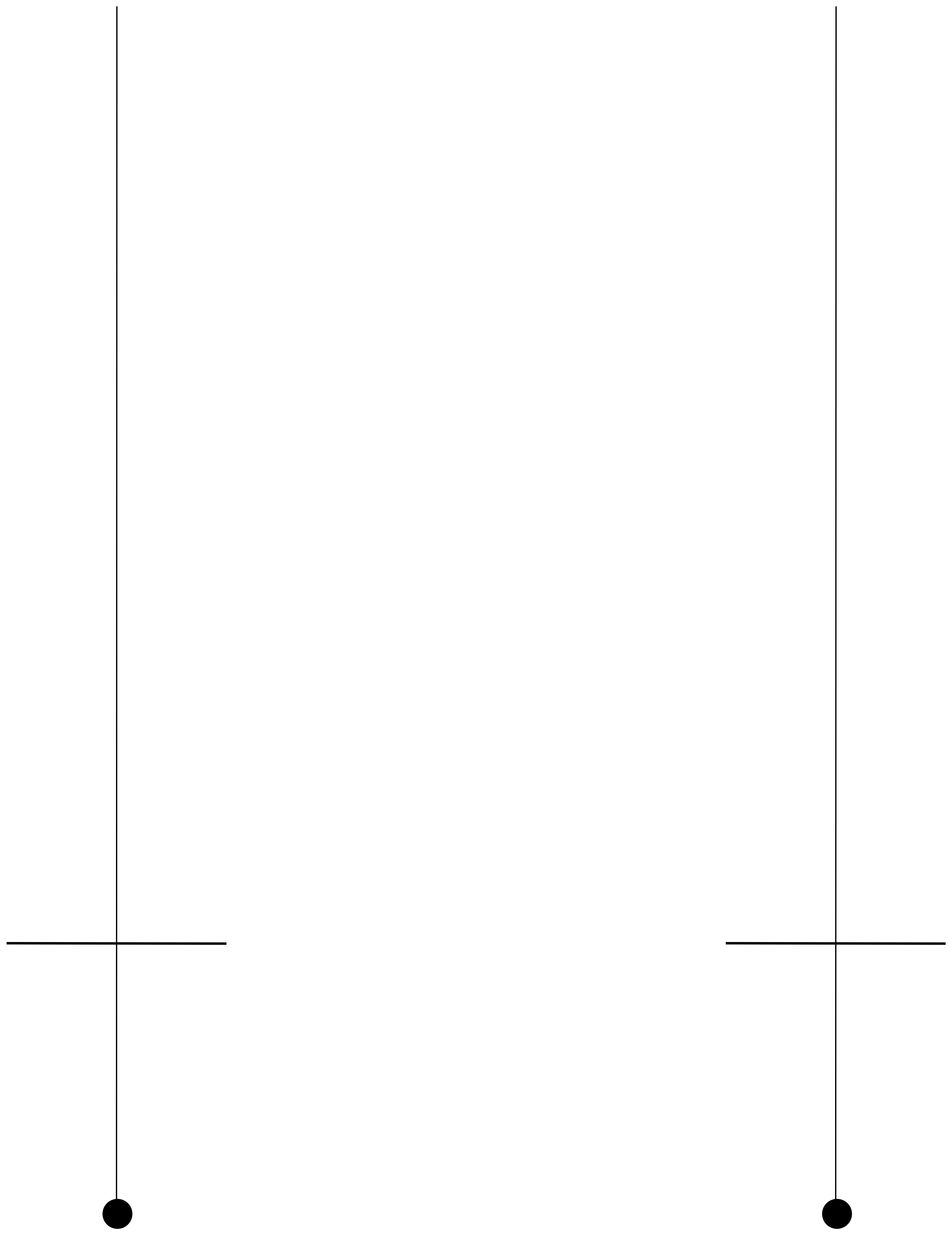
correlated SOLUTIONS

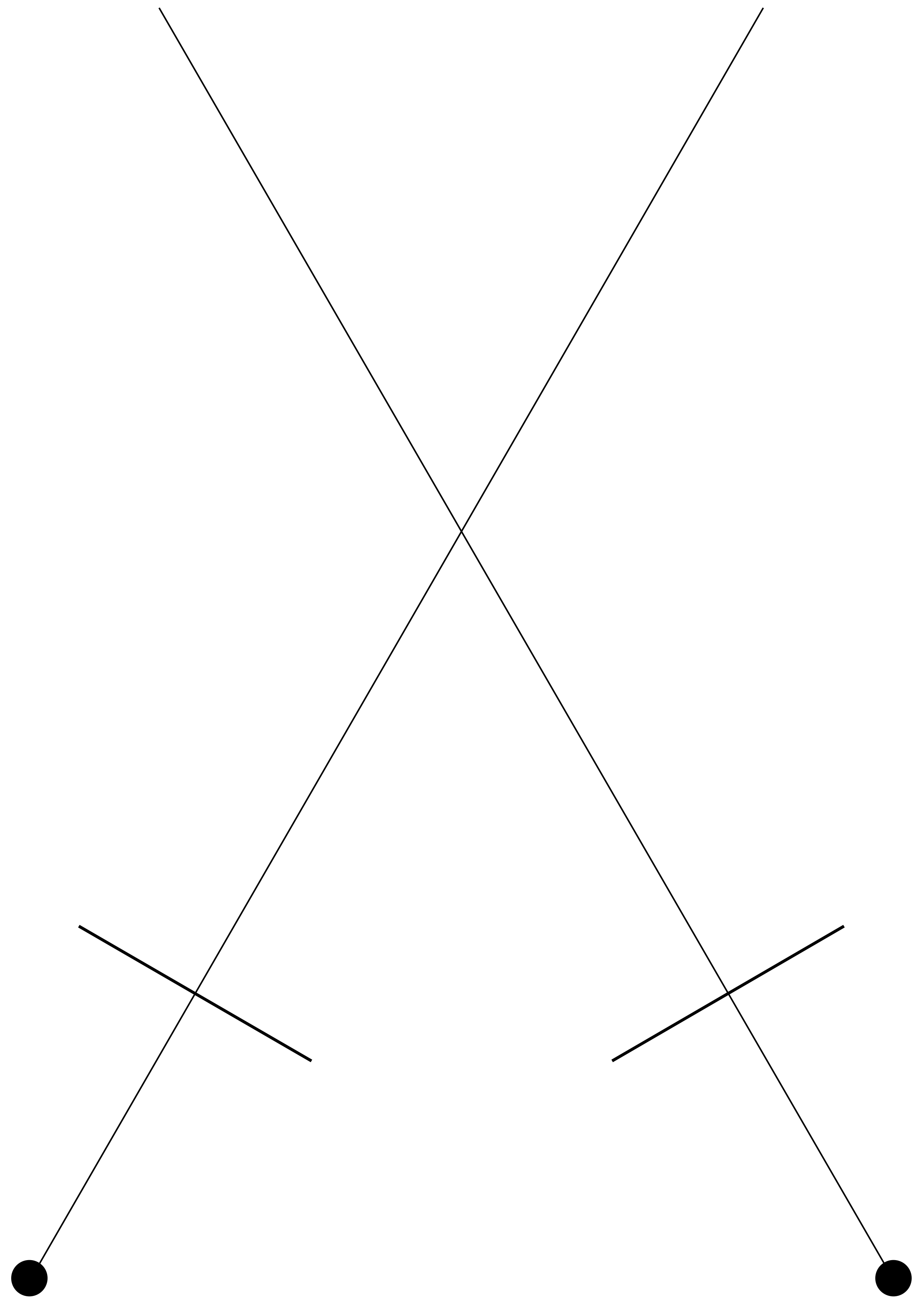
Confidence Margins in 3D




Optical axis
Sensor plane
Focal length
Camera pinhole point

Confidence Margins in 3D

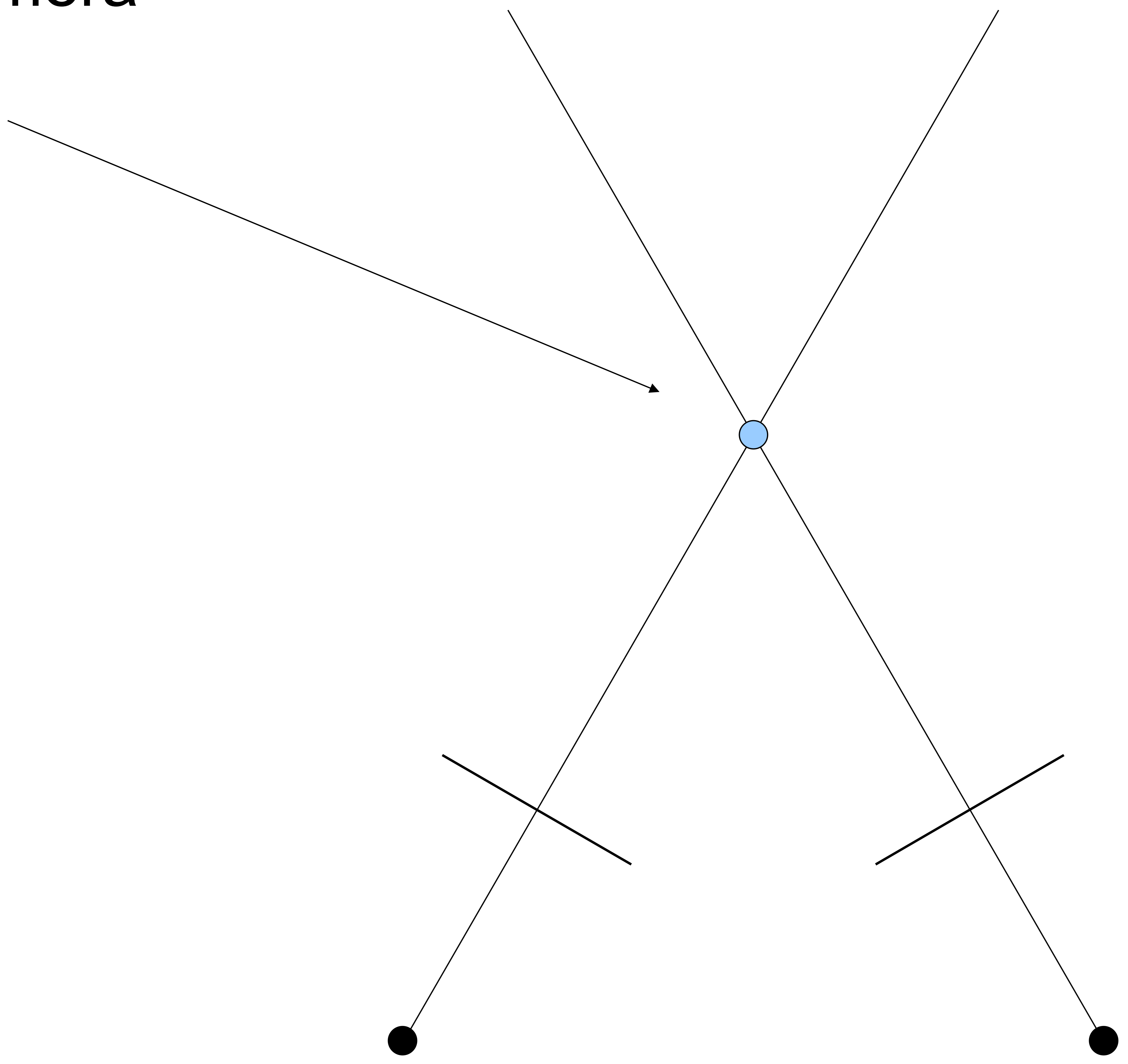




Stereo system

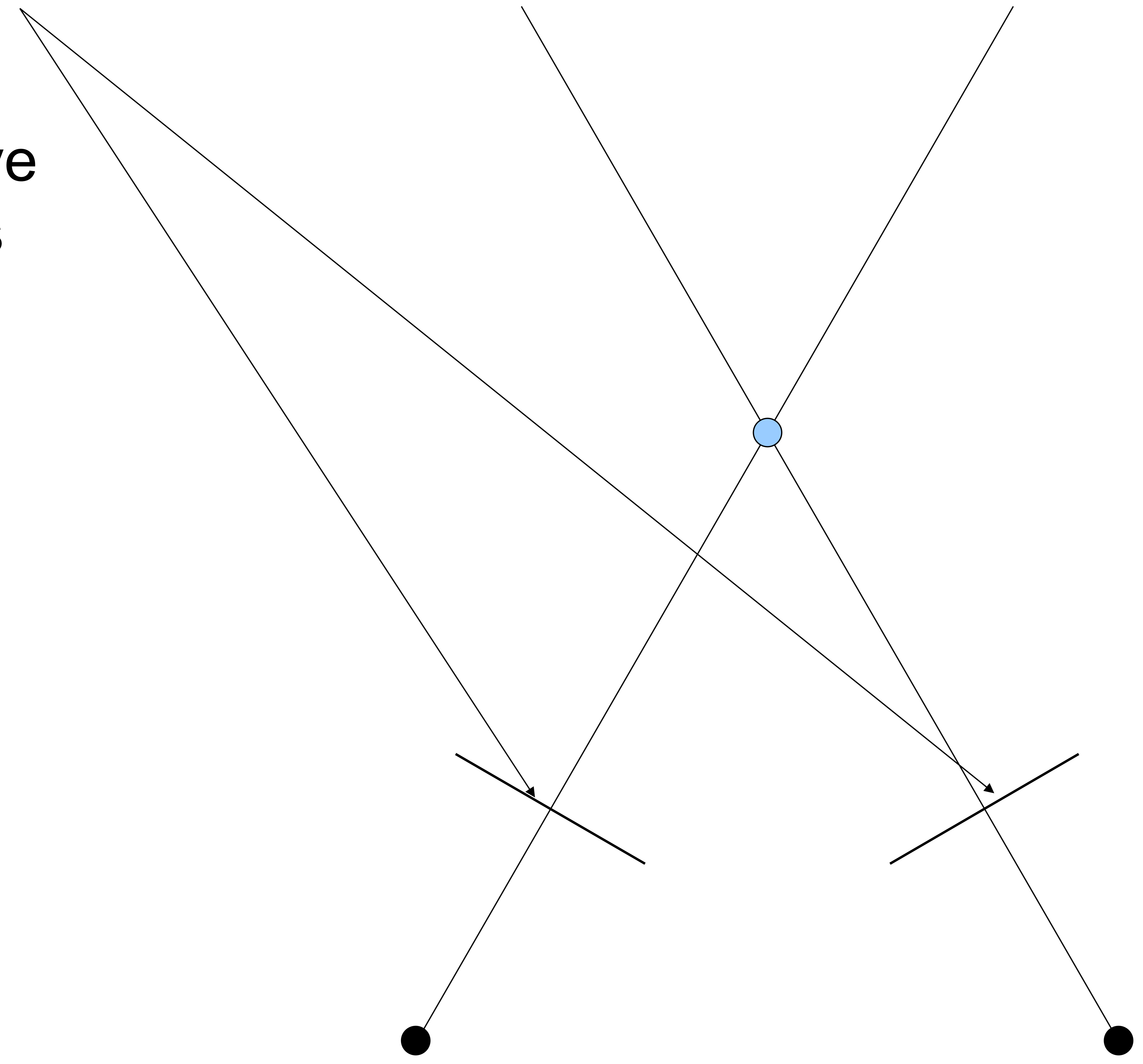
Confidence Margins in 3D

Triangulate point located on optical axis of each camera



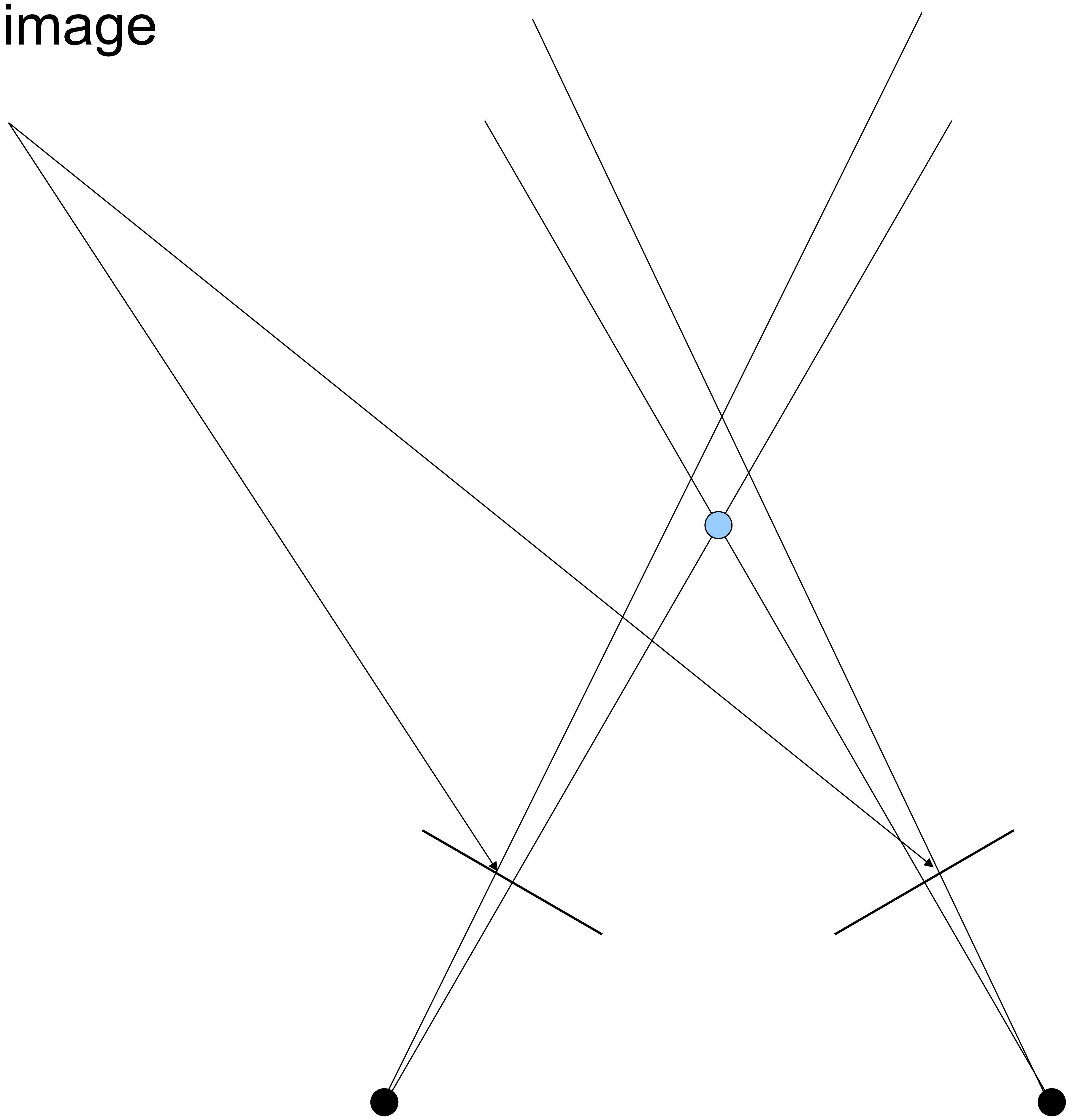
Add noise to 2D image points:

This is the noise we have discussed so far in this presentation

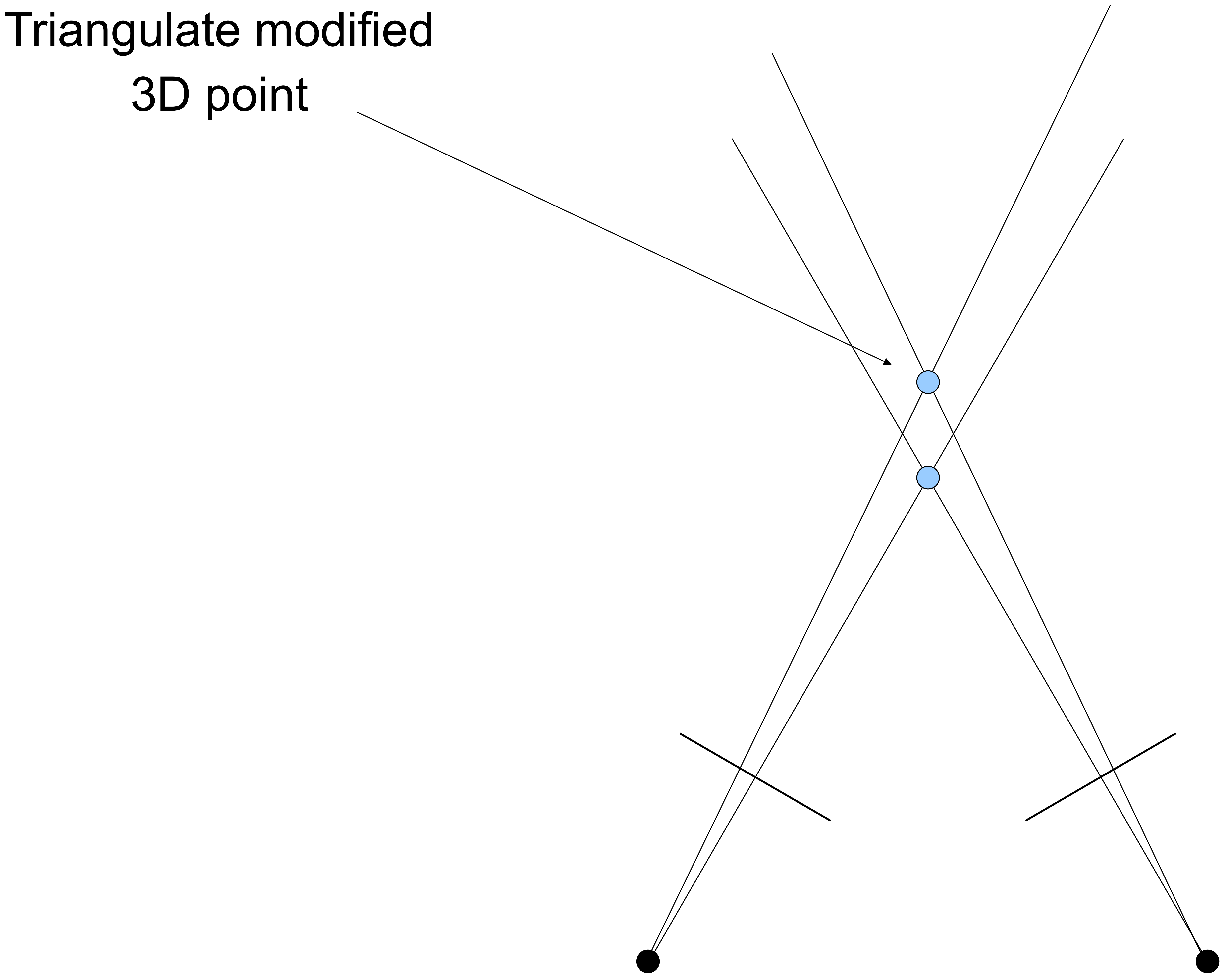


Confidence Margins in 3D

Add noise to 2D image points

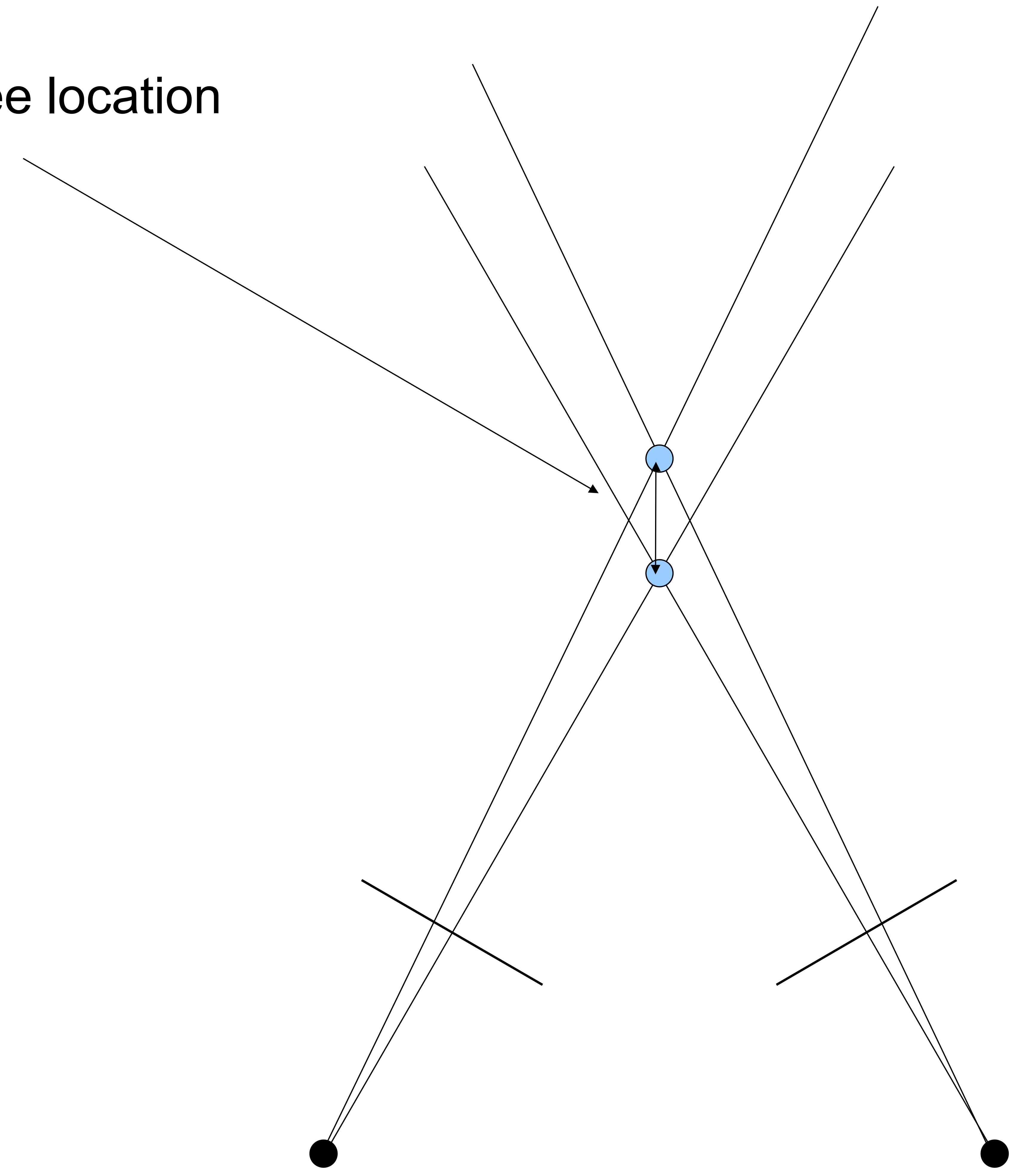


Confidence Margins in 3D



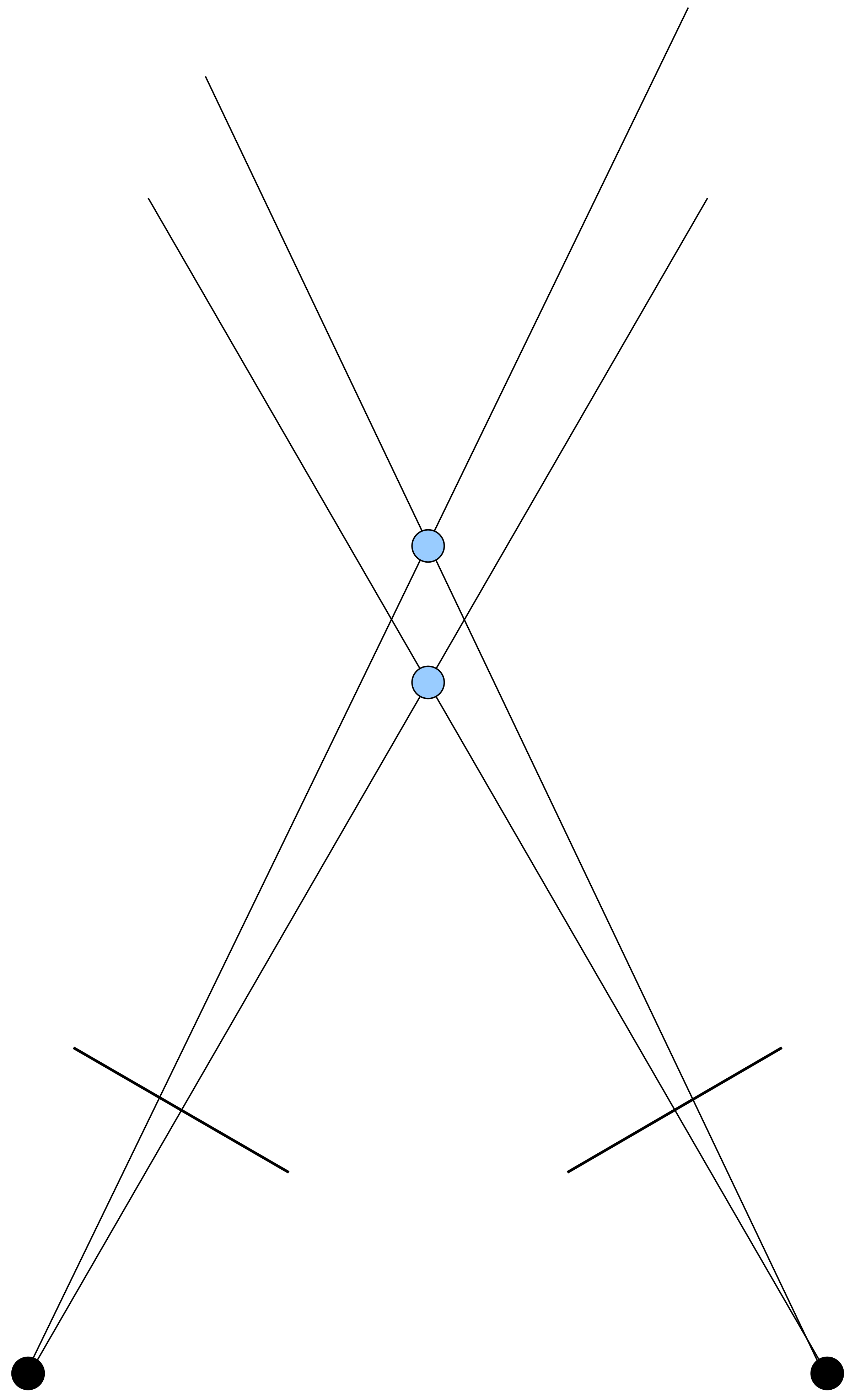
Confidence Margins in 3D

Measure deviation from noise-free location



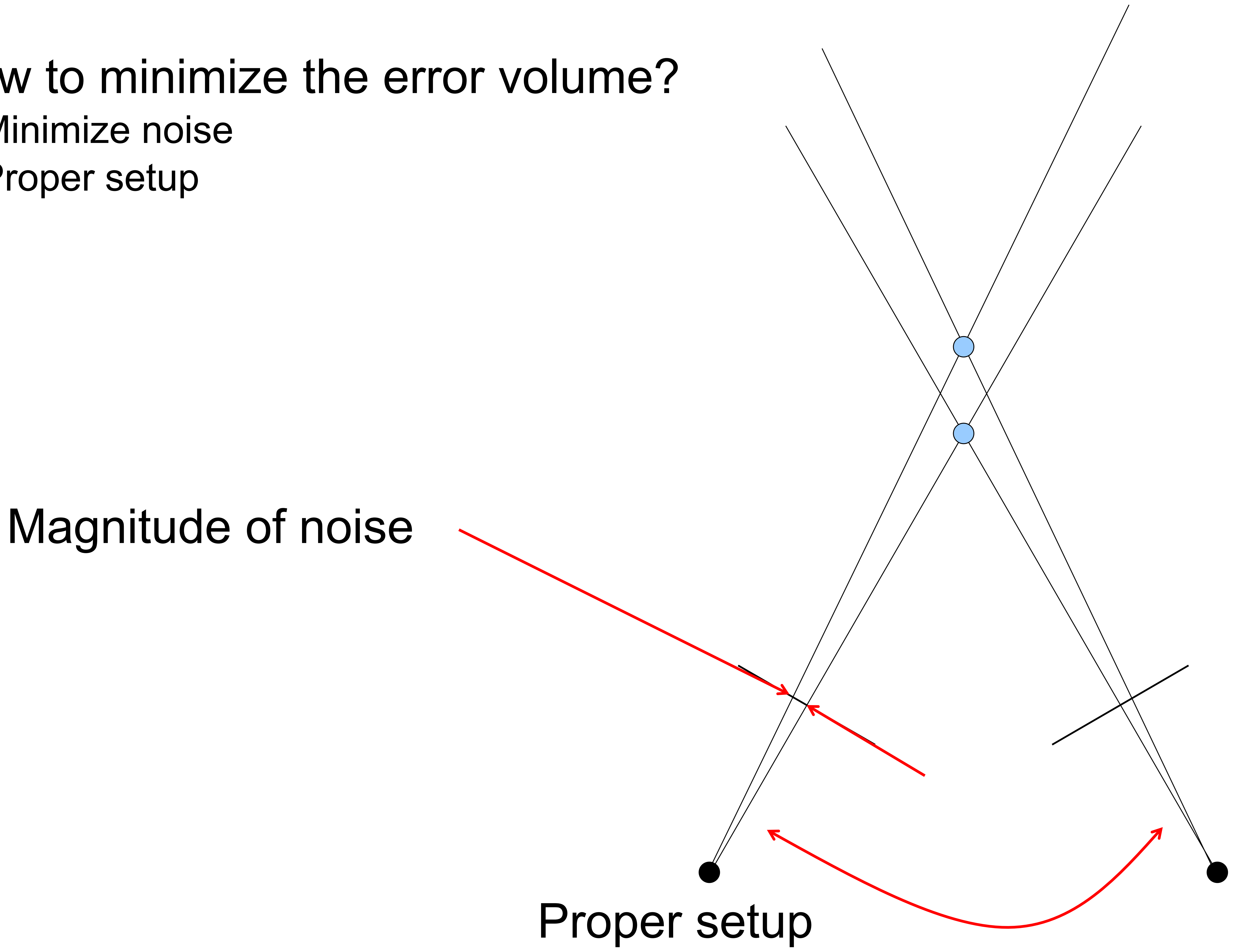
Confidence Margins in 3D

- By taking the set of all possible points, we generate a 3D volume in space.
- The volume has a height (Sigma_Y), a width (Sigma_X), and a depth (Sigma_Z)



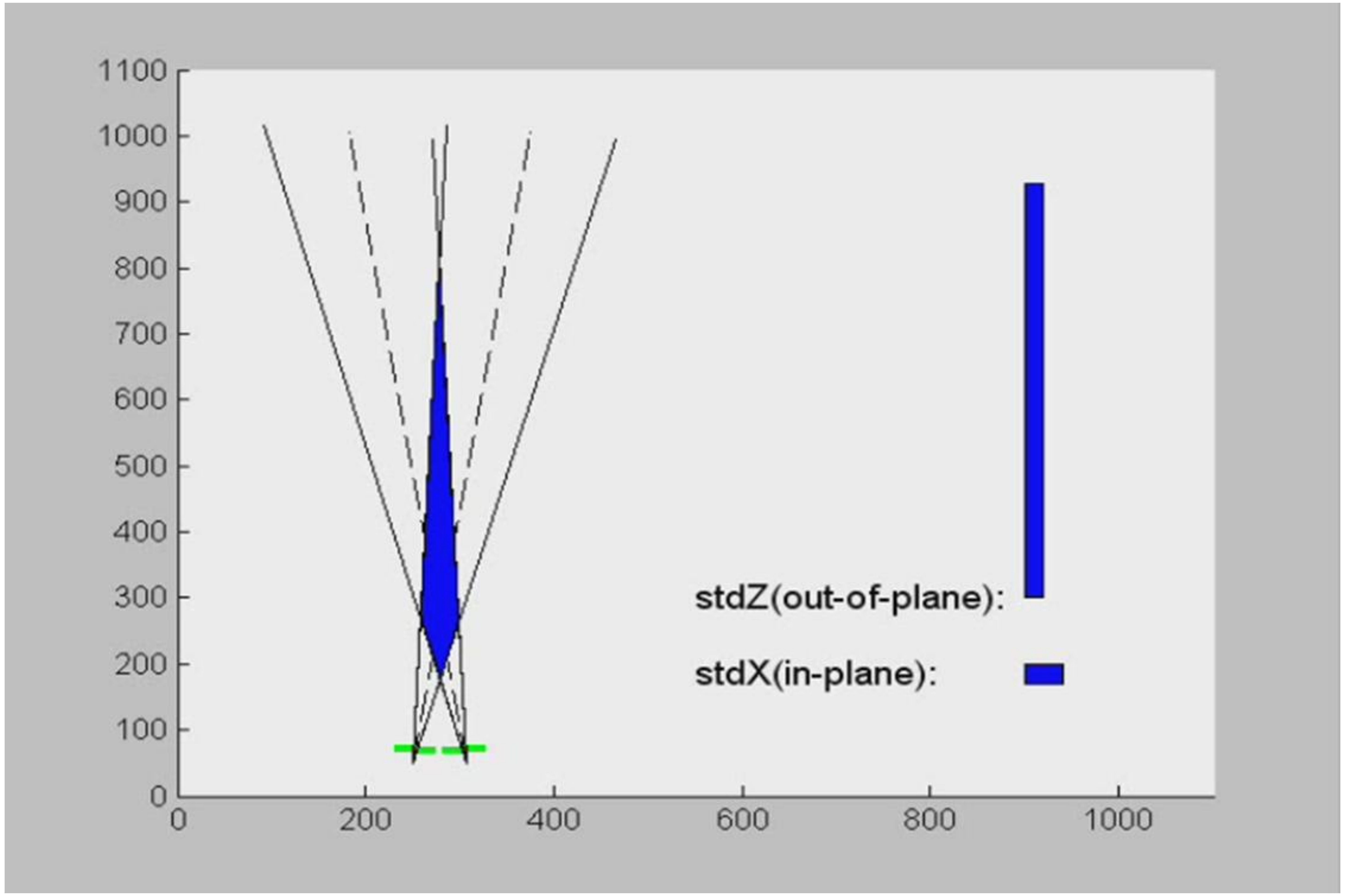
Confidence Margins in 3D

- How to minimize the error volume?
  - Minimize noise
  - Proper setup



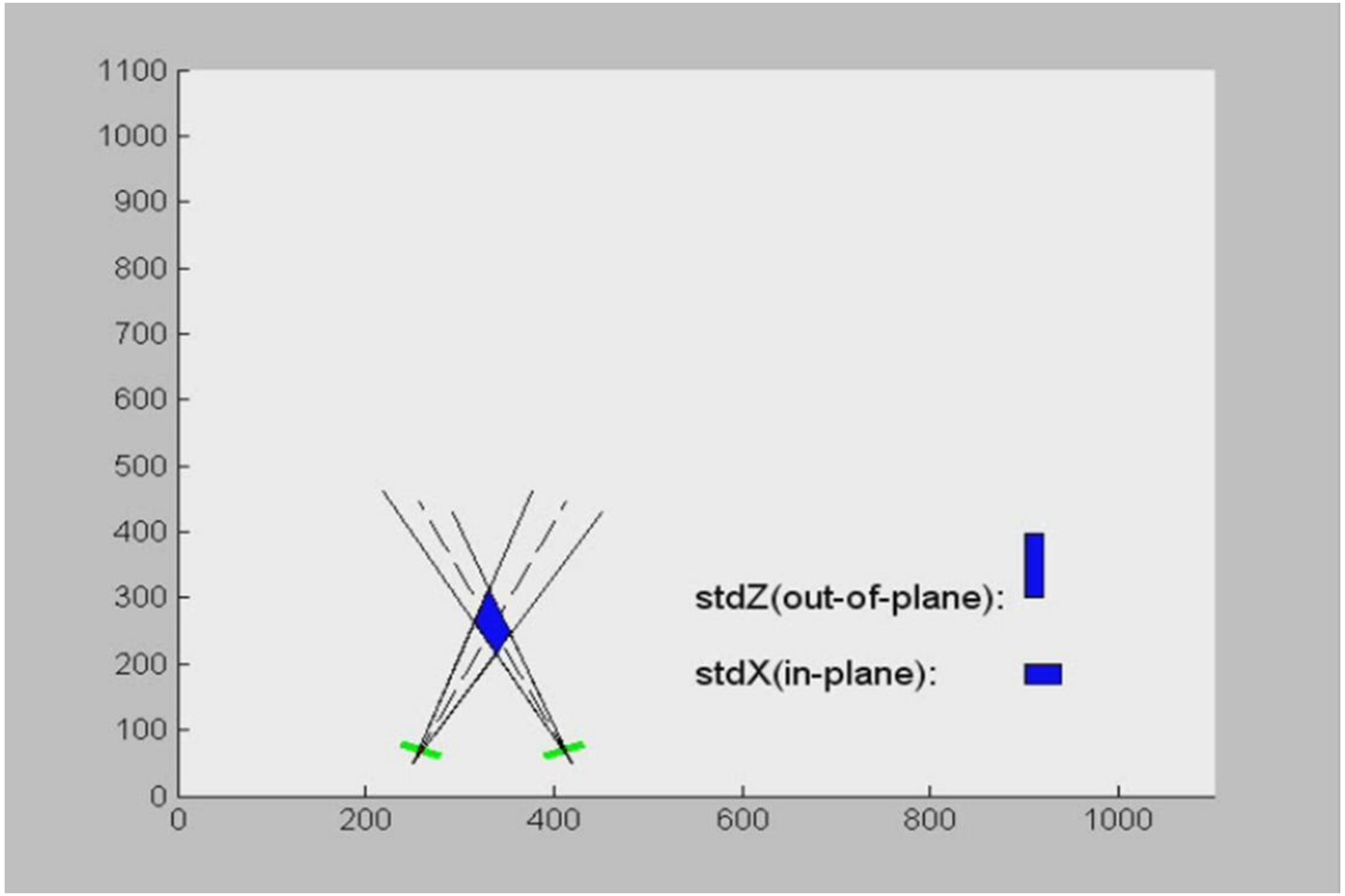
correlated SOLUTIONS

Effects of setup



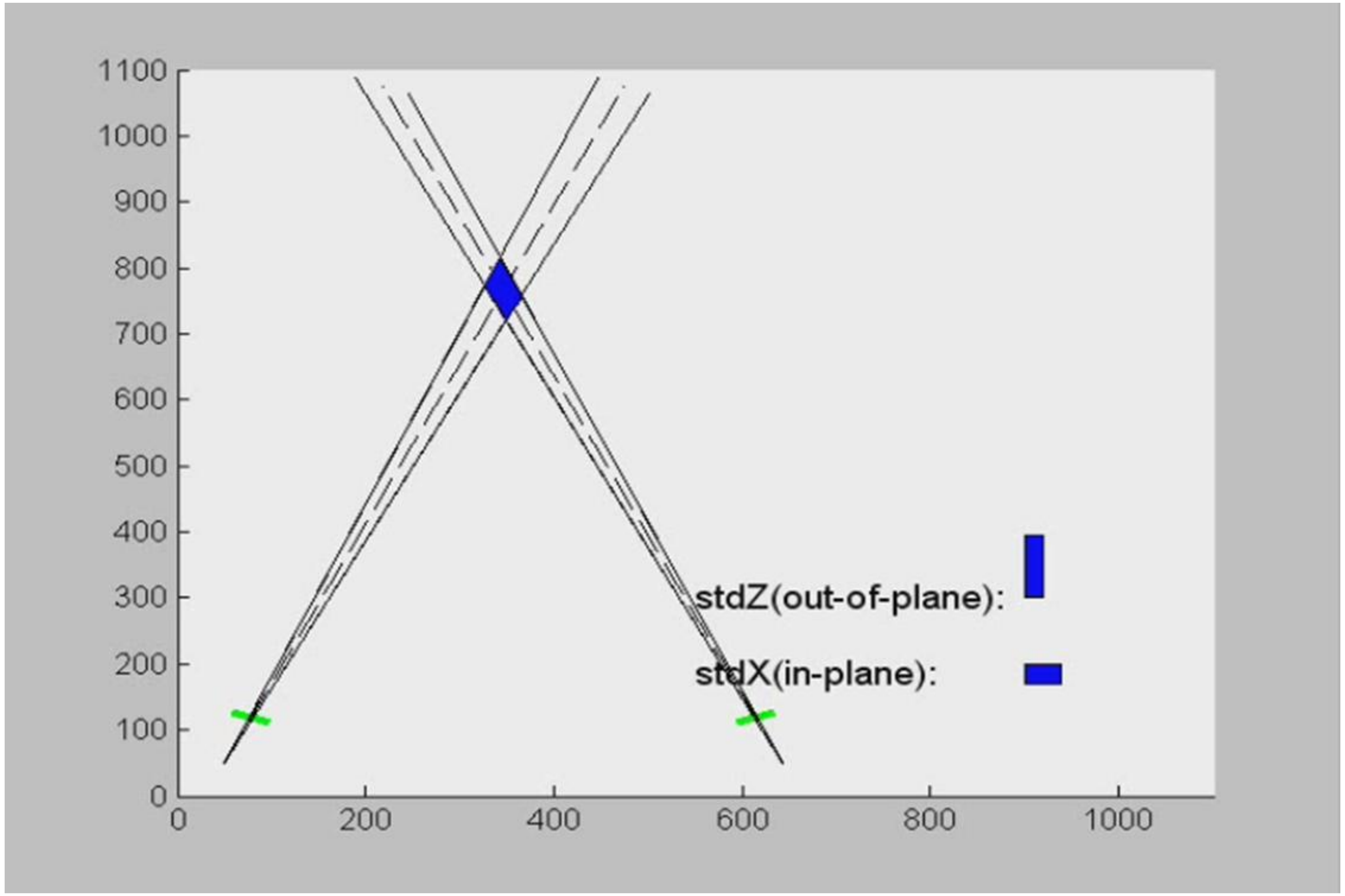
Short focal length; small angle

Effects of setup



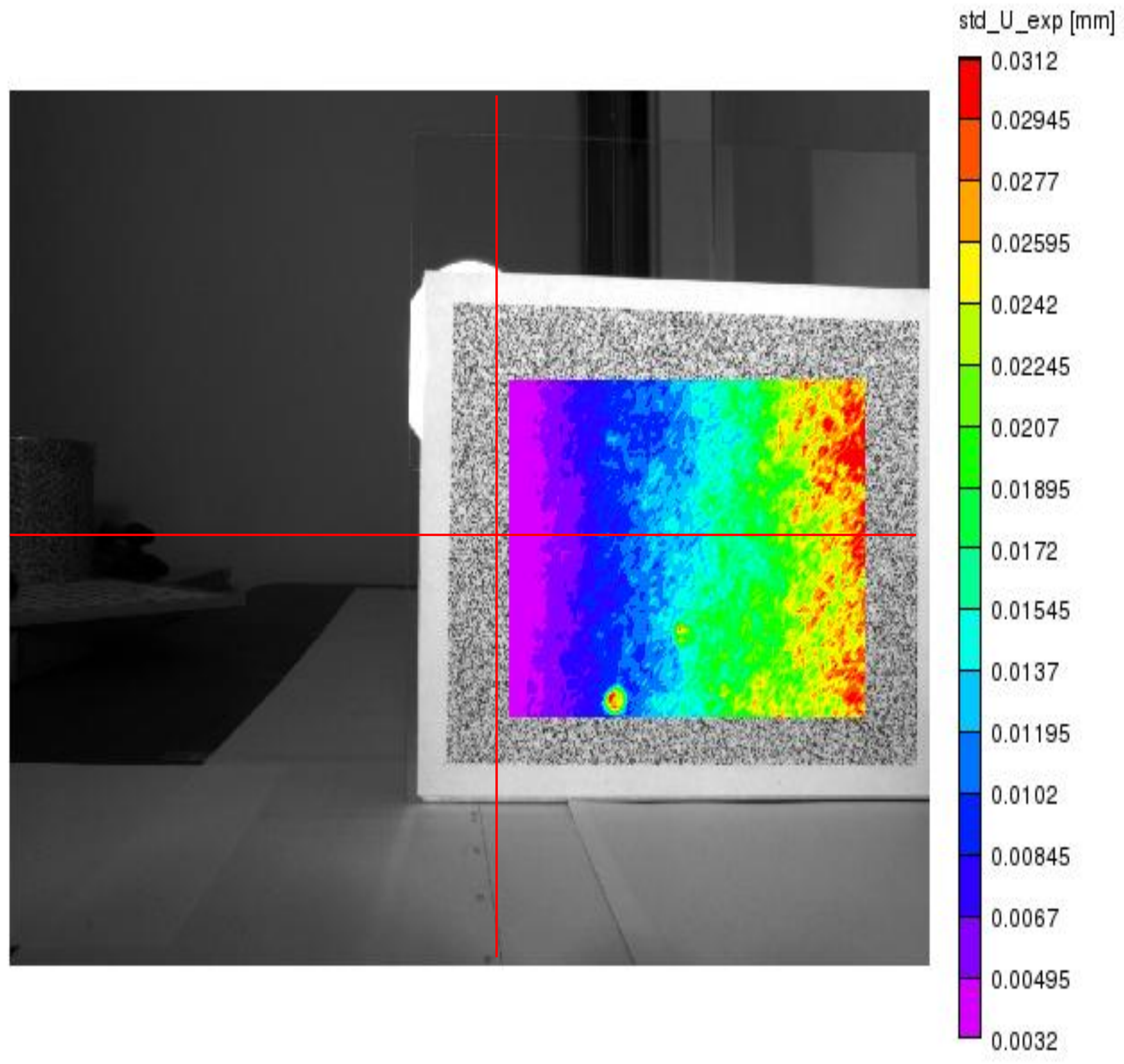
Short focal length; large angle

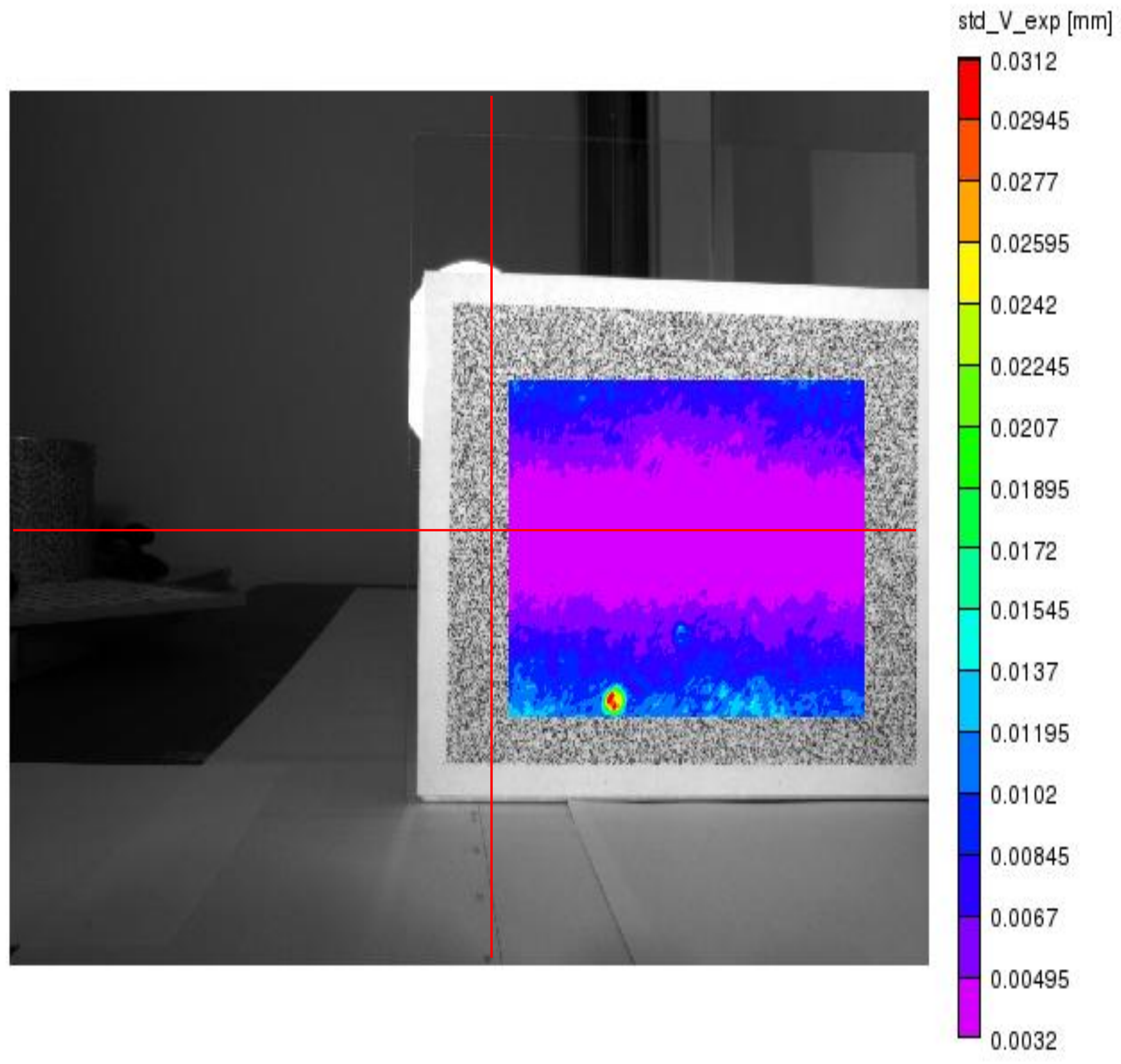
Effects of setup



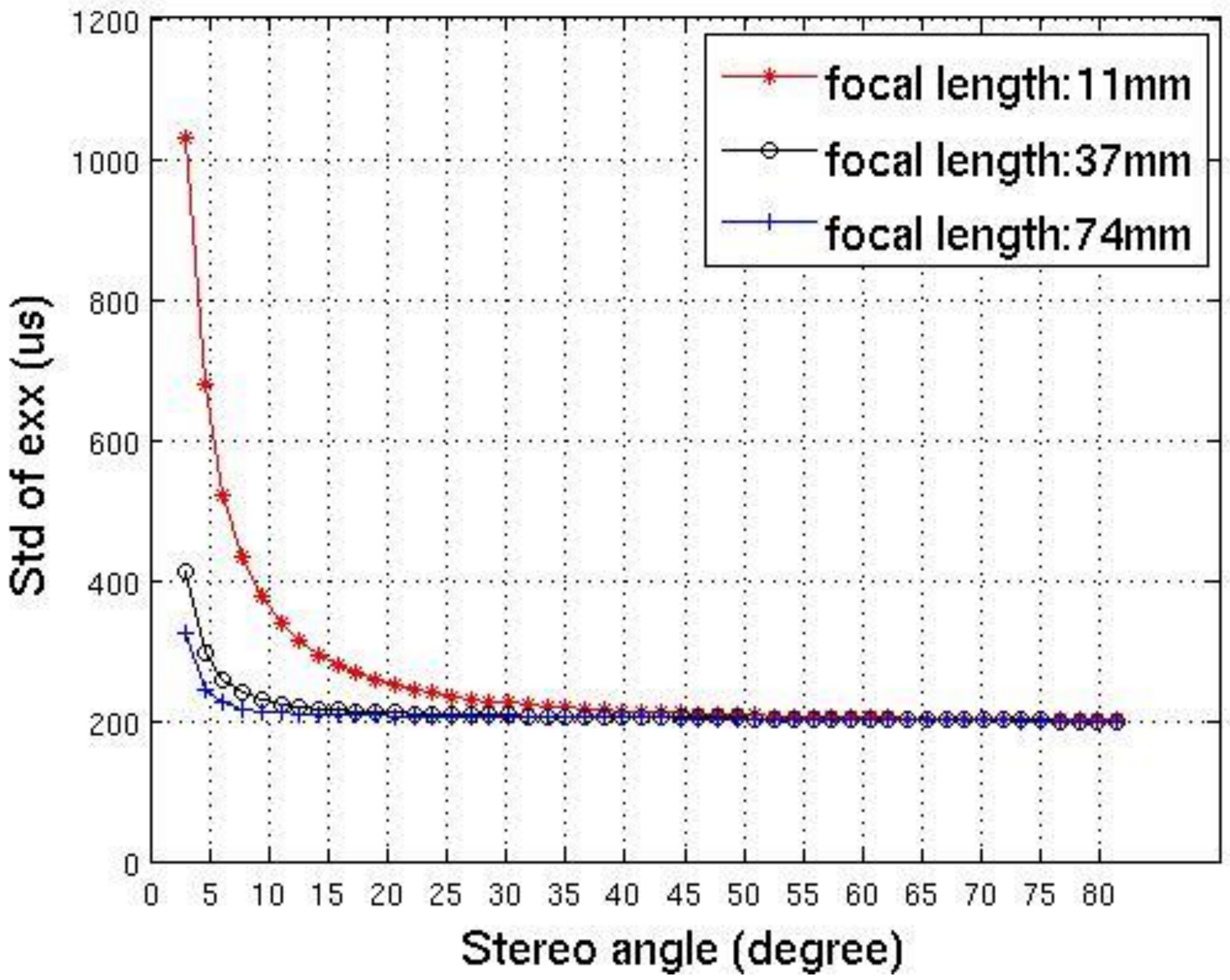
Long focal length; large angle

Noise is lowest near the optical axis





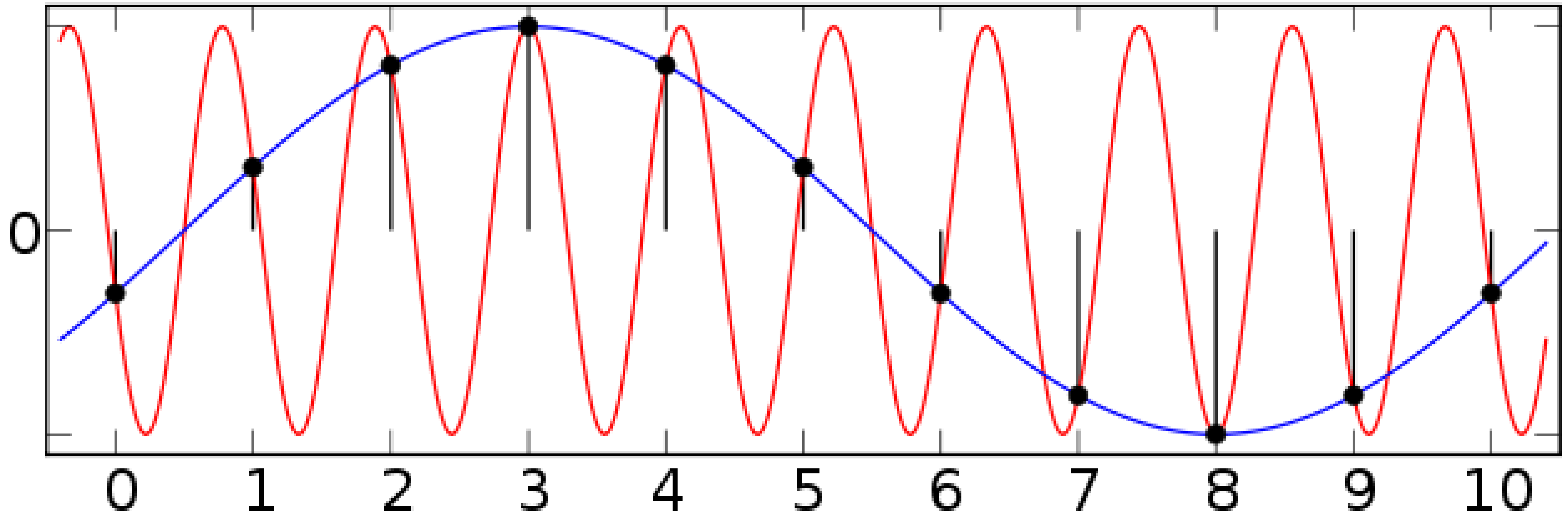
Noise in displacement and strain is strongly dependent on stereo angle



Bias in DIC

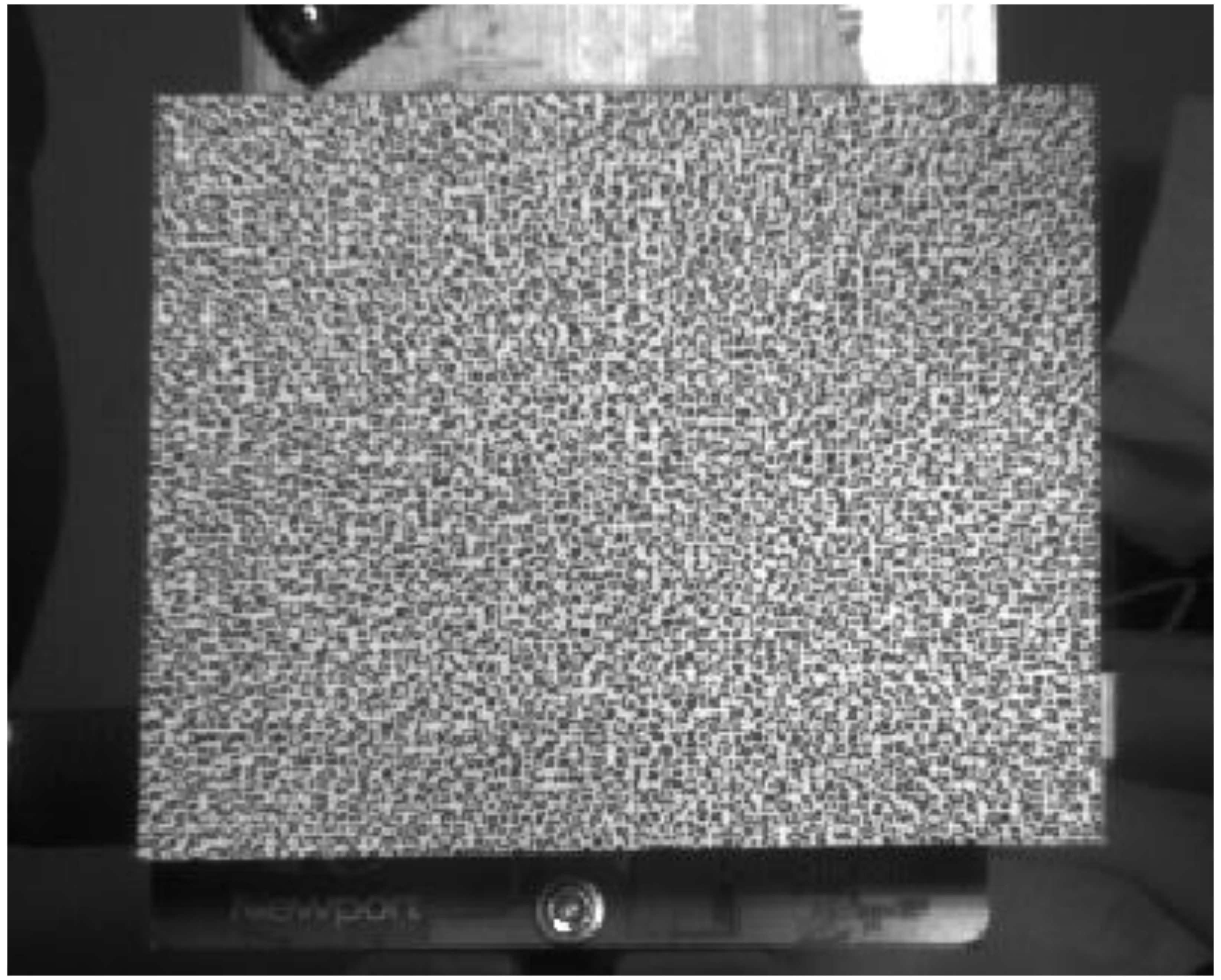
- Bias: systematic deviations from the correct result
- Can be present in location, displacement, and strain
- Bias can be reduced or eliminated with proper setup and parameters
- Common sources of bias in DIC:
  - Aliasing
  - Heat waves
  - Contaminations
  - Poor calibration
  - Non-parametric distortions

- Aliasing occurs when a signal isn't sampled frequently enough to represent it.
- Aliasing in a 1D signal:

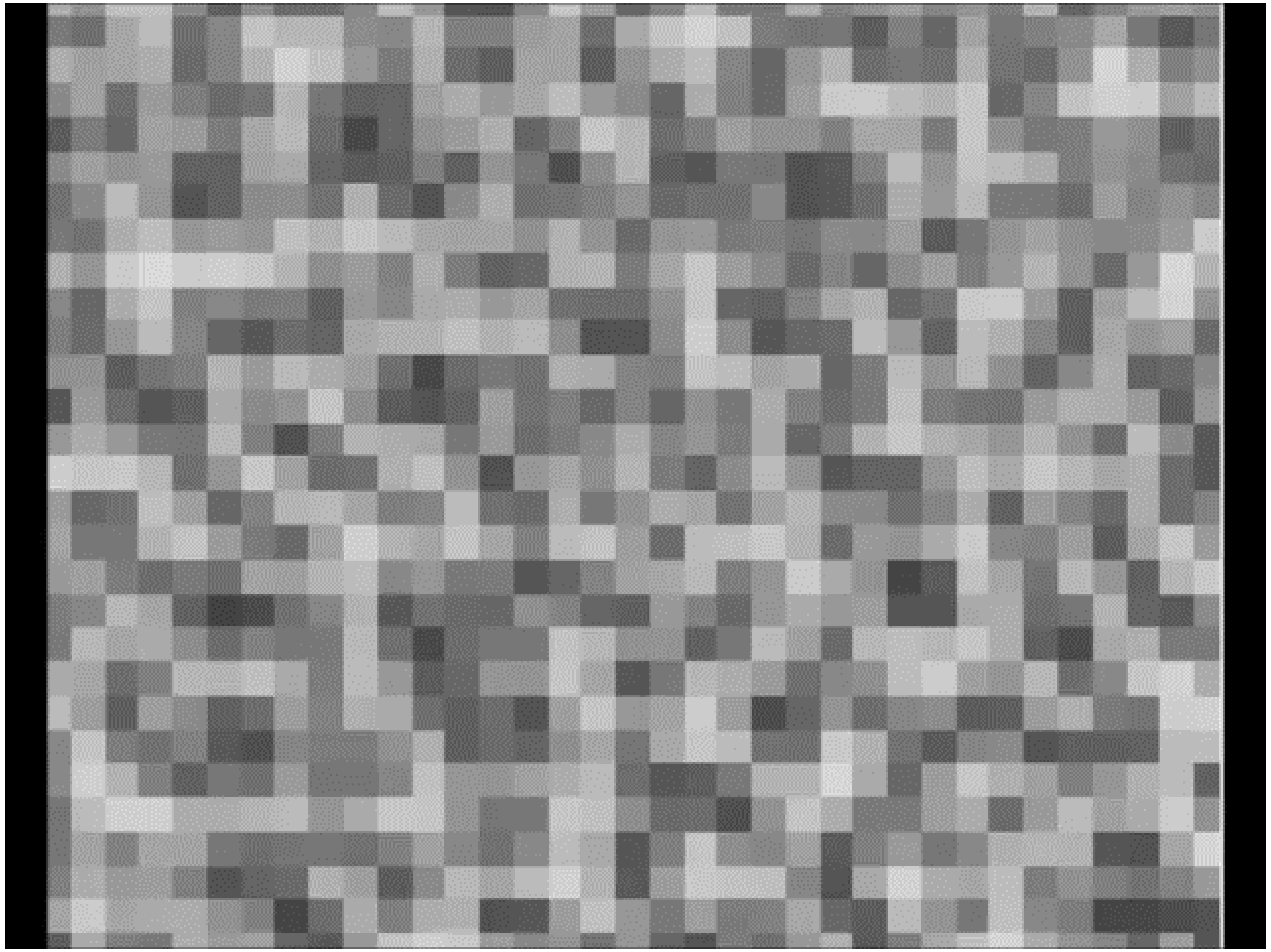


Aliasing occurs when the scene contains high-frequency content that cannot be represented by the pixel resolution of the image.

Overly fine pattern



Showing translation

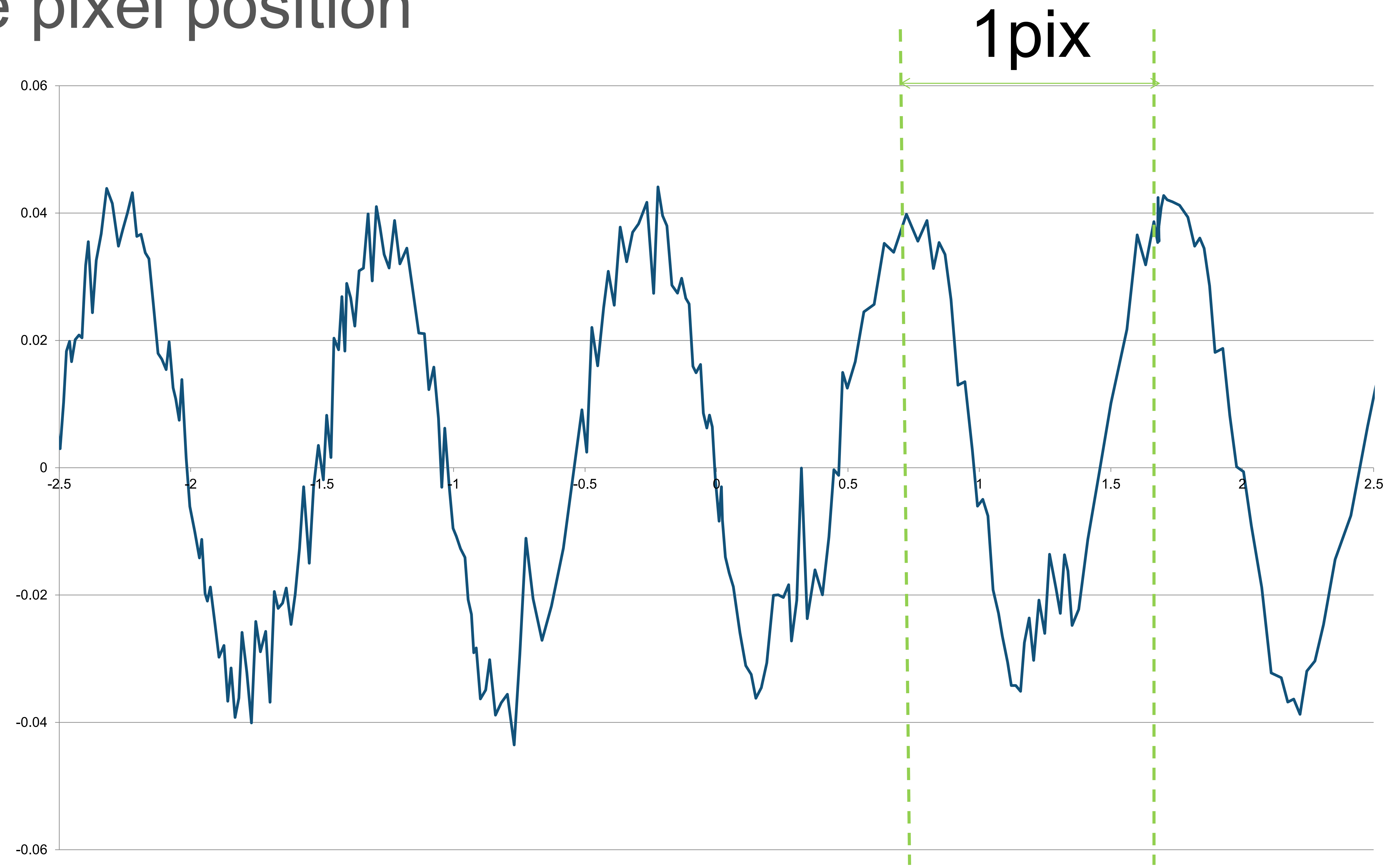


Bias Due to Aliasing

We calculate the **actual** displacement vs. the local **measured** displacement

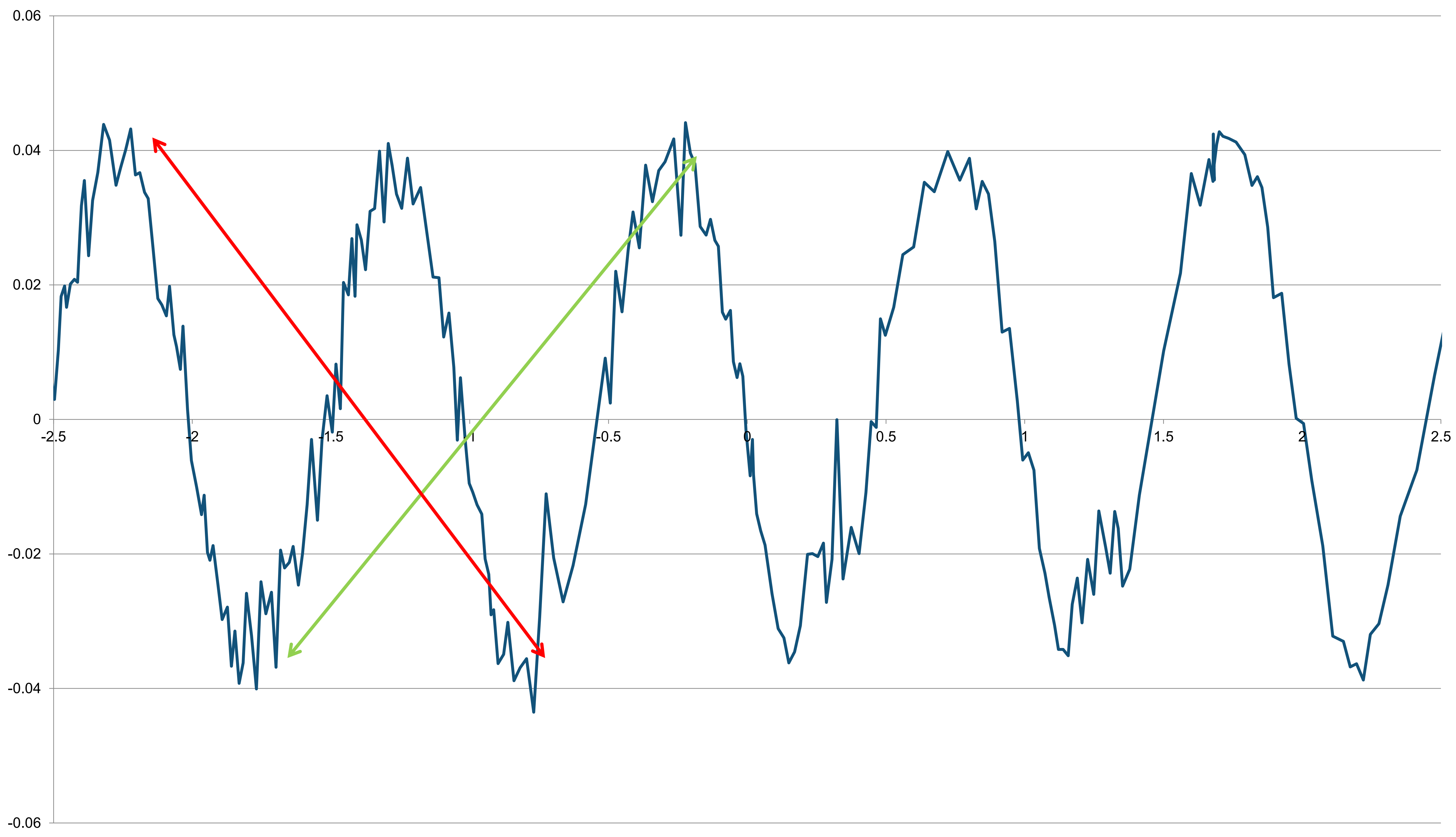
The error is plotted vs. position

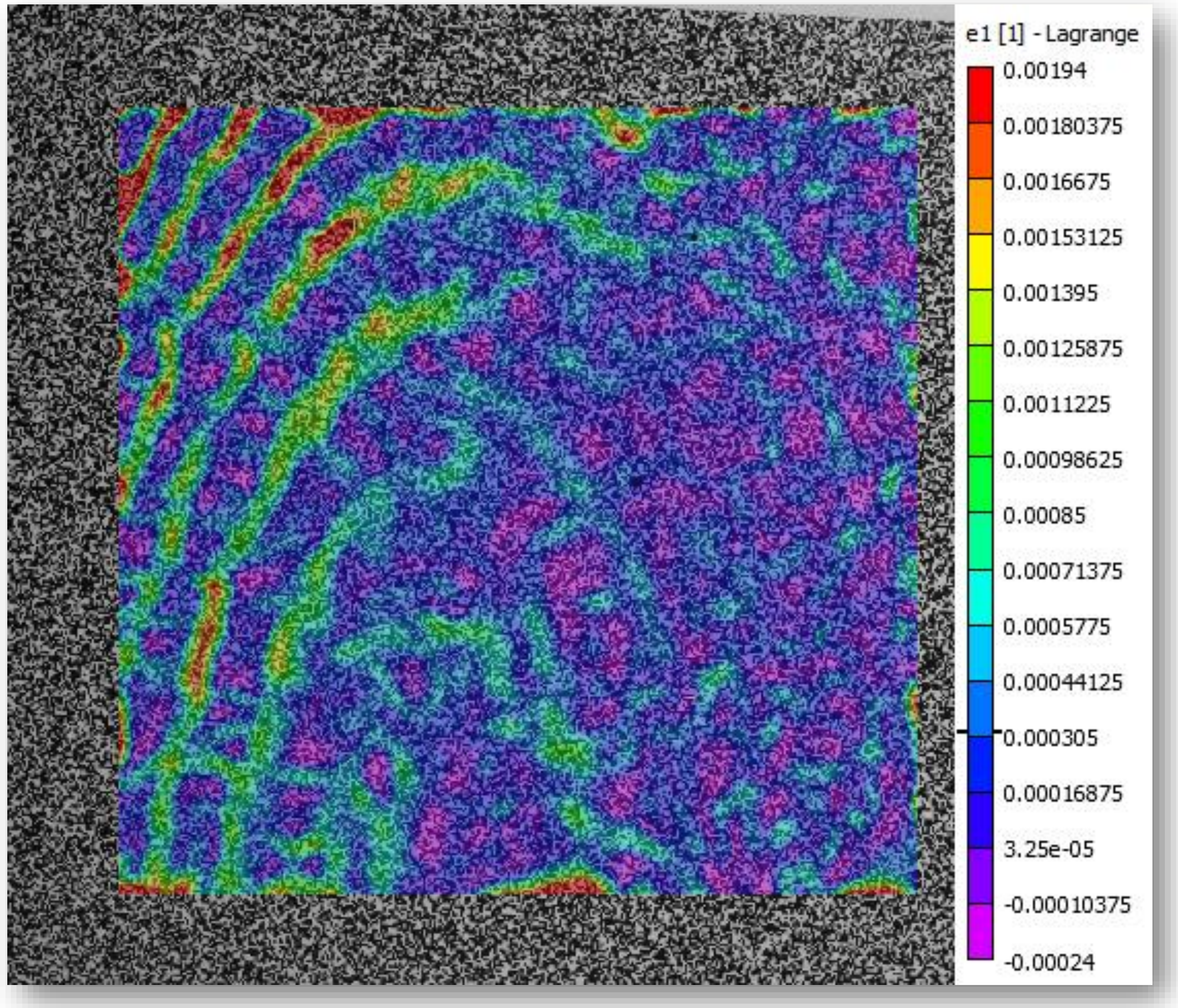
The error varies with the pixel position



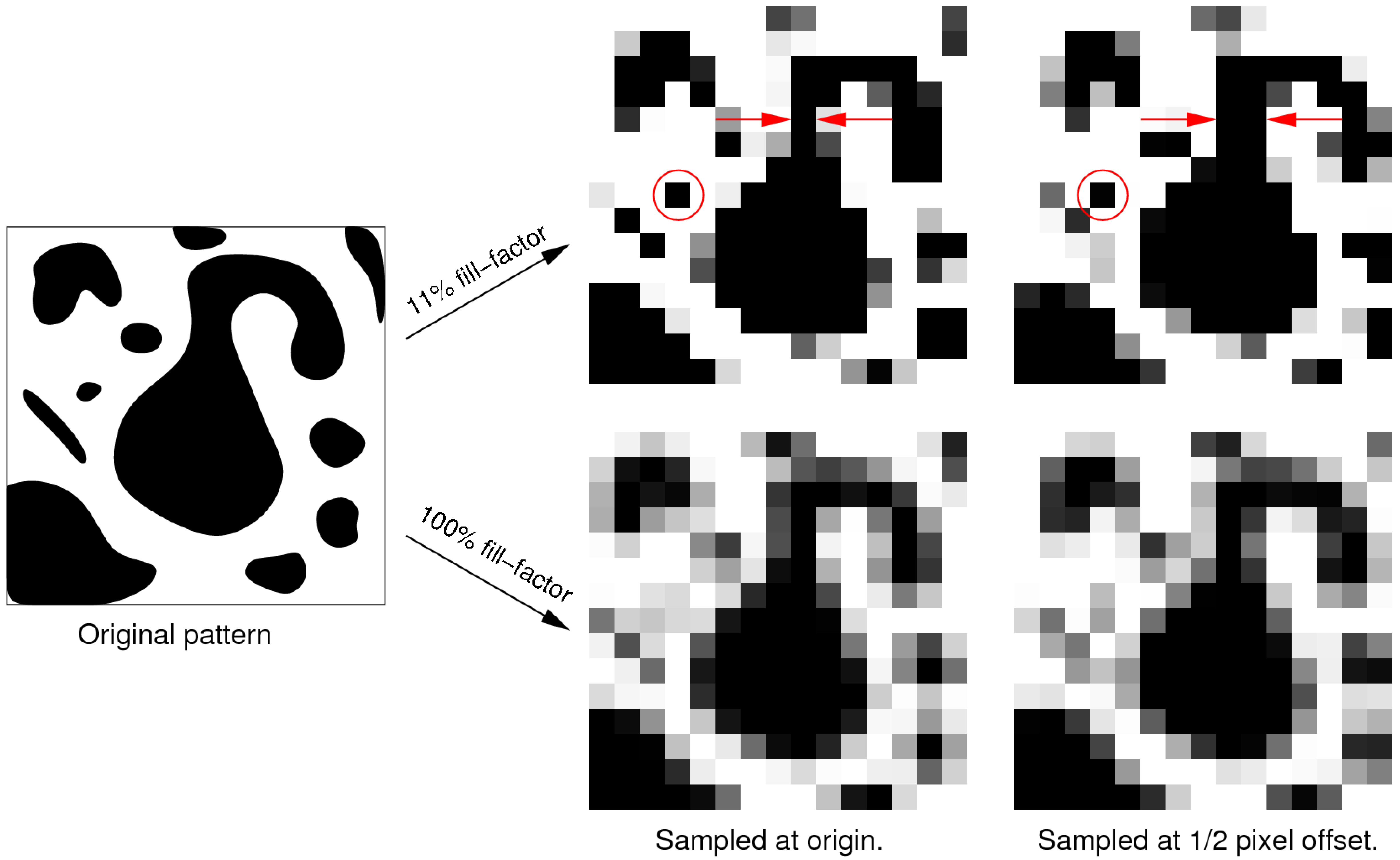
This can cause serious strain errors!

Waves of compressive strain and tensile strain causes a moiré pattern.

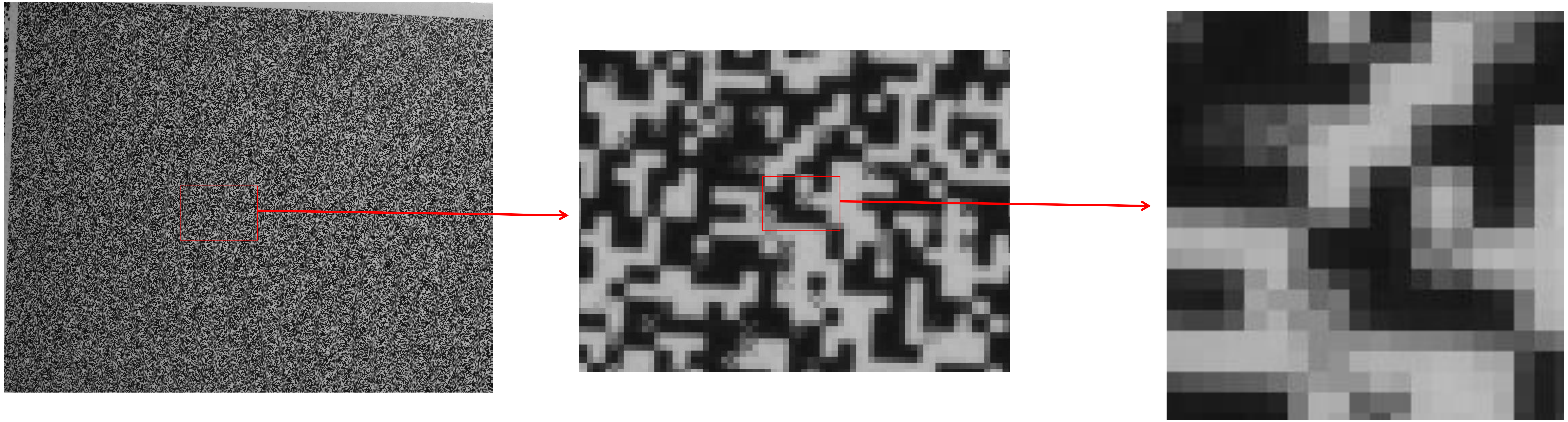




Low fill factors can exacerbate the aliasing issue for a given pattern

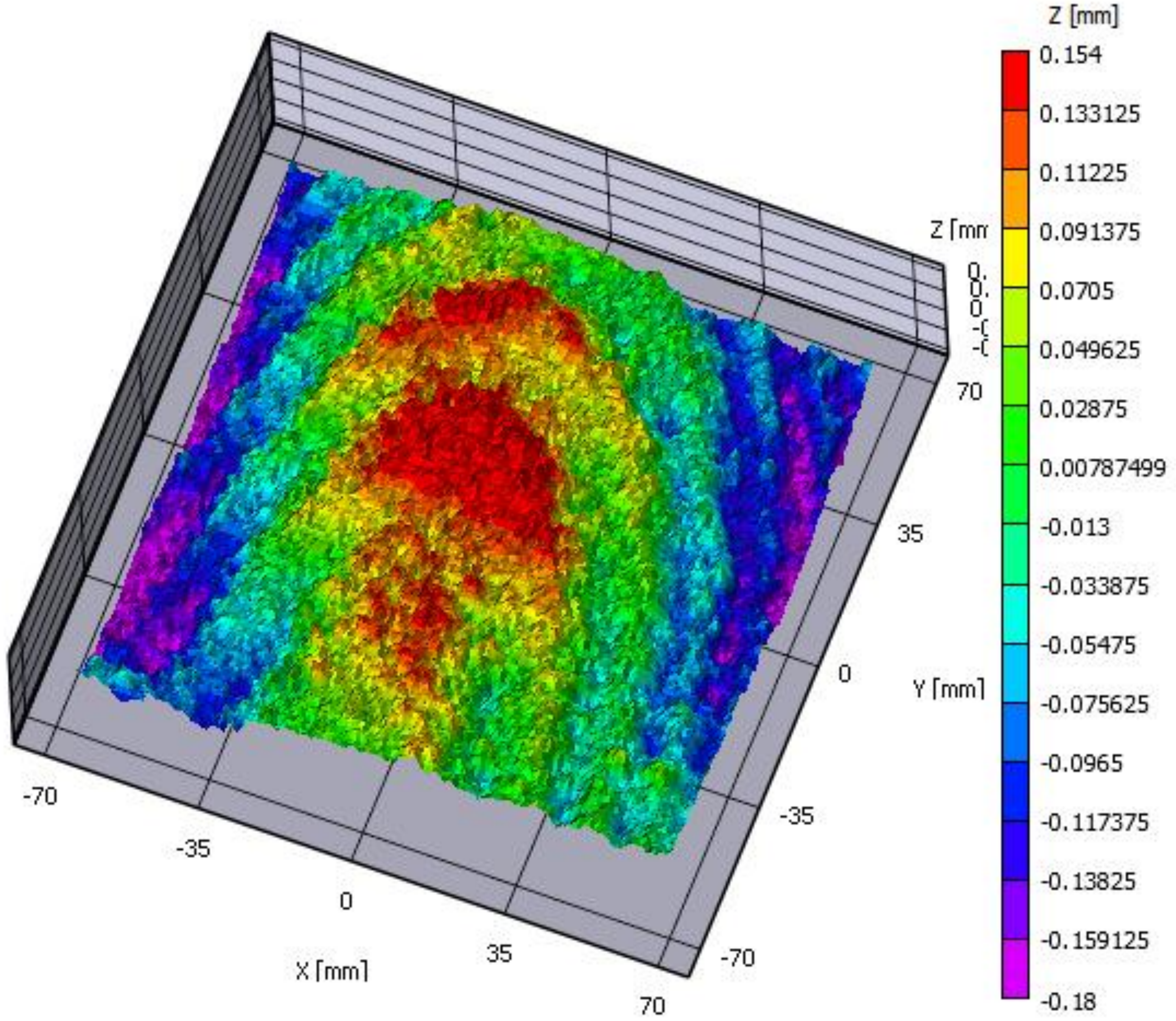


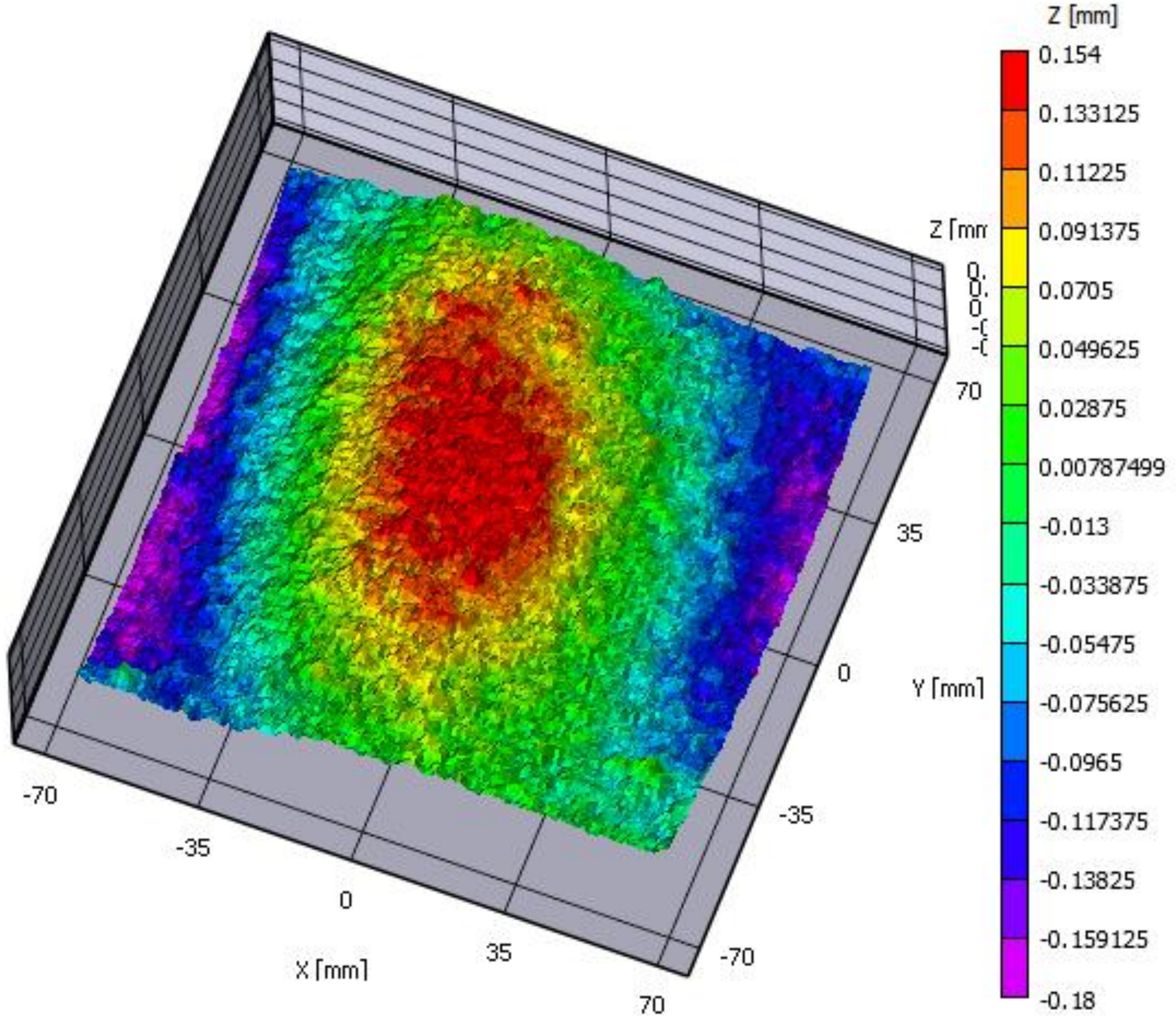
An example of an extremely aliased image – due to dithering from a laser printer



Bias Due to Aliasing

Can be mitigated by low-pass filtering image at the expense of resolution

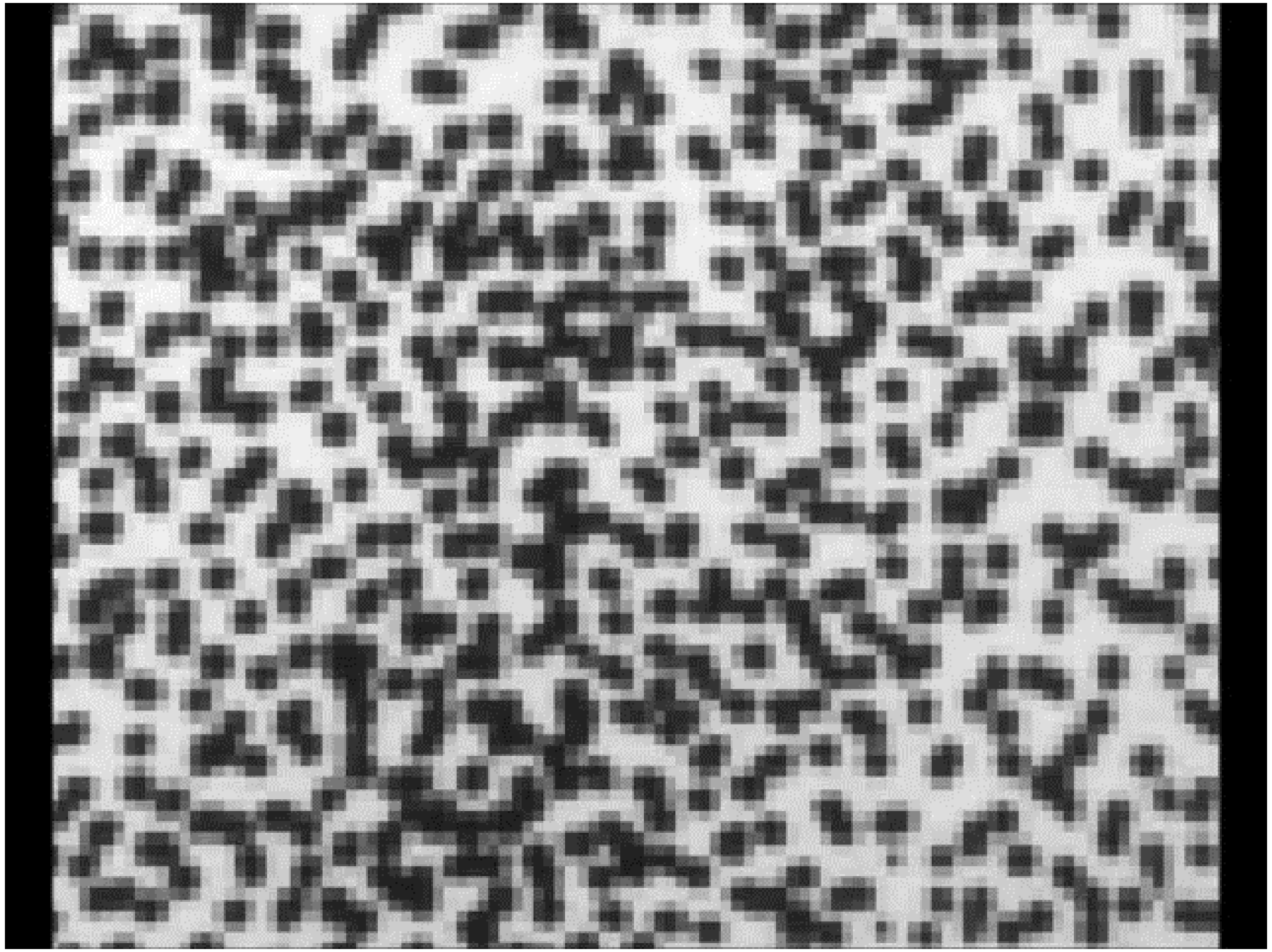




Bias Due to Aliasing

- Aliasing can cause severe biases and noise in displacement and strain
- Dangerous because it **does not always** appear in the “sigma” value
- Best to avoid in the first place – bigger patterns or more magnification
- Can be mitigated
  - Low-pass image filter
    - This comes at the expense of resolution
  - Higher order interpolation

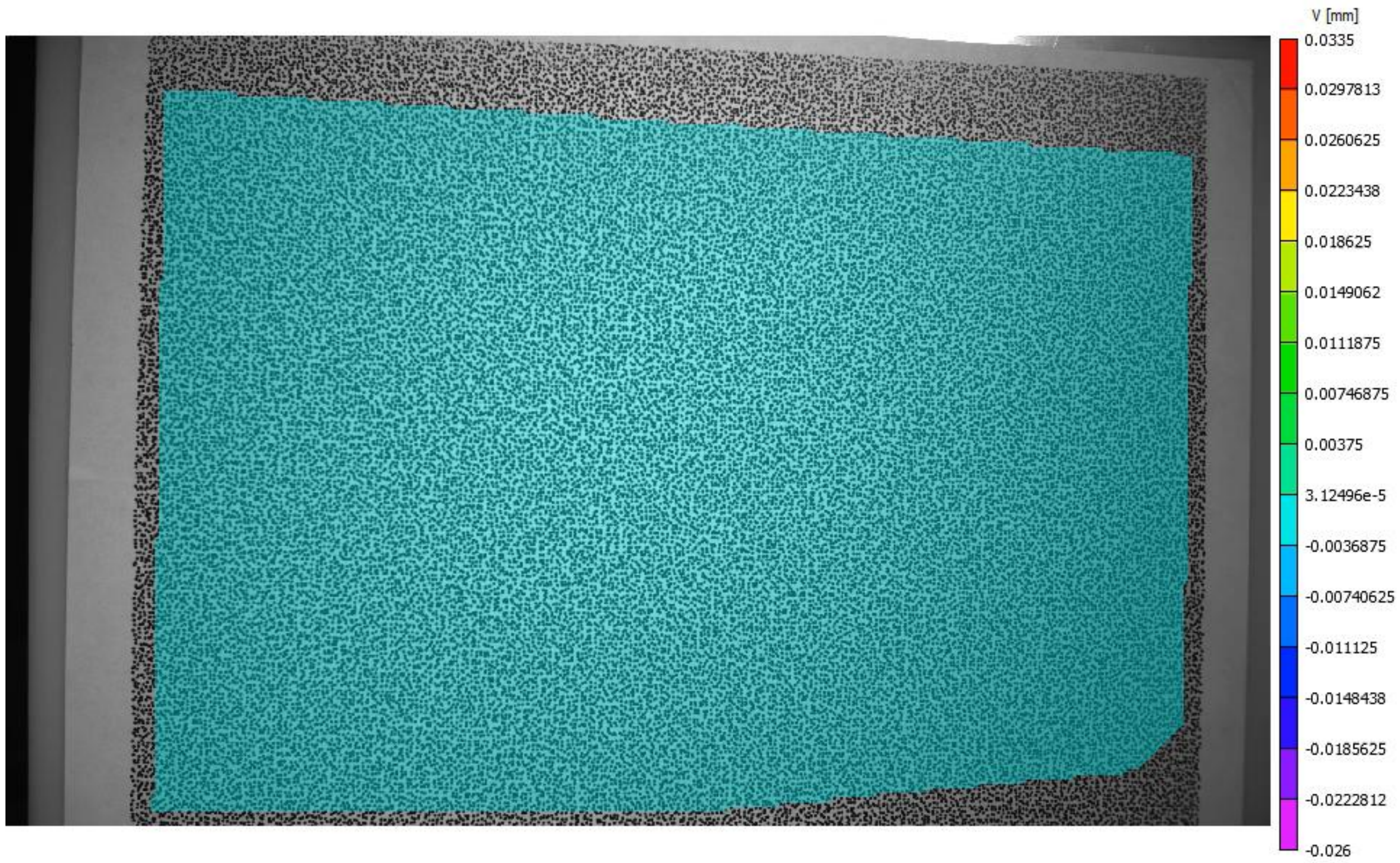
Better pattern



correlated SOLUTIONS

Bias Due to Heat Waves

- Refractive heat waves can distort images
- May not be visible to the eye
- Look for shifting bands in displacement and strain data



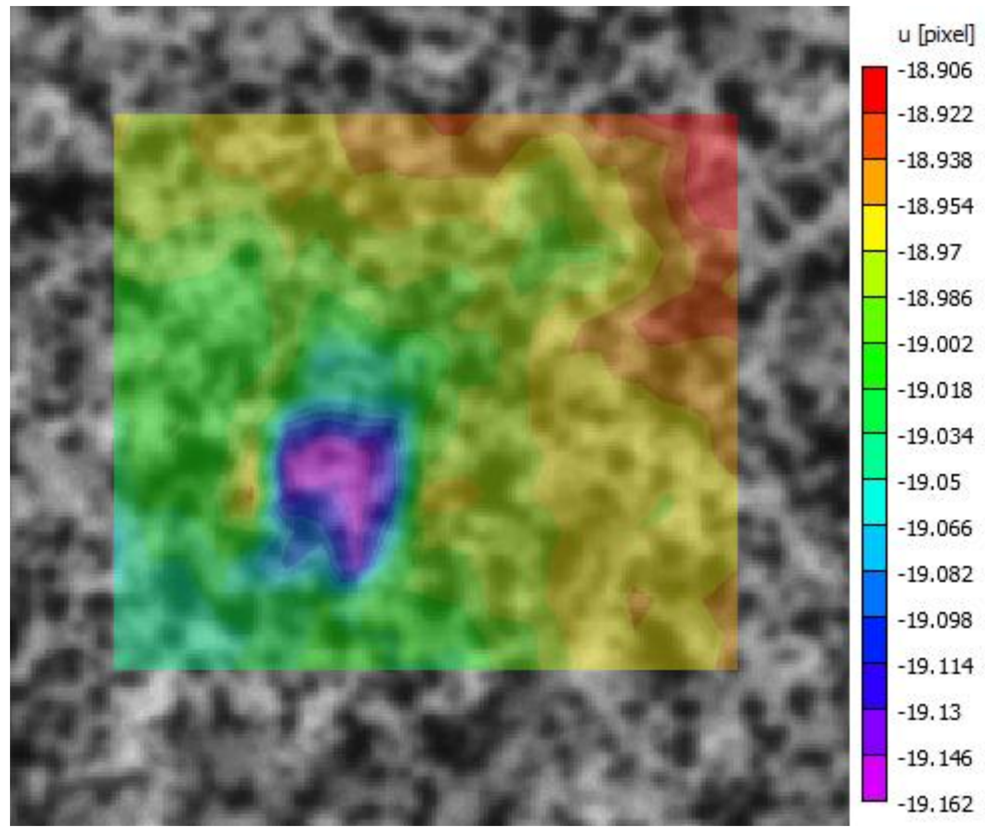
Bias Due to Heat Waves

Solution:

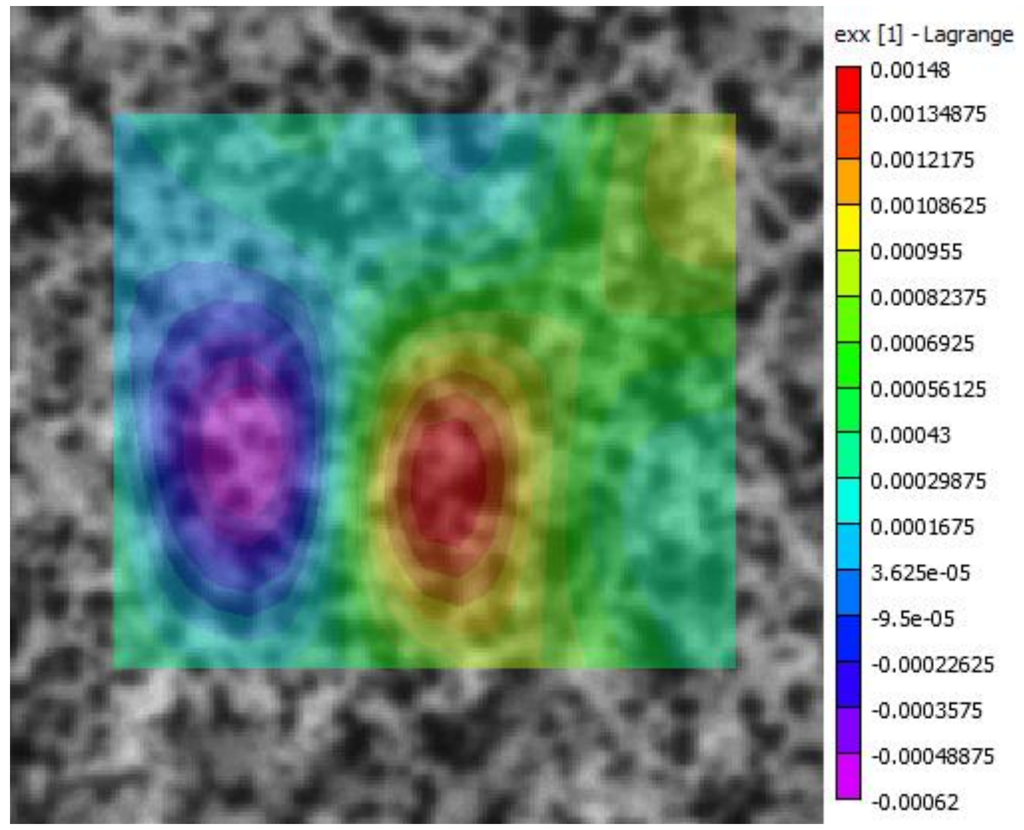
- Cool light sources (LED, fiber optic)
- Move heat source so heat waves are out of optical path
- Small fan to mix air
- Time average results

Bias Due to Contaminations

Contamination (e.g. dust on sensor) can cause severe local bias in displacement and strain



Displacement



Strain

- Not possible to mitigate through processing techniques
- Check before taking measurements
- **May not be seen in speckle images**

correlated SOLUTIONS

Checking for Contaminations

- Contaminations can be seen by
  - Completely defocusing camera
  - Using a uniform gray background
- Move camera
  - If spot stays fixed, contamination present
- If contaminations are present, turn lens
  - If spot moves with lens rotation, contamination is on lens
  - If spot stays in place, spot is on sensor or IR filter
- Use compressed air to blow dust particles away
- Always use lens caps and camera covers to avoid contaminations in the first place

Bias Due to Poor Calibration

A low calibration score is indicative of a good calibration IF we have enough information in the calibration images

- Grid fills image
- Large grid tilts
- 15-25 image sets

If using short focal length lenses (8mm, 12mm), you might need to change the distortion order to 2 or 3 in the distortion window.

In high magnification applications, you might need to select “High Mag” in the calibration window.

Distortion order for short lenses

- Calibrate at distortion order 1. Look at your kappa 1 (a lens distortion parameter) in your calibration results
- Calibrate at distortion order 2. You'll have a kappa 2 now, but if your kappa 1 is the same as what you got for a distortion order of 1, then the distortion order of 1 was OK
- If the kappa 1 changed, then repeat for an order of 3 and see if kappa 2 changed
- Once you figure out the distortion order, you can use that that order anytime you use that camera-lens combination

High Magnification

- For high magnification instances you might see very large calibration errors.
- This is because the limited depth of field doesn't allow us to tilt the grid enough in order to extract the camera sensor positions
- Check your center x, center y for each camera in your calibration results
- The centers should be ROUGHLY the centers of the sensors (i.e. for 5MP cameras that are 2448x2048 pixels, you should see centers of 1224,1024)
- If centers are WAY off (by more than 50%; maybe even negative), select “high mag”
- This will force the centers to the center of the sensor (1224x1024 in this case)
- Only use the high mag option when completely necessary because it forces the software to make some assumptions that we'd rather extract from the calibration image
- “High mag” is not an option for the stereo microscope module; we use a different calibration method (see next slides)

correlated SOLUTIONS

CSI Social Media

Follow us for the latest updates!

facebook.com/CorrelatedSolutions

@CorrelatedSol

@CorrelatedSolutions

youtube.com/user/CorrelatedSolutions

linkedin.com/company/correlated-solutions-inc-

Visit

support.correlatedsolutions.com

For more help and to search our extensive knowledgebase

Support Portal