Automated optical inspection

Image analysis and defect recognition

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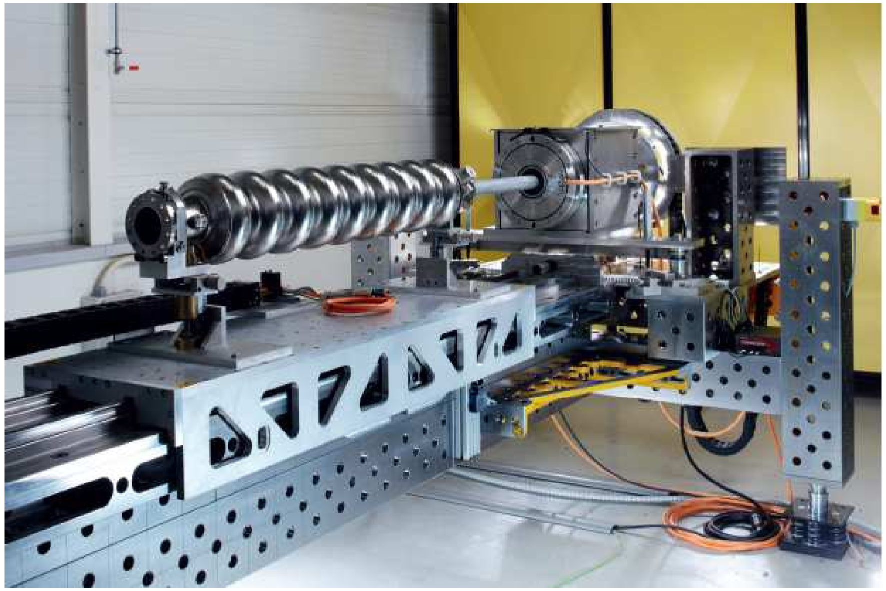
DESY

Motivation

- Optical Inspection is a well established tool
  - Quality assurance: Check after delivery
  - Defect identification and further understanding of cavity behavior
  - Helps to understand surface treatment
- Inspection procedure takes about several days
- Images are analyzed by operator
- For XFEL or ILC, this is not feasible
- Therefore an automated setup for image taking and image analysis

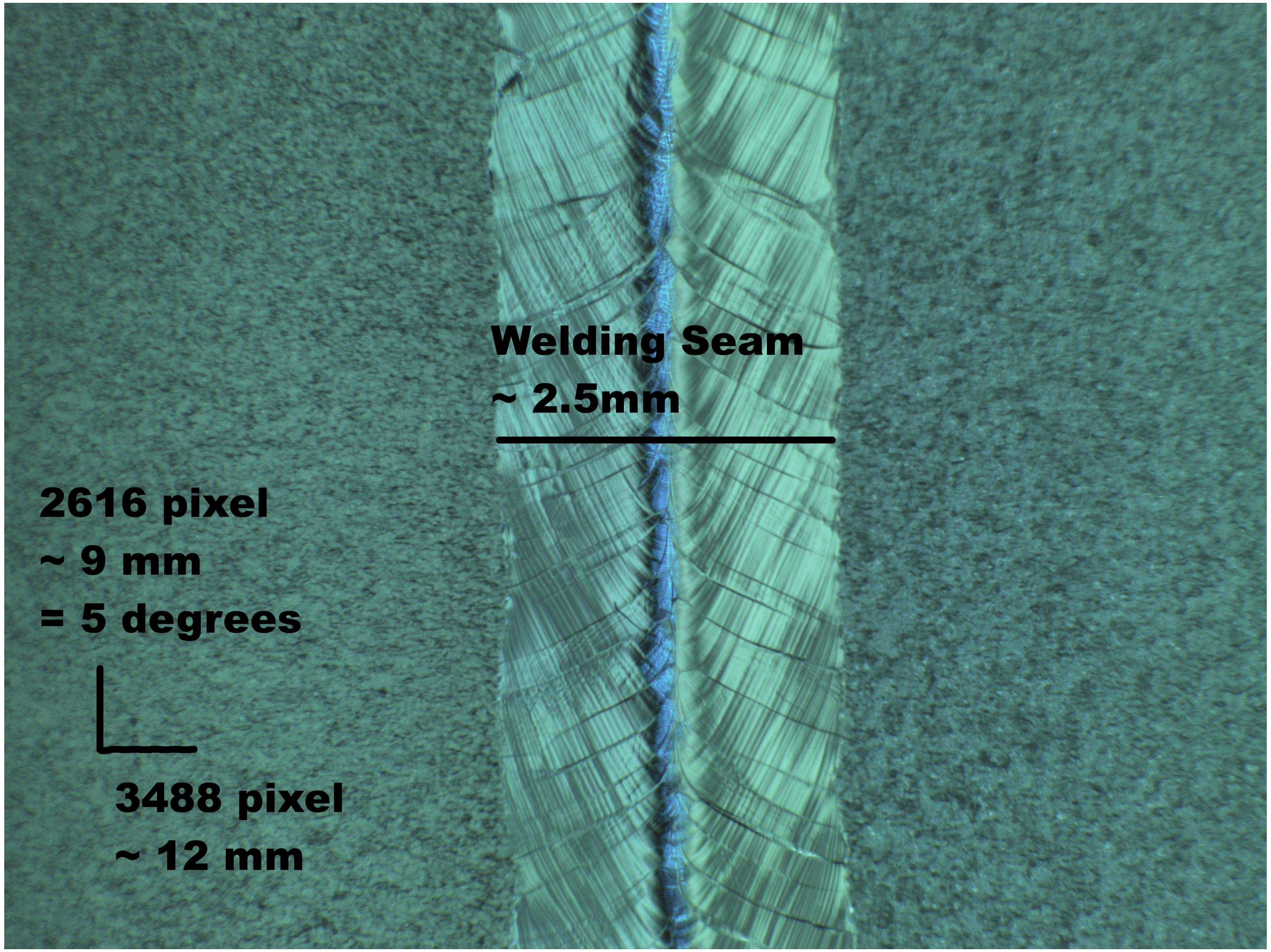
OBACHT

- **O**ptical **b**ench for **a**utomated **c**avity inspection with **h**igh resolution and short **t**imescales



- Fully automated optical inspection: camera position, illumination, auto focus, image taking and image storing
- The timescale for a single inspection decreases from the order of days to half a day
- Image processing will run in parallel using the stored images
- Camera system based on Kyoto Camera

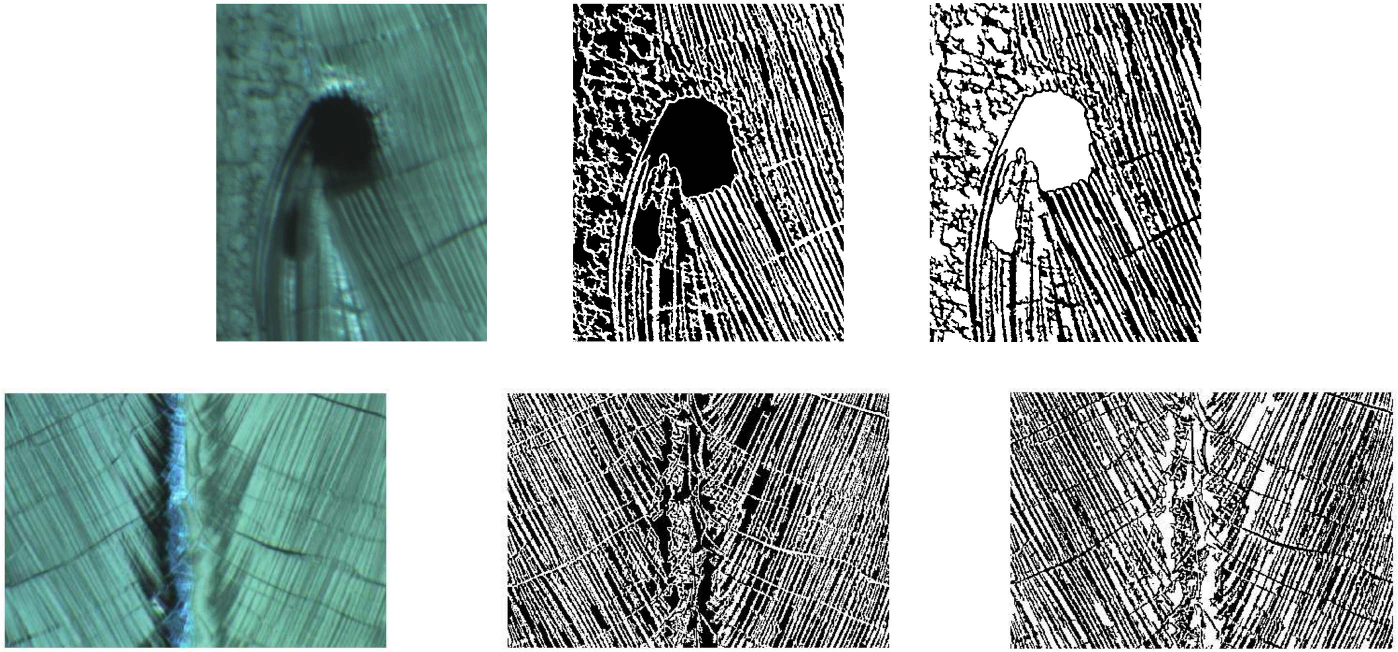
Example



- Effective resolution of 3.5 µm x 3.5 µm per pixel

Image processing

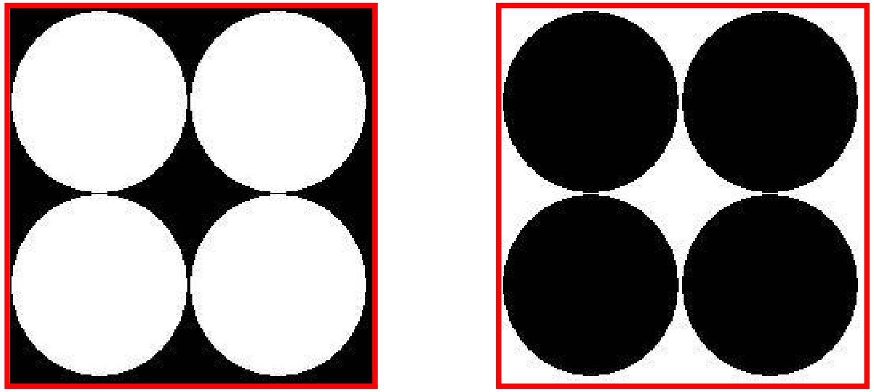
- Image processing steps are applied to the original color image
- A binary image is derived



- Sets of parameters are deduced using the image representations

Complementary representations

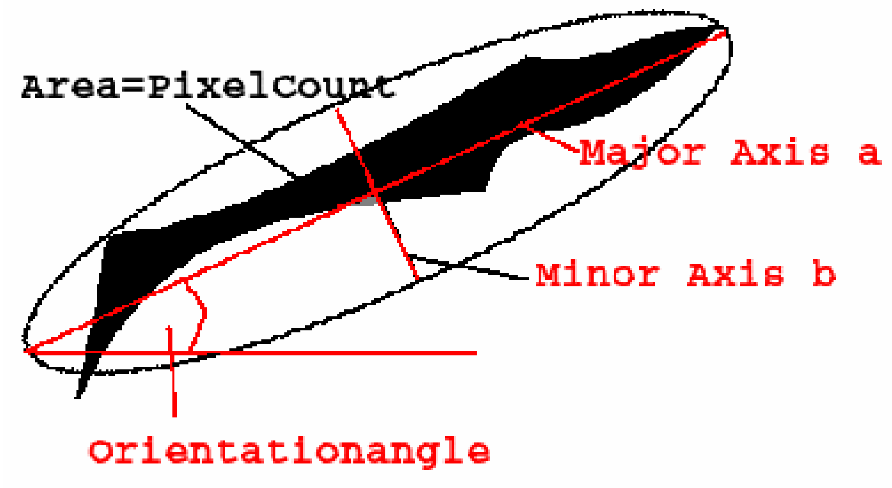
- Define the regions with pixels equal to one as objects, regions with pixels equal to zero as background
- In the image on the left, the algorithm derives quantities for four circular objects while for the image on the right the algorithm does this for a single object



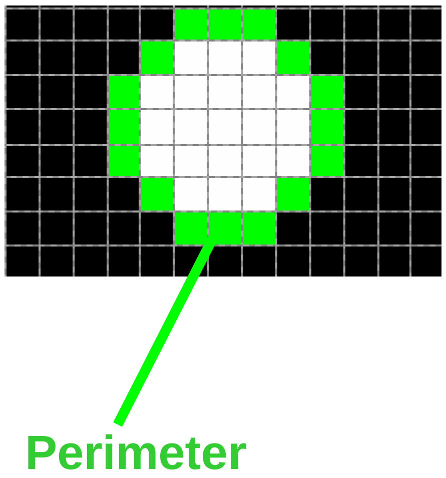
- Both representations are useful since they carry different information although they are just complements

Measured quantities

- Several quantities are derived for each representation
- Some are derived from the binary image
  - Area
  - Major & minor axis length
  - Perimeter
  - Orientation
  - Numerical eccentricity



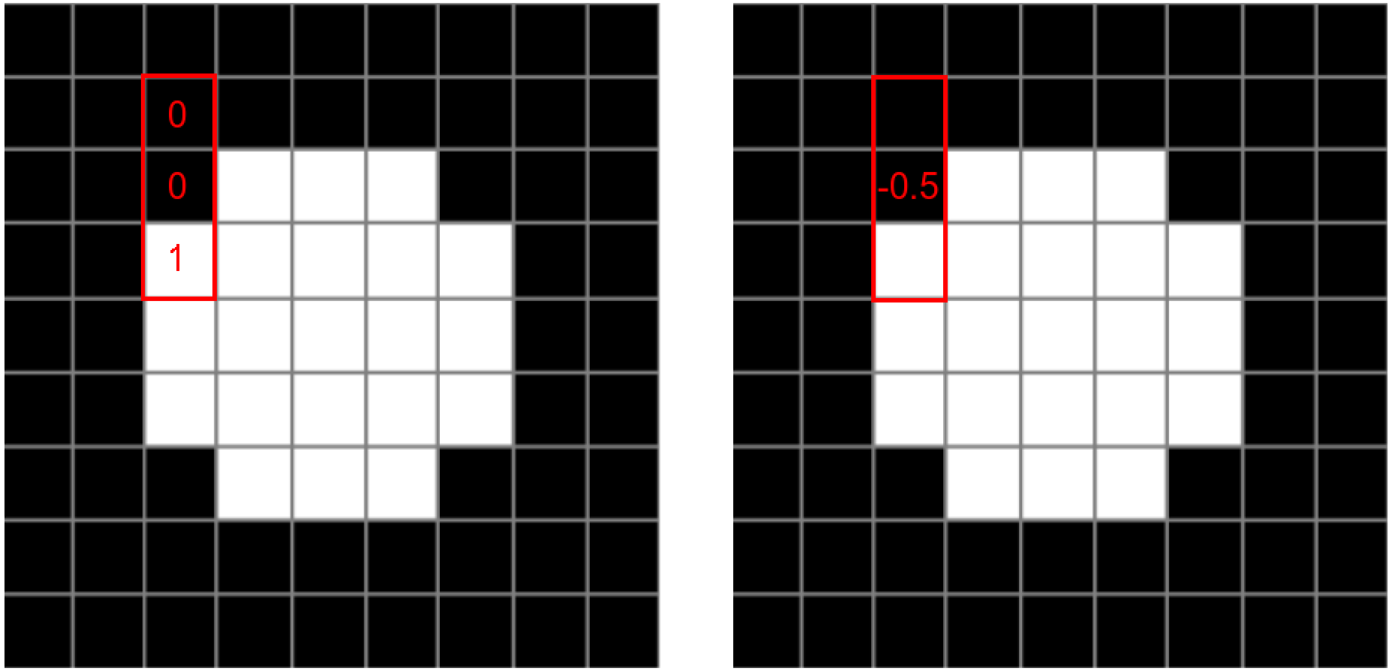
- Some are derived from the original image
  - Surface Roughness



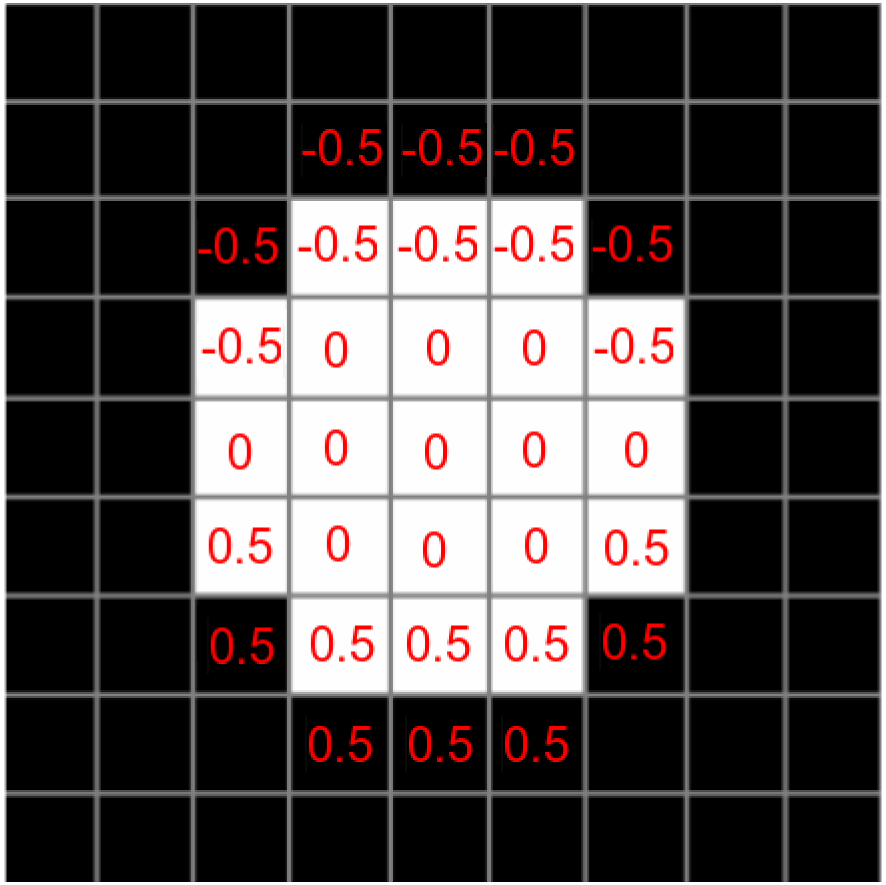
Surface Roughness

- Pixel to pixel intensity difference is calculated (intensity gradient) for the x and for the y direction using the finite central difference

$$\frac{\Delta I(x,y)}{\Delta x} = \frac{I(x+1,y) - I(x-1,y)}{(x+1)-(x-1)} = \frac{0-1}{2} = -0.5$$

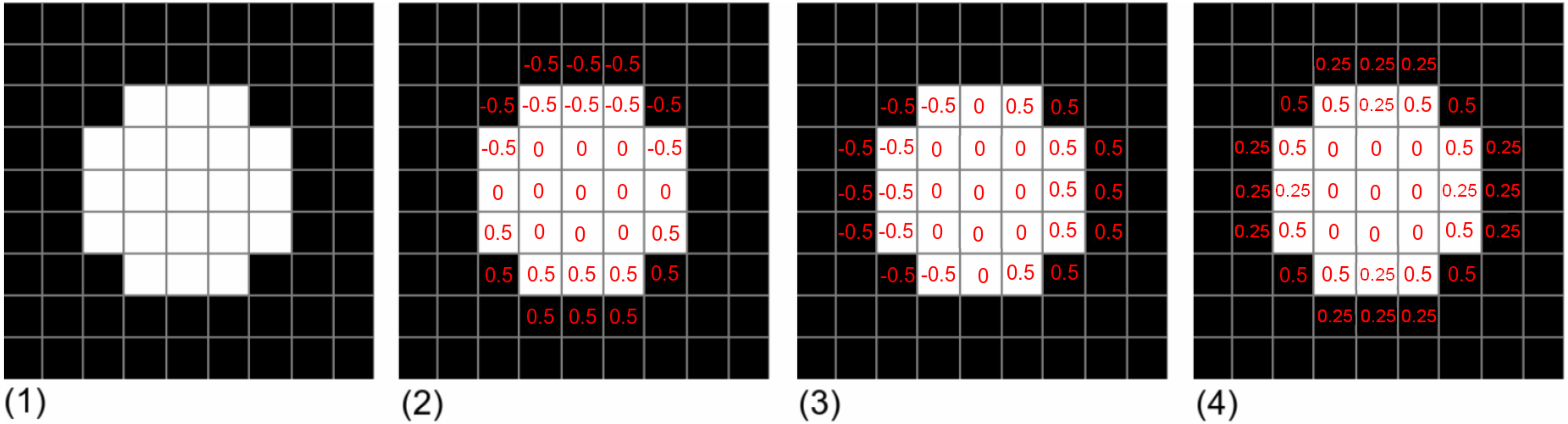


Surface Roughness



Surface Roughness

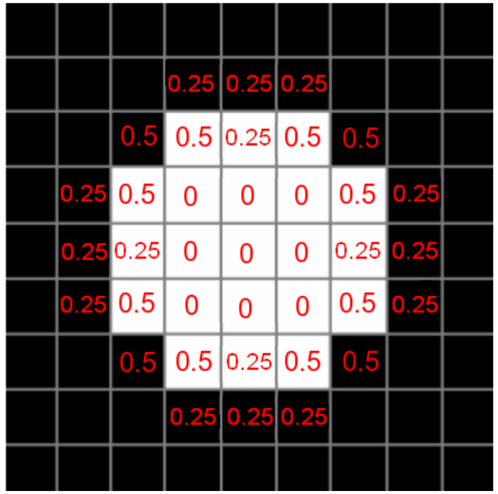
- After doing this for the x (1) and y (2) direction, one will get two difference values for each pixel

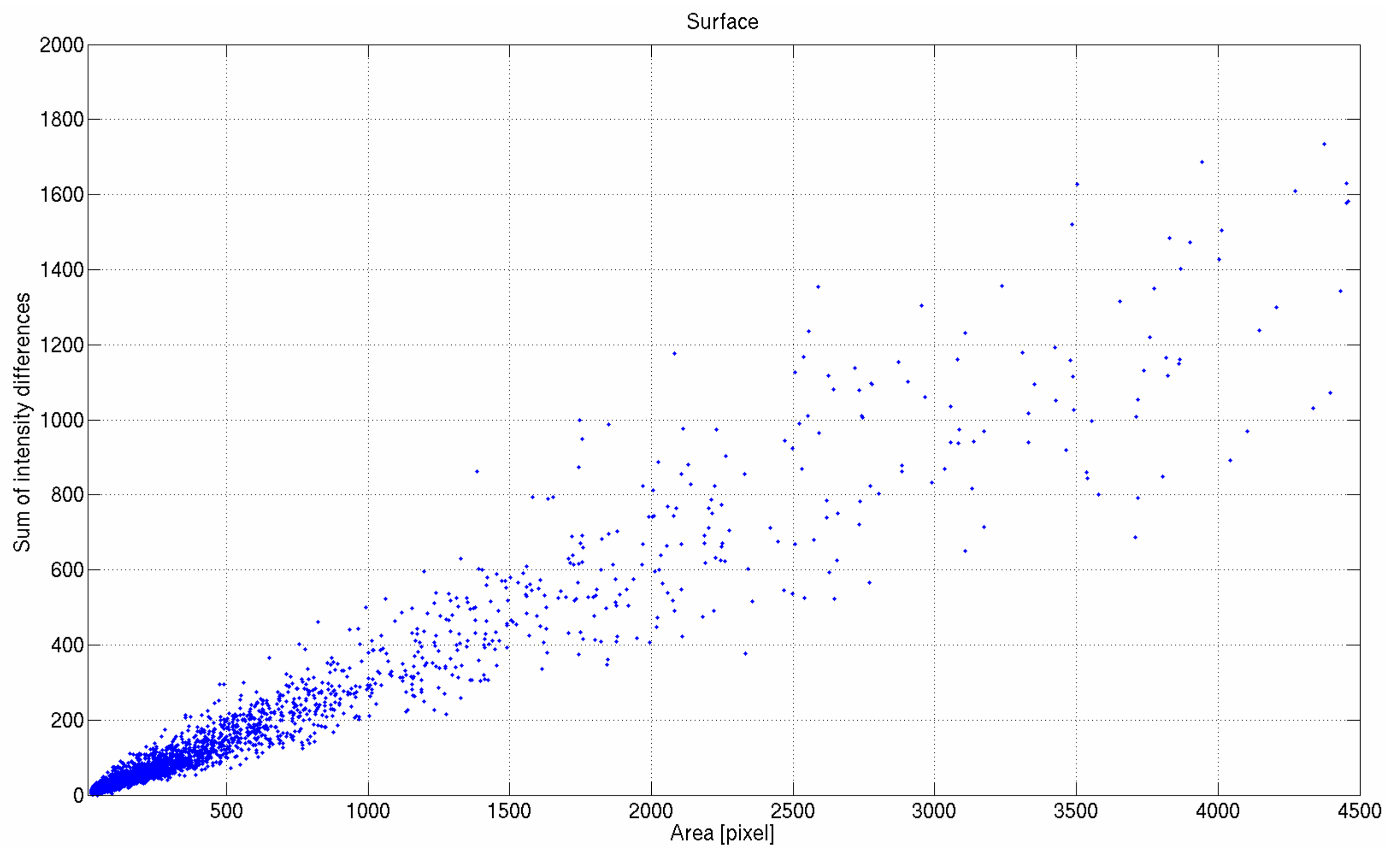


- These two values for each pixels are squared and summed up and a single scalar value Δ for each pixel is derived (4)

Surface Roughness

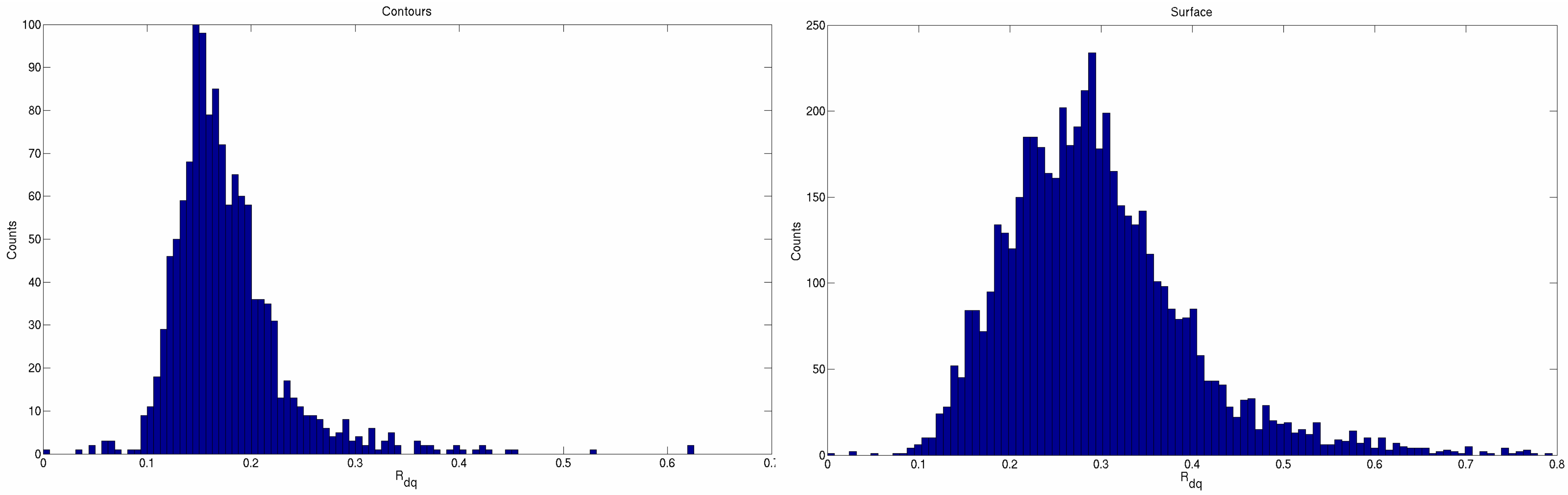
- For an object in the image, the sum of Δ is calculated
- In this case, the sum would be 5





Surface Roughness

- Dividing the sum by the perimeter (or the area) a measure of the slope of an edge (or a surface) is derived

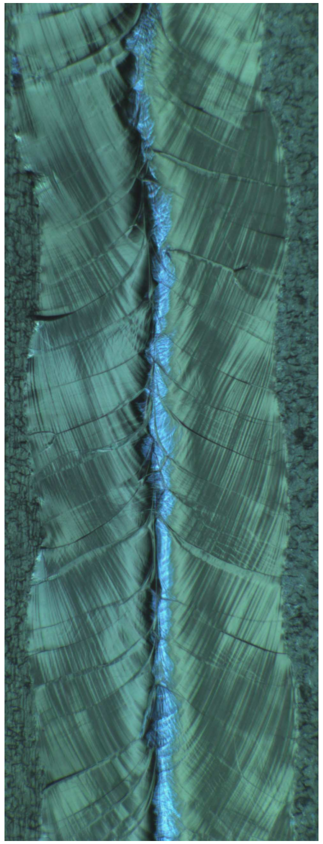


- The shape and the most likely value of the distribution can be used to characterize the surface roughness

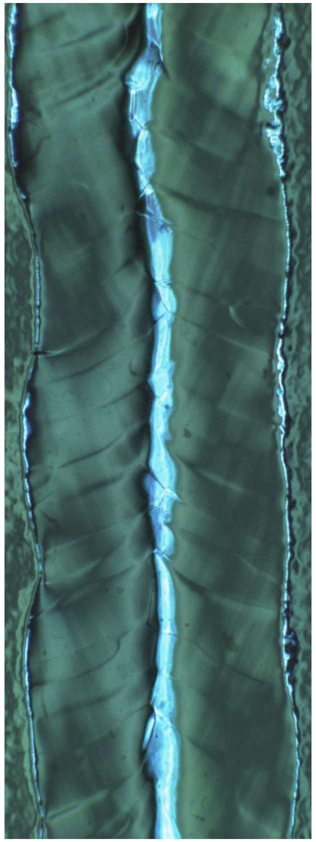
Influence of EP onto the welding seam

> Z161 – Equator 1. Example images: 0° till 4°

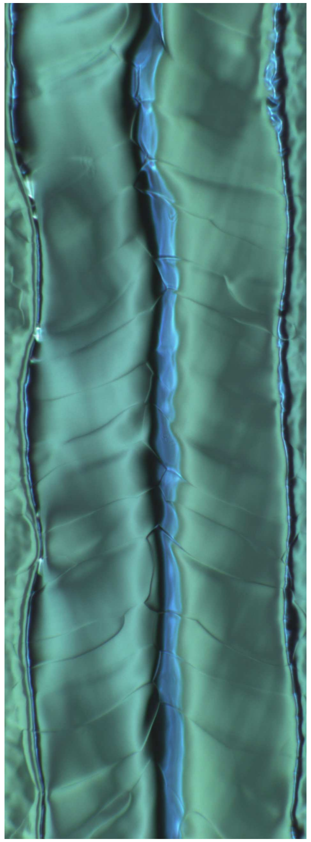
Before EP



After 1st EP



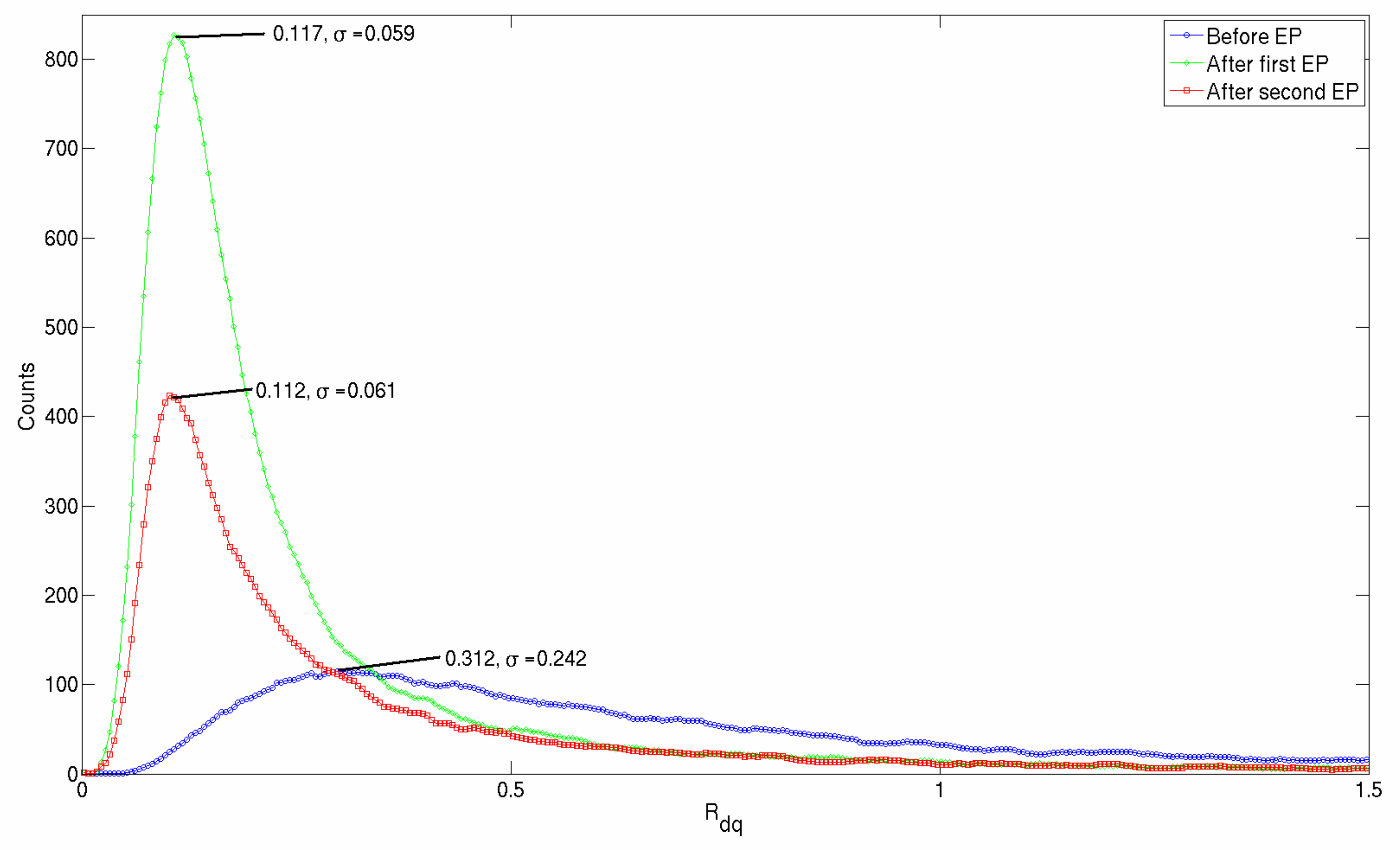
After 2nd EP



Most likely values

	Before EP	After 1st EP	After 2nd EP
	$R_{dq} = 0.312$	$R_{dq} = 0.112$	$R_{dq} = 0.117$
	$\sigma = 0.242$	$\sigma = 0.061$	$\sigma = 0.059$

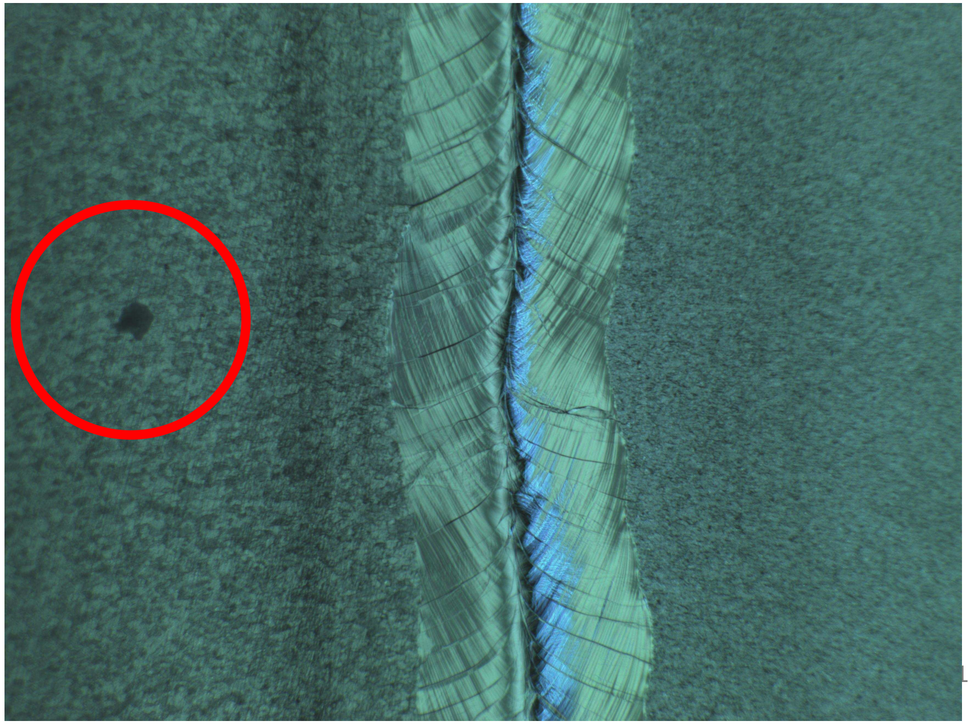
Influence of EP onto the welding seam



- Most likely value decrease, which means the edge roughness decreases
- The coverage ratio before EP and after the EP changes drastically.
  - Before EP: 2745 objects – 12.89 mm² (51.56%)
  - After EP: 2 objects – 21.92 mm² (87.68%)

Defect Recognition

- Sets of quantities used to compare an object with the neighborhood
  - Major Axis Length, Eccentricity, Area
- The neighborhood are all objects inside a circle with a radius 3.5 the major axis length
- If the mean difference of the single object compared to the other objects are above a threshold, mark it as an irregularity



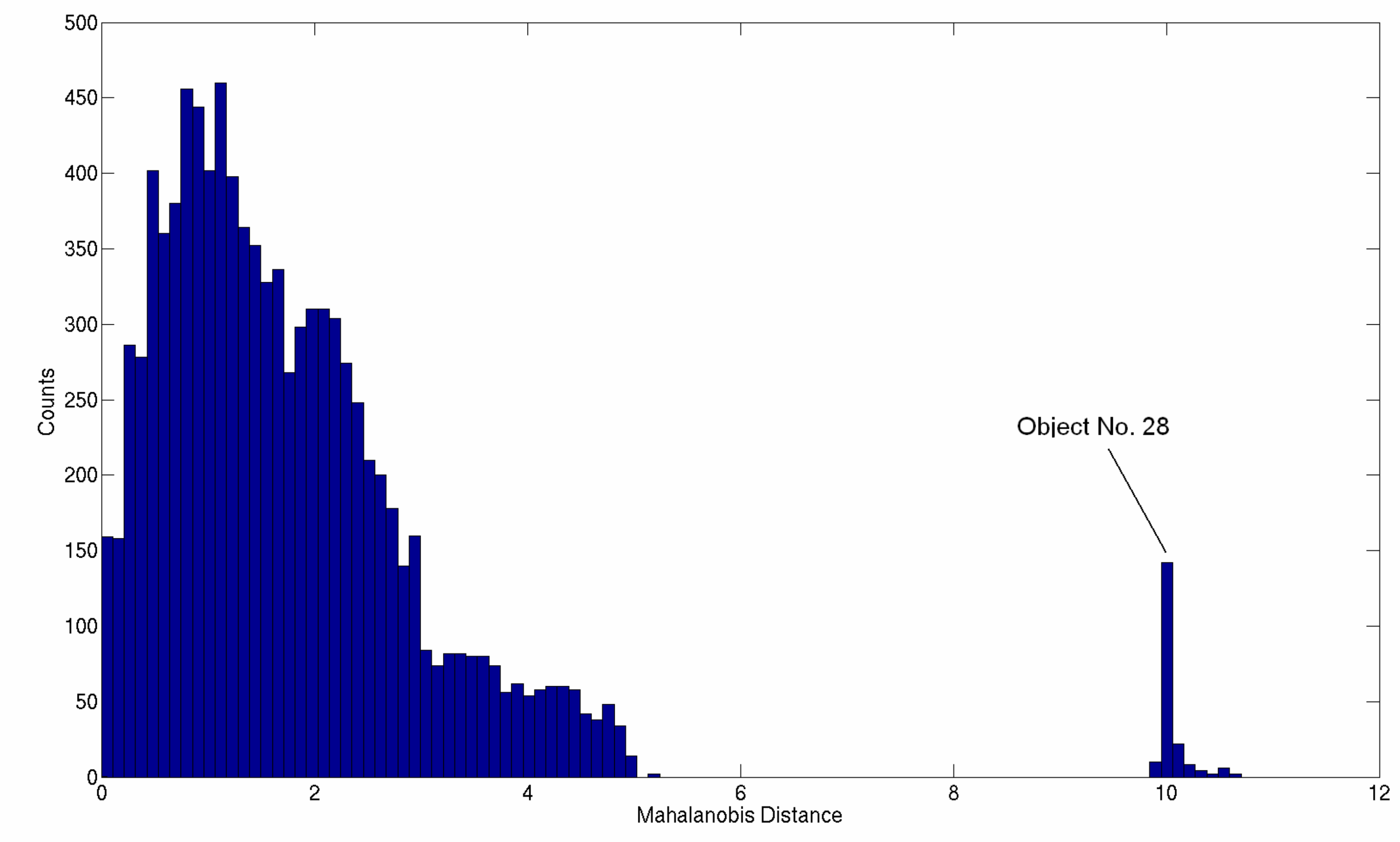
A measure of distance

- x_i and y_i are the i-th entries (e.g. eccentricity, color, area) of the n-tupel describing the two objects

$$d(\vec{x}, \vec{y}) = \sqrt{\sum_{i=1}^{N} \frac{(x_i - y_i)^2}{\sigma_i^2}},$$

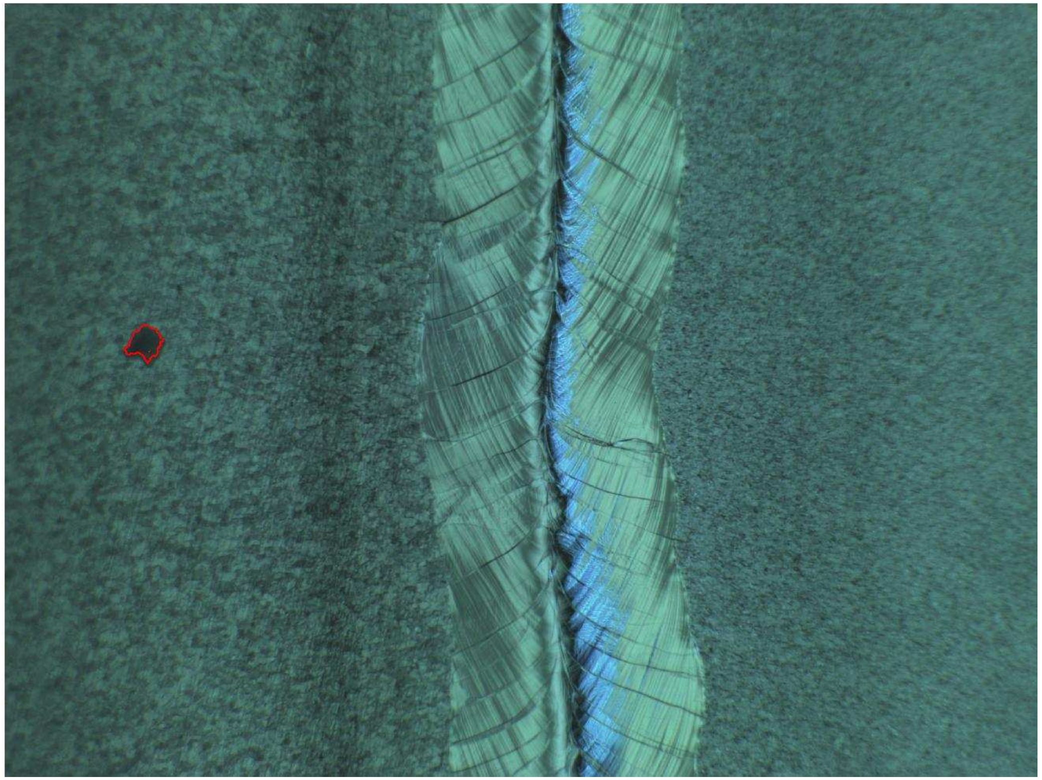
- The difference is normalized by the variance of this quantity
- This allows us to compare different properties and their values
  - A difference of 0.3 in eccentricity and a difference of 100 µm² of the area of two objects have different ranges
  - When normalizing this, we can compare these distances

A measure of distance

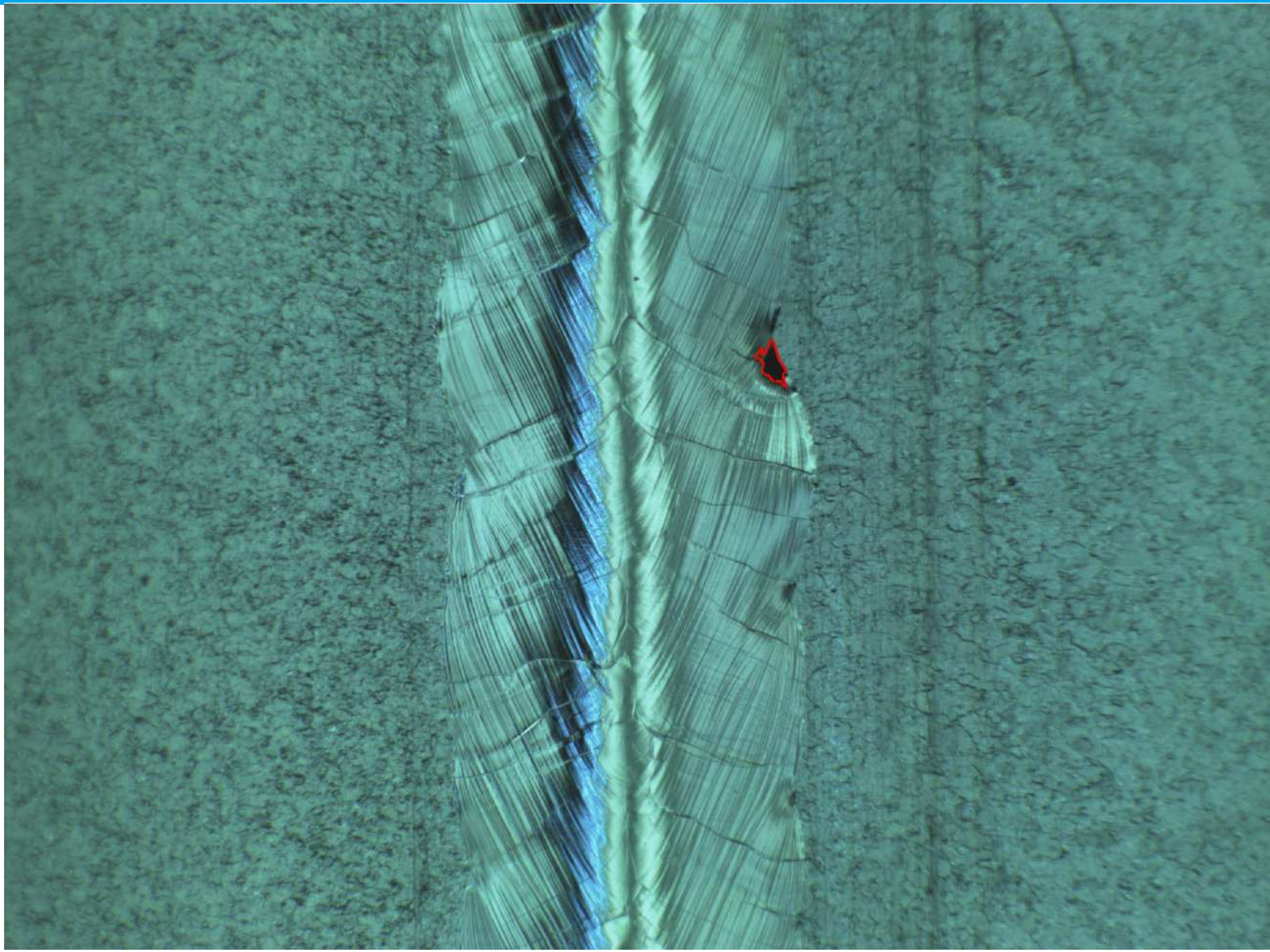


Defect Recognition

- One object was identified as an irregularity
- The boundary of this object is shown in this image
- Fits well with the impurity on the surface



Other defects



Summary

- OBACHT is being commissioned
- It will be used for the optical inspection of XFEL and ILC HiGrade cavities

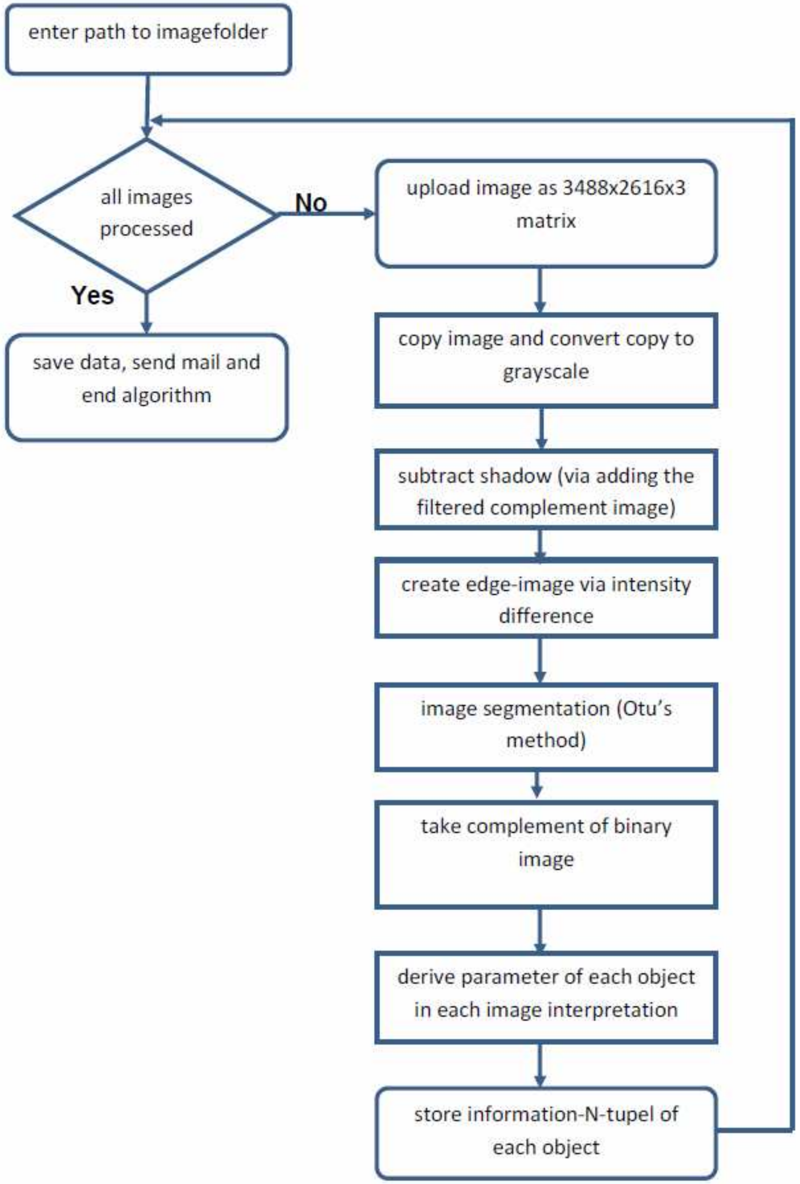
- An image processing algorithm is being developed to classify the cavity surface properties

- Defect recognition with obvious defects works (4 different types)

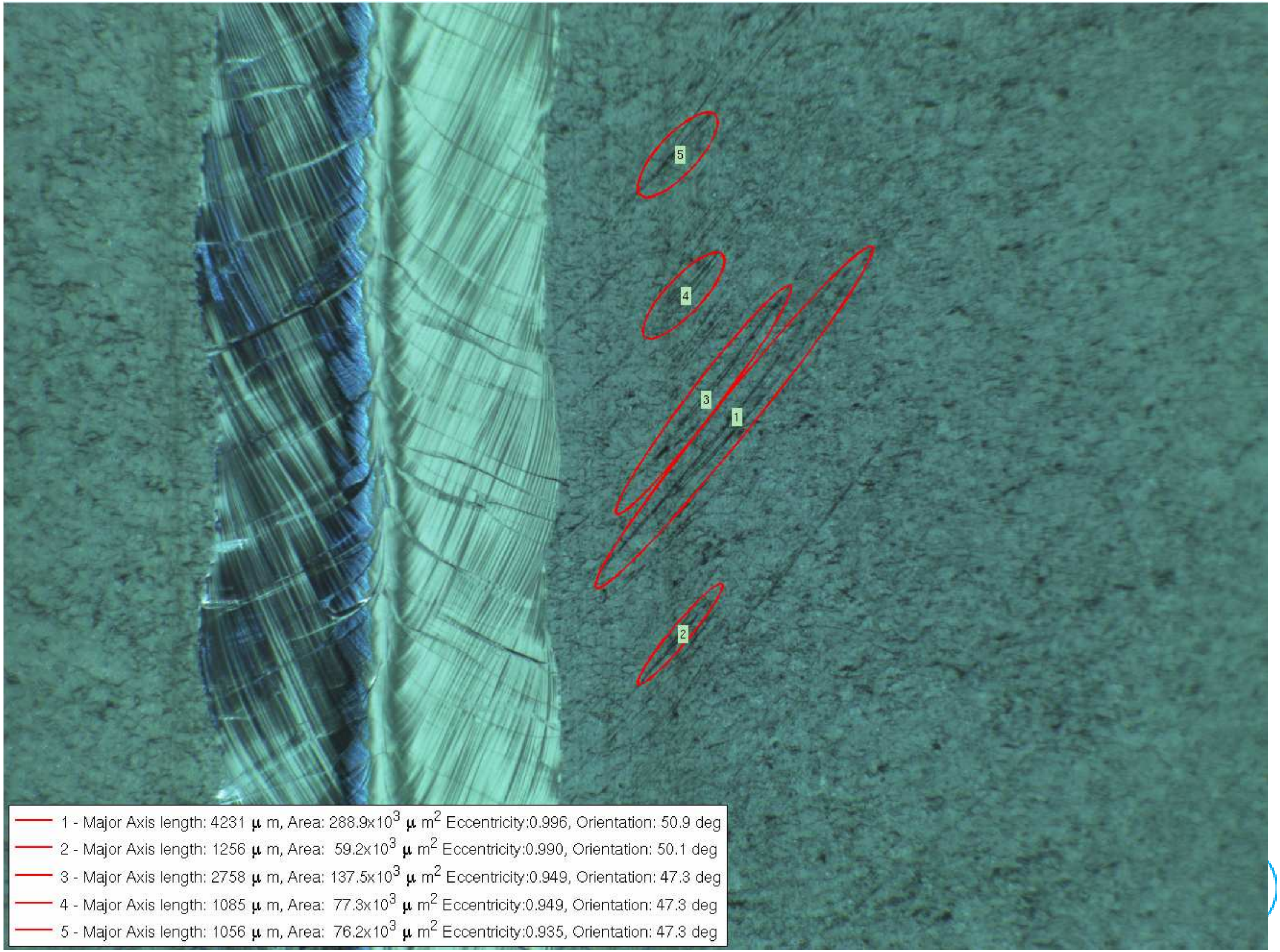
Thank you

Back Up

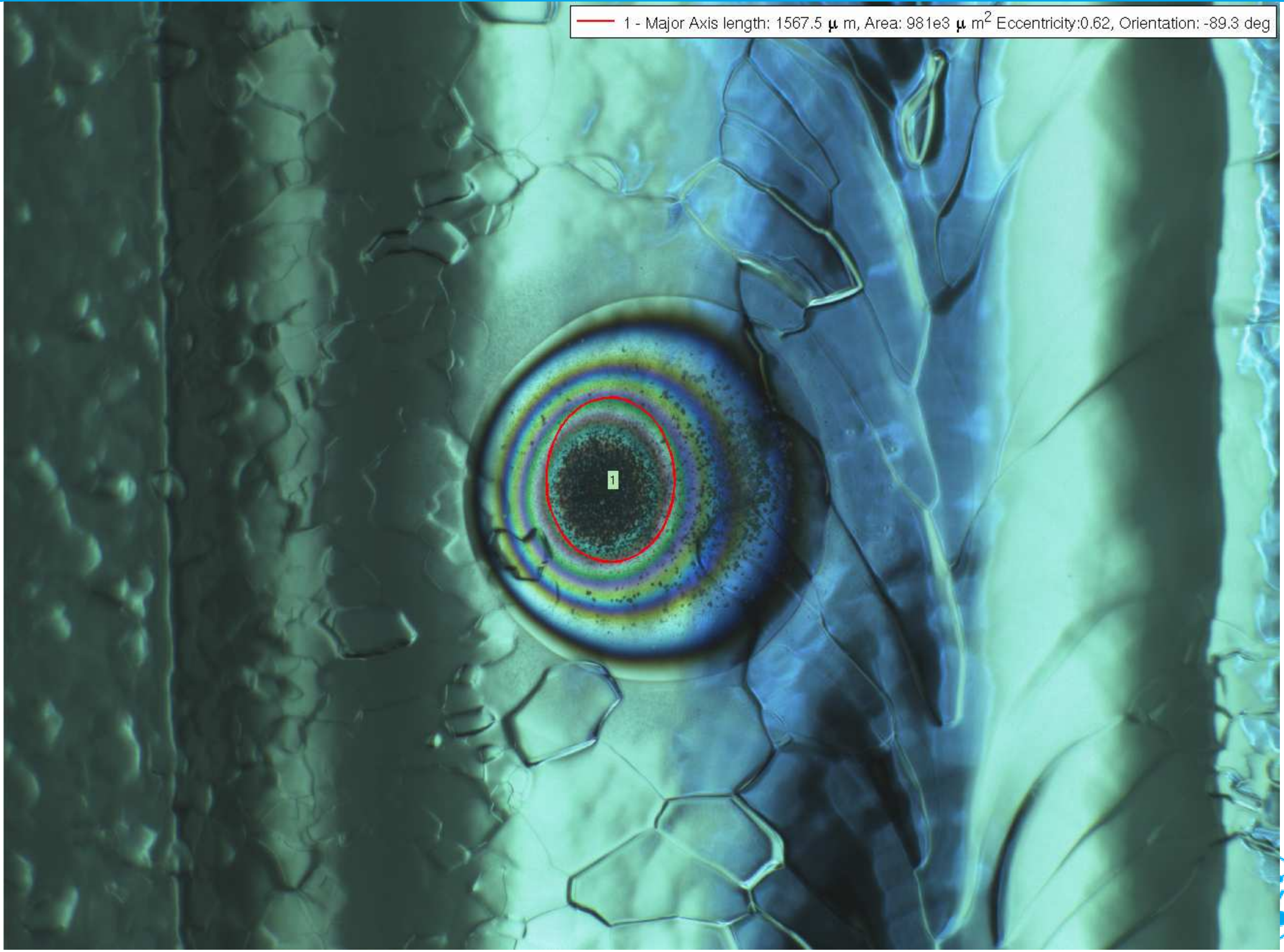
Flowdiagram



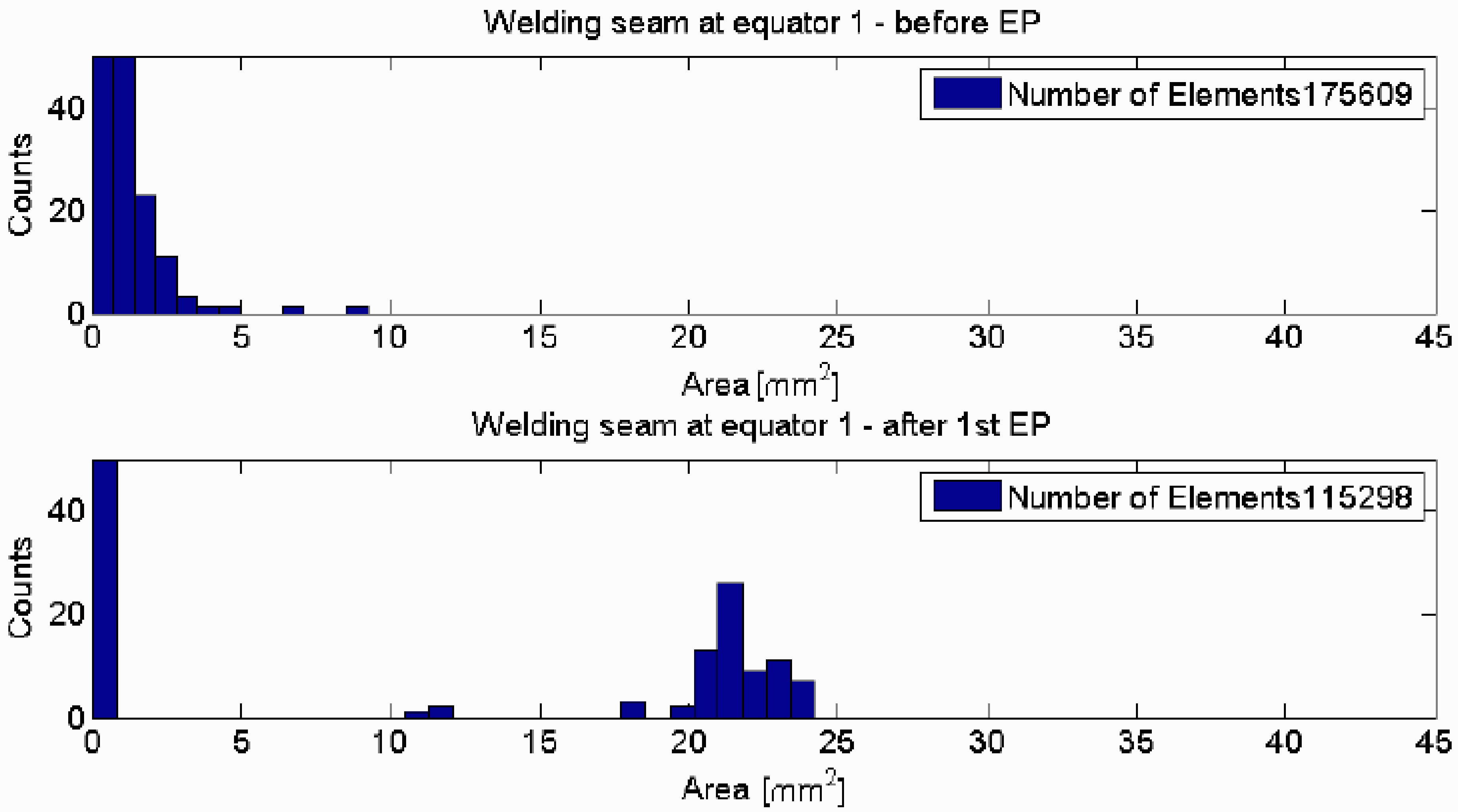
Other defects



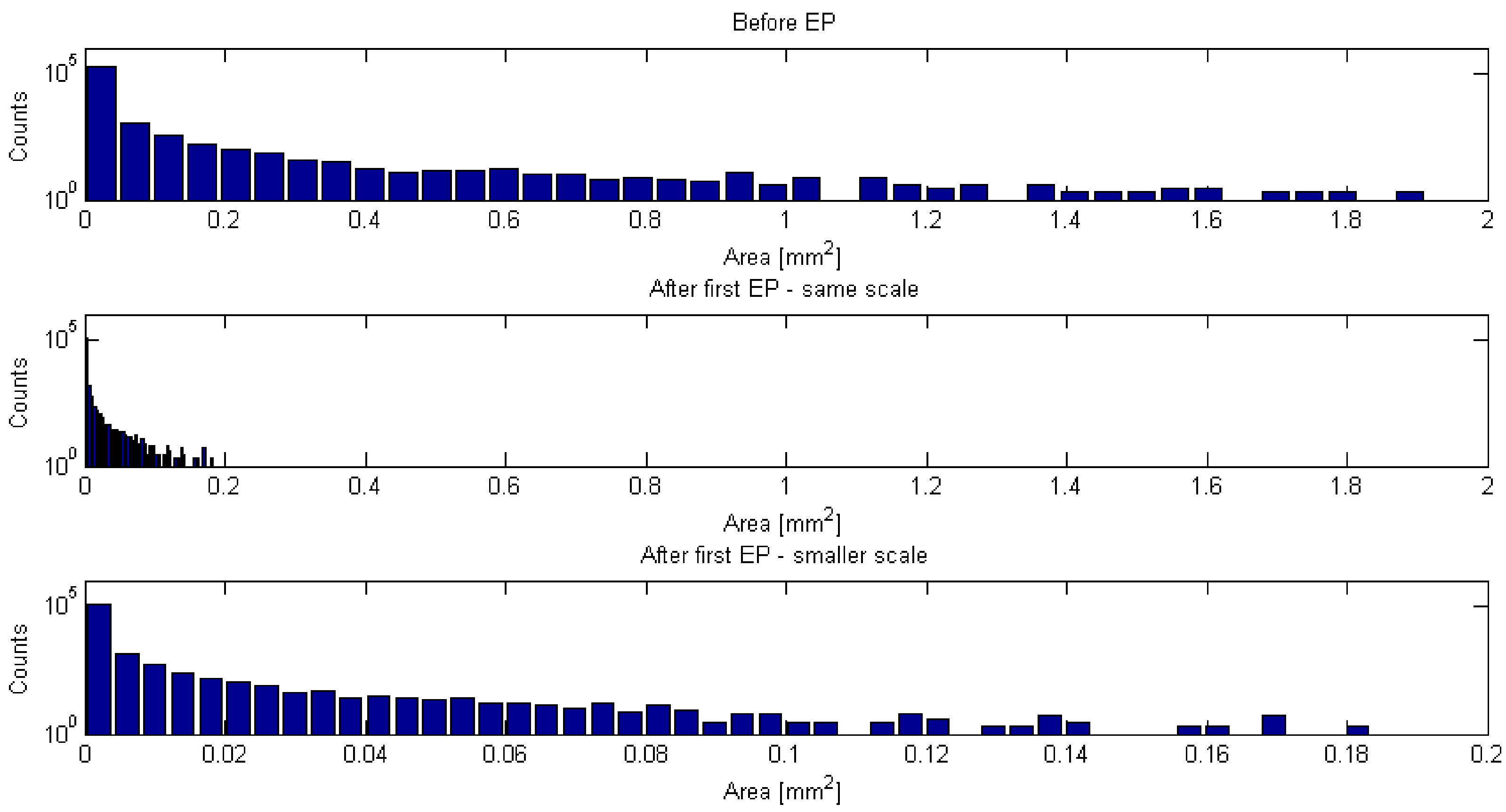
Other defects



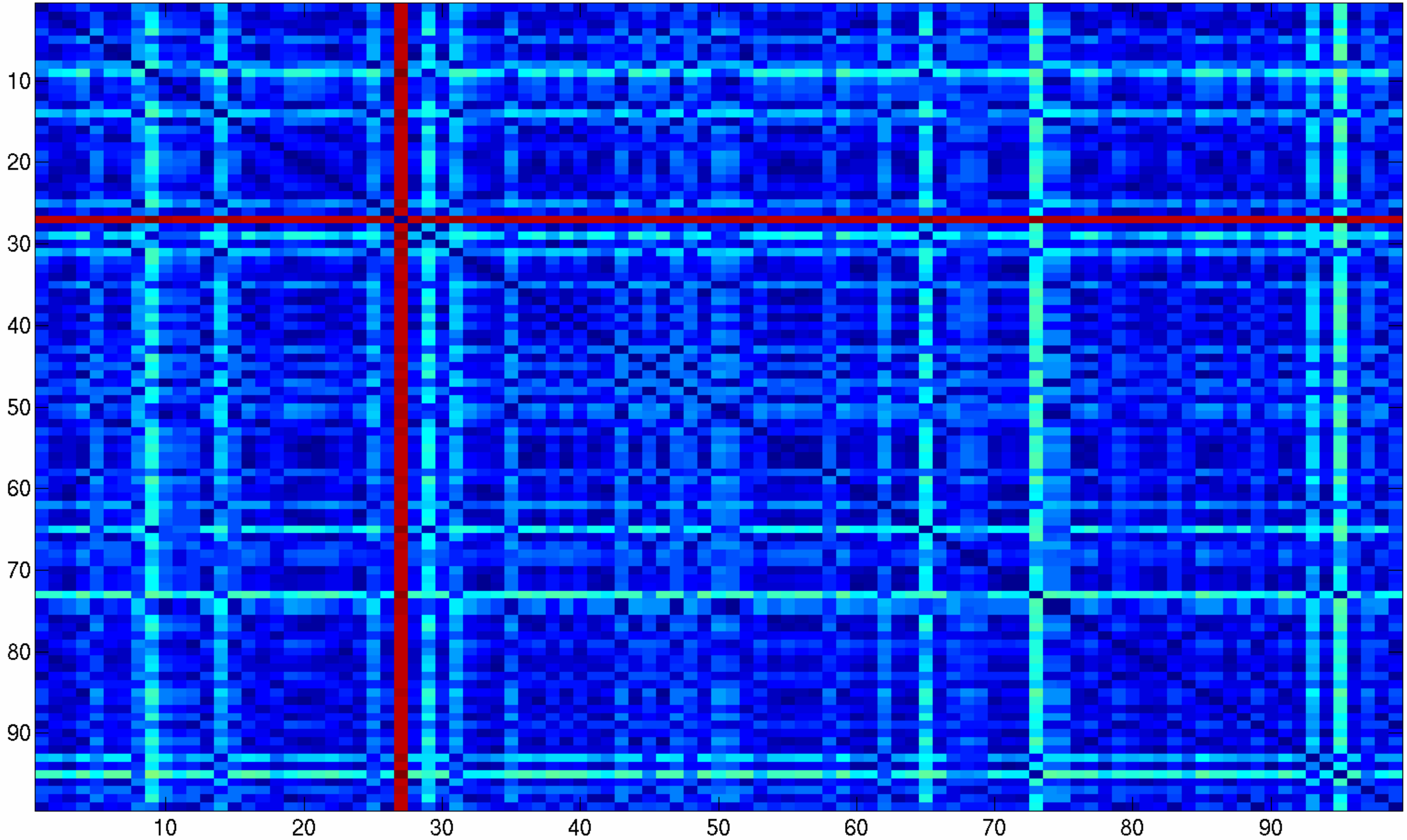
Influence of EP onto the welding seam



Influence of EP – objects below 2 mm²

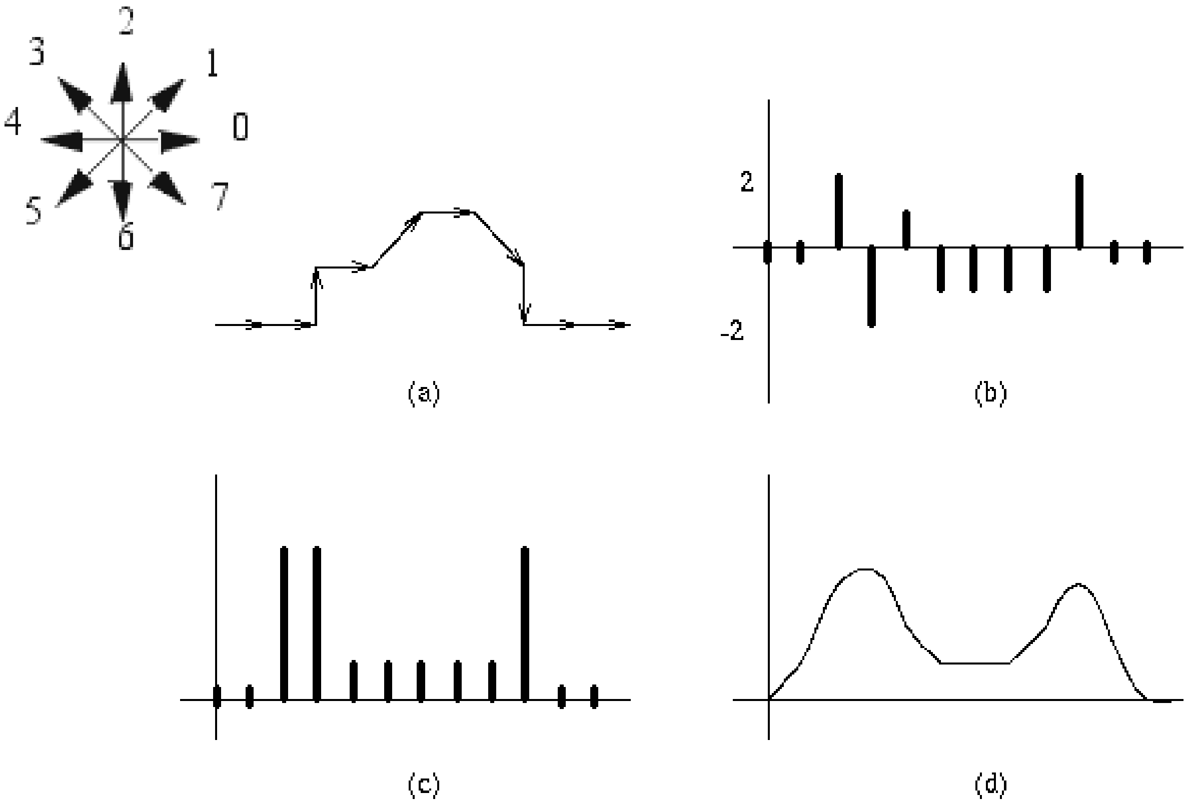


Mahalanobis Distance



Chaincode – Perimeter – Bending Energy

8-connected

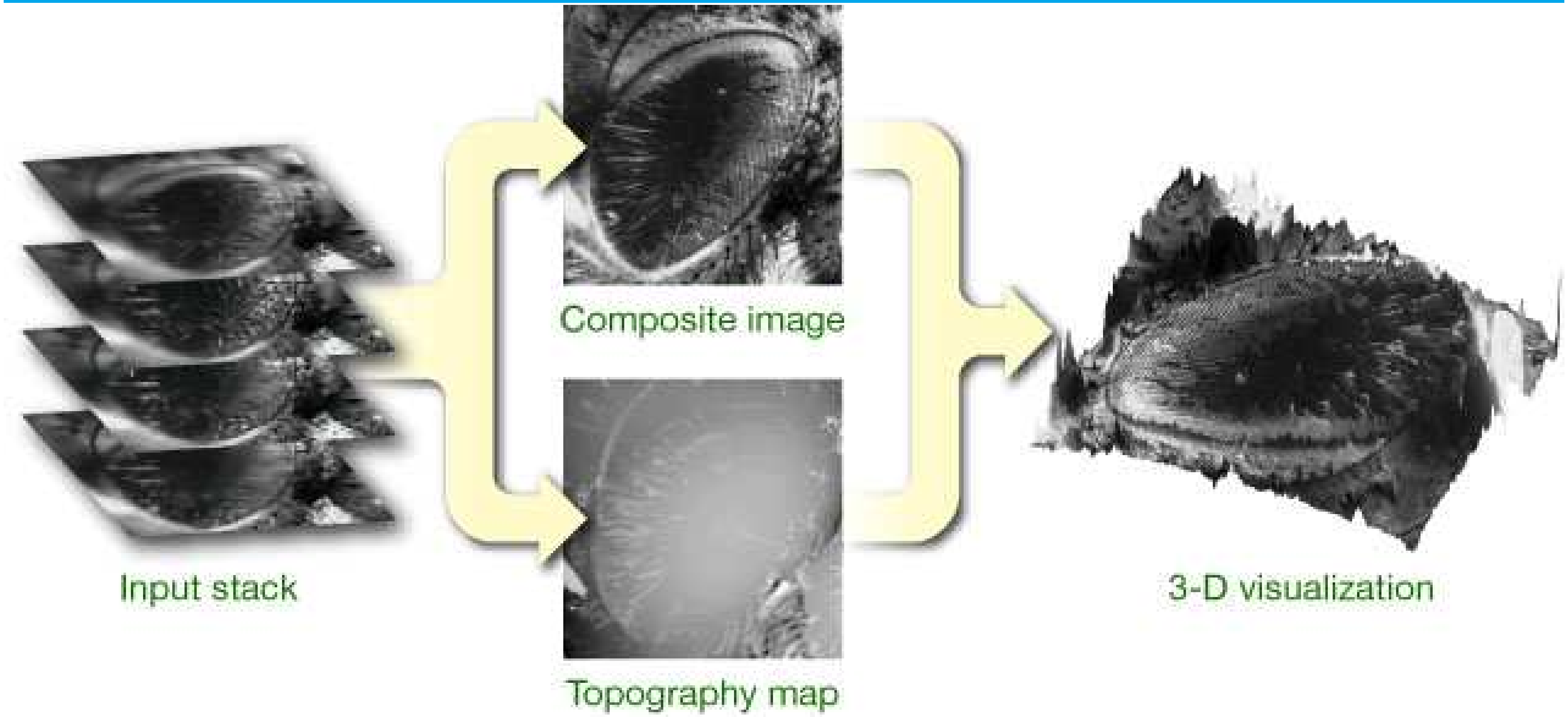


$$Curvature = \mathrm{mod}(c_{n+1} - c_n, 8)$$

$$BendingEnergy = \frac{1}{L}\sum Curvature^2$$

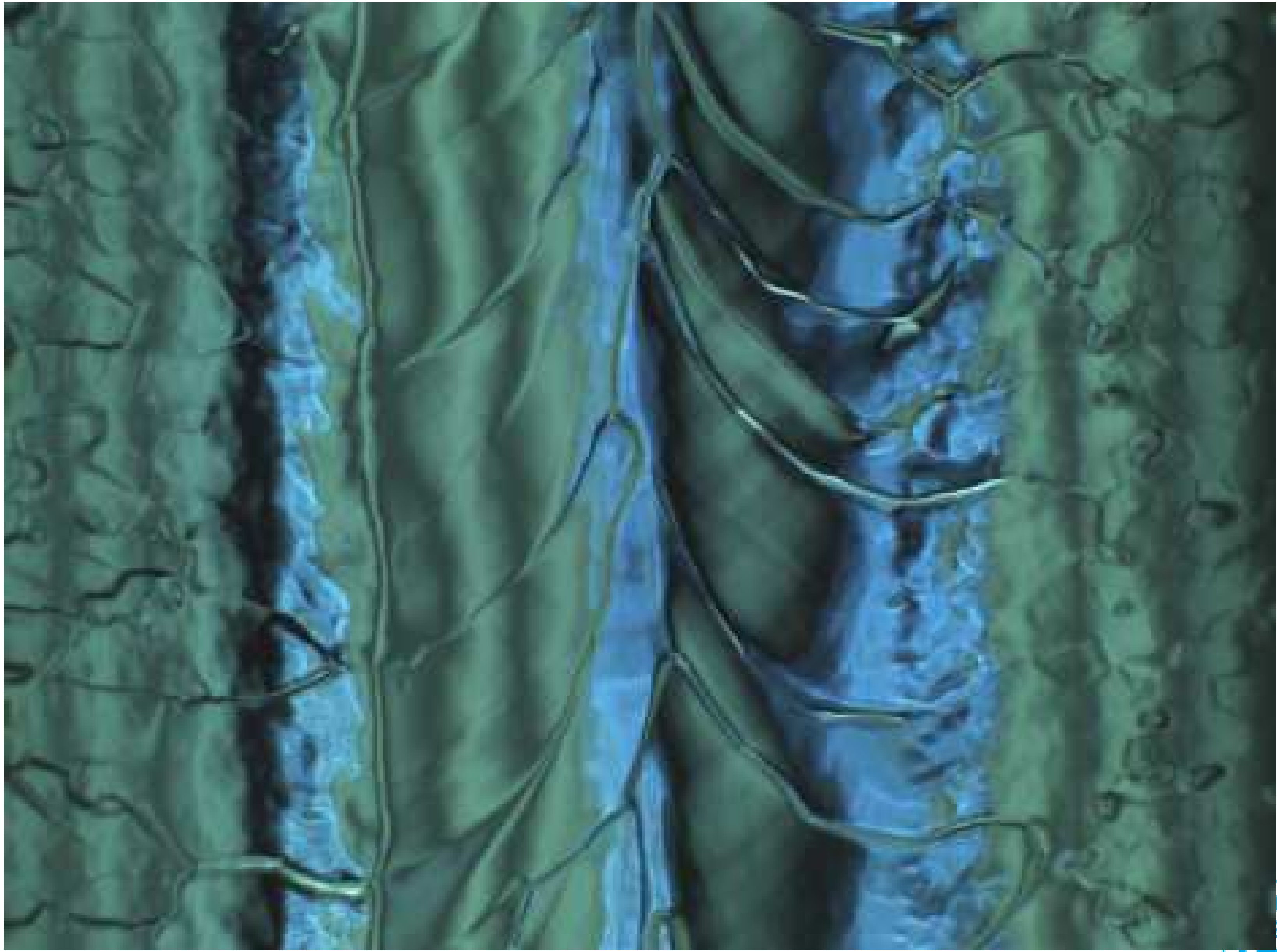
Figure 6.8 *Bending energy: (a) Chain code 0, 0, 2, 0, 1, 0, 7, 6, 0, 0, (b) curvature 0, 2, -2, 1, -1, -1, -1, 2, 0, (c) sum of squares gives the bending energy, (d) smoothed version.*

2D - 3D

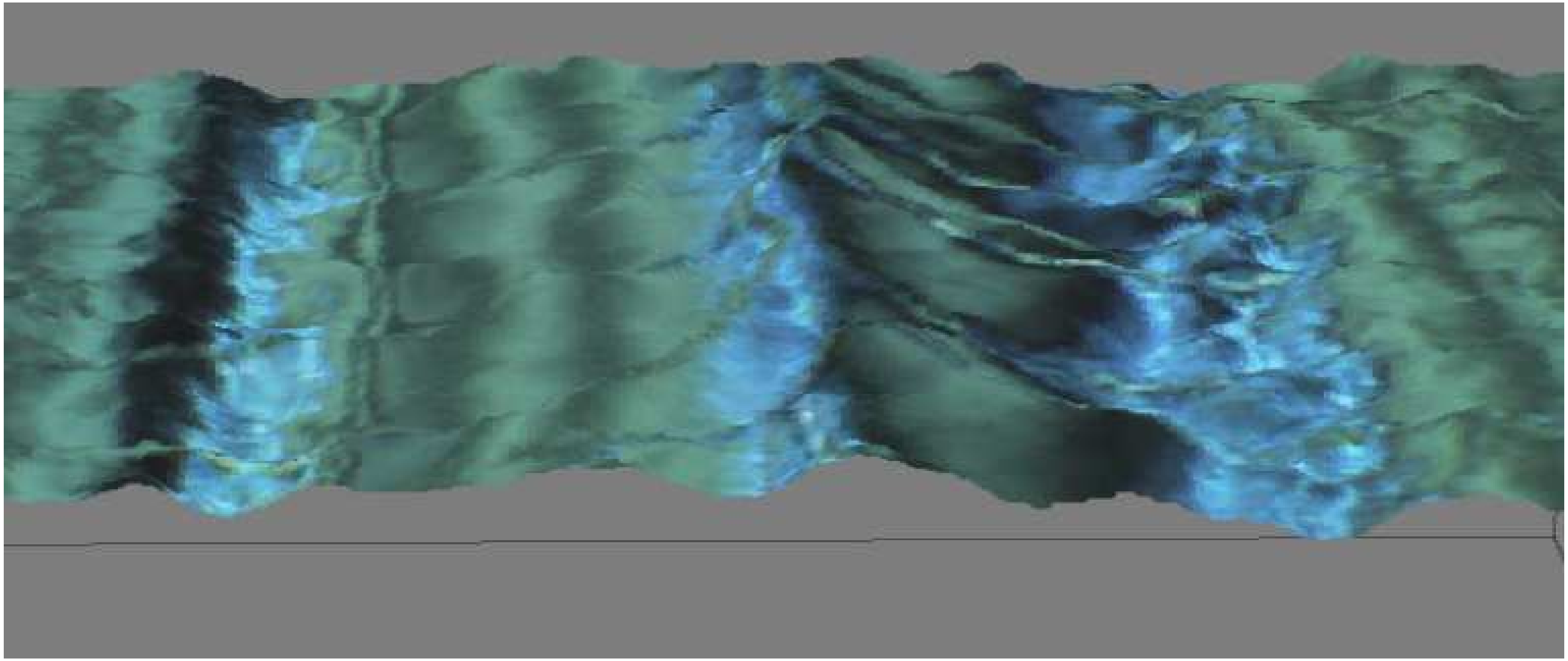


Externes Programm – ‚Complex wavelet-based method' (Focus Stacking)
B. Forster, D. Van De Ville, J. Berent, D. Sage, M. Unser,
"Complex Wavelets for Extended Depth-of-Field: A New Method for the Fusion of Multichannel Microscopy Images ," Microsc. Res. Tech., 65(1-2), pp. 33-42, September 2004.

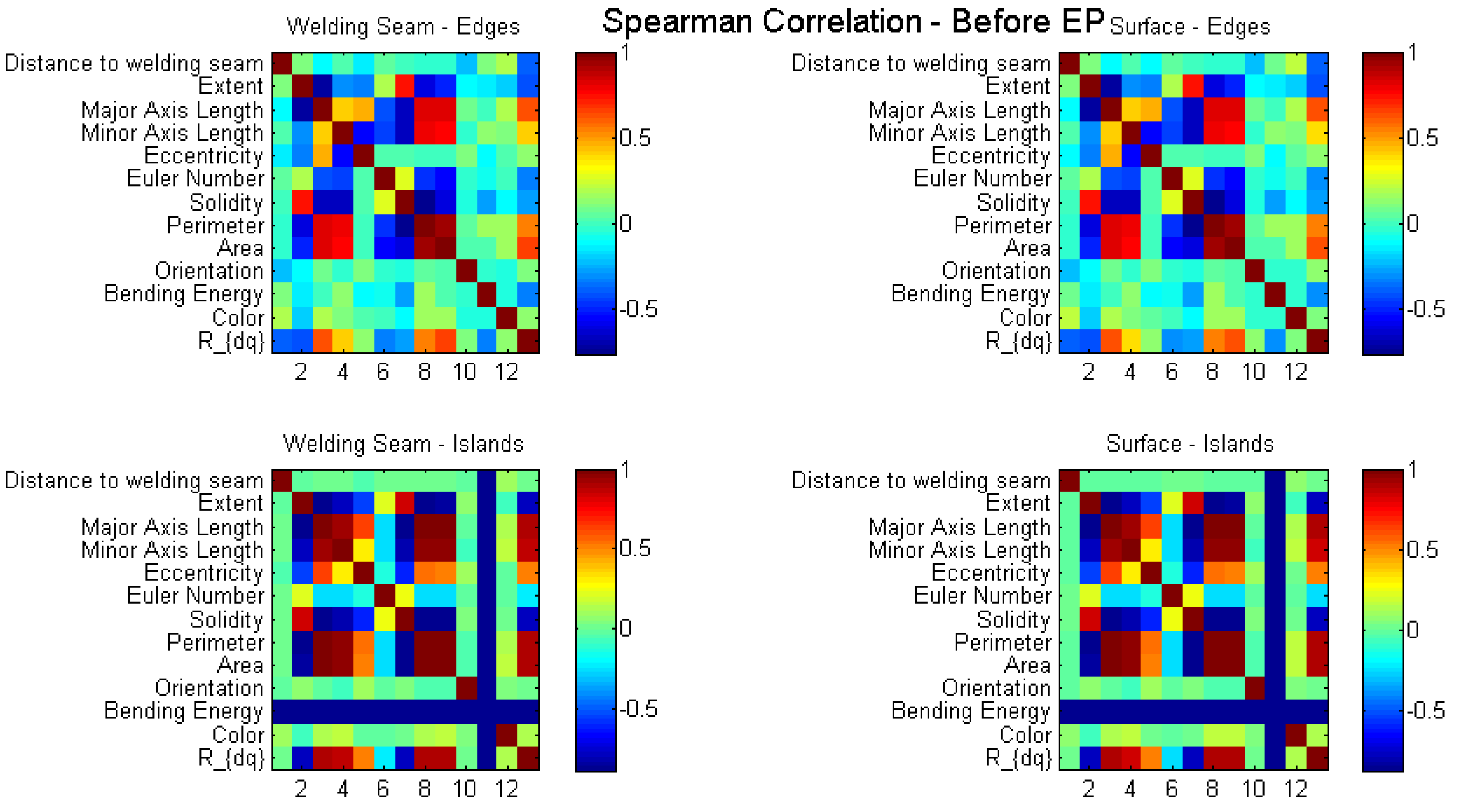
2D - 3D



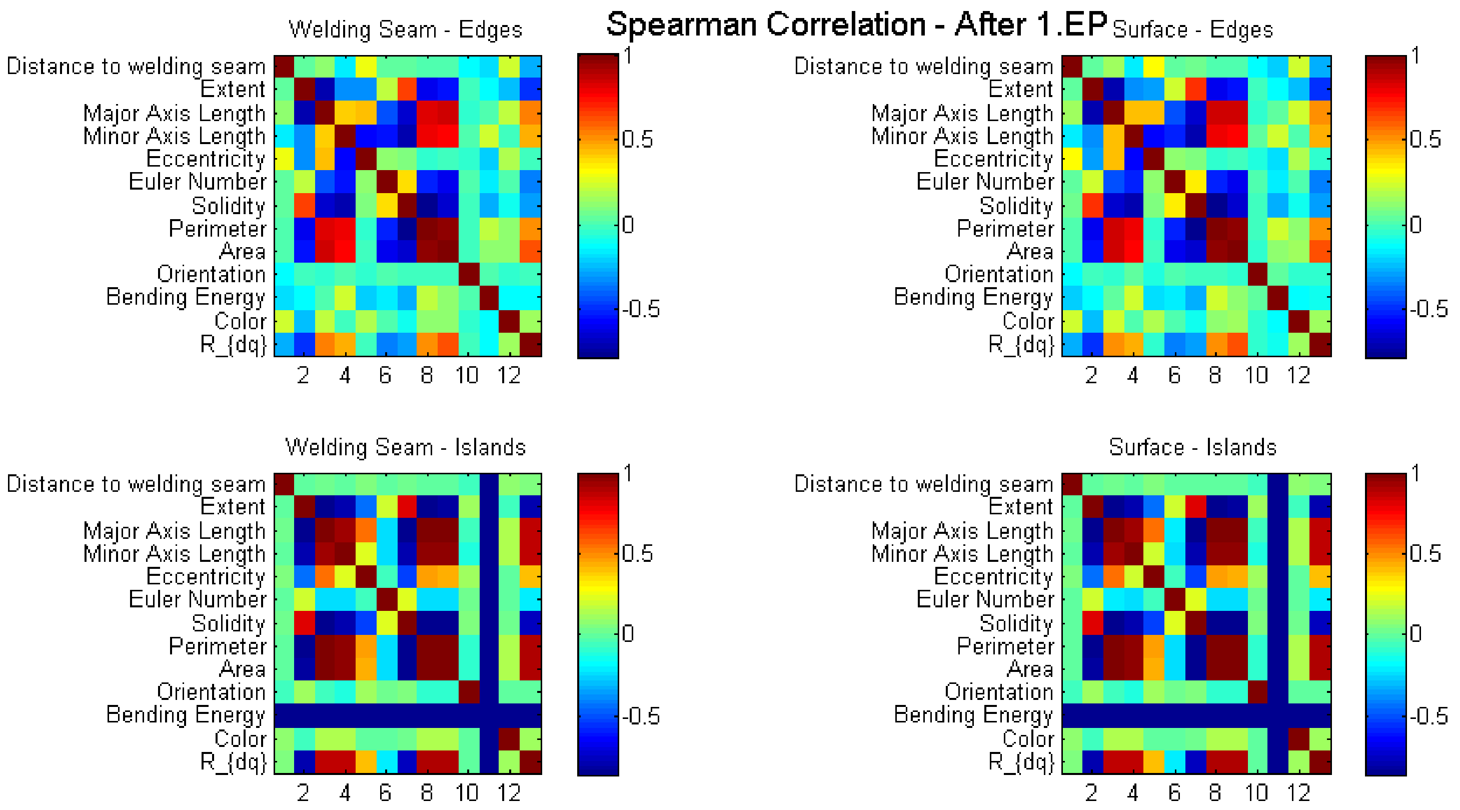
2D - 3D



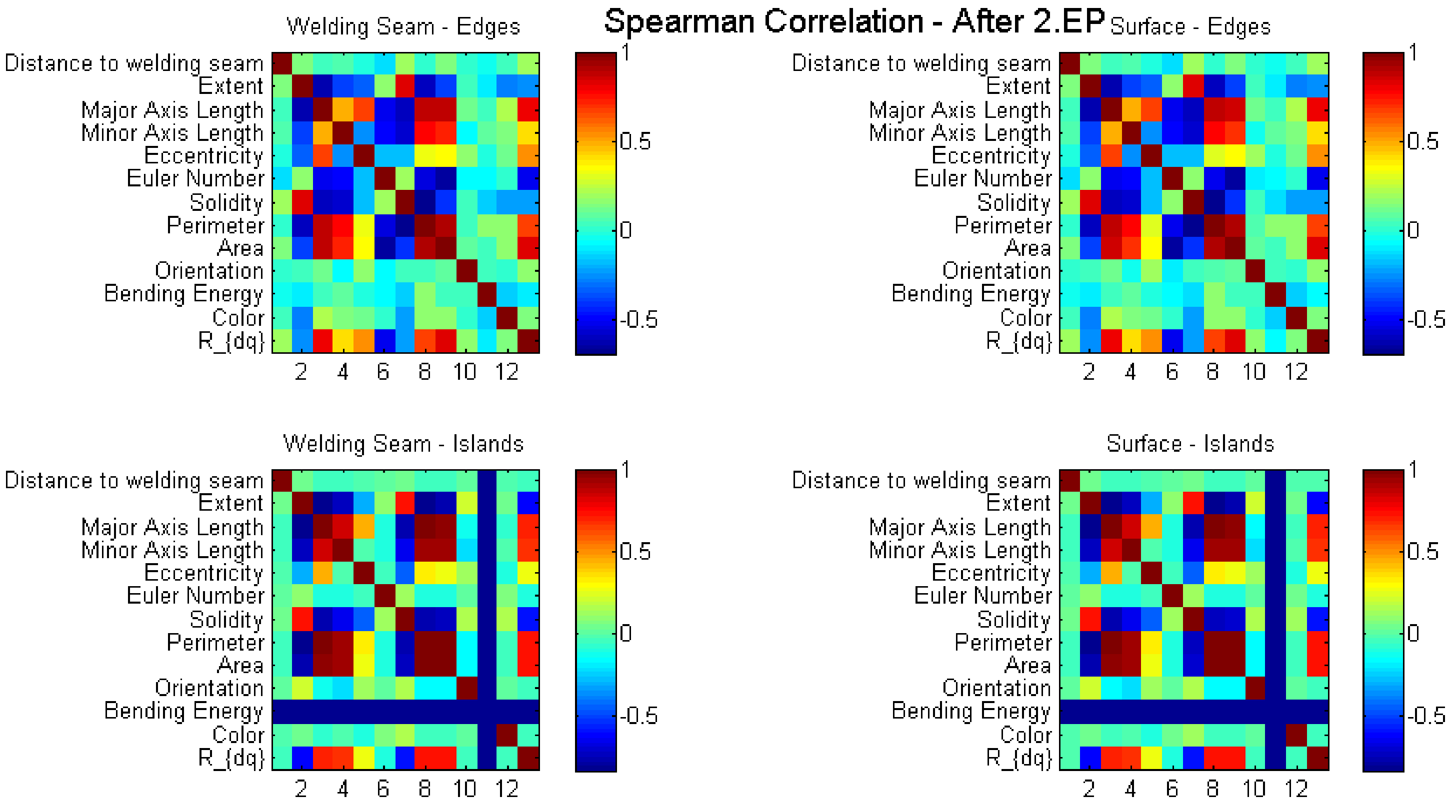
Correlation



Correlation

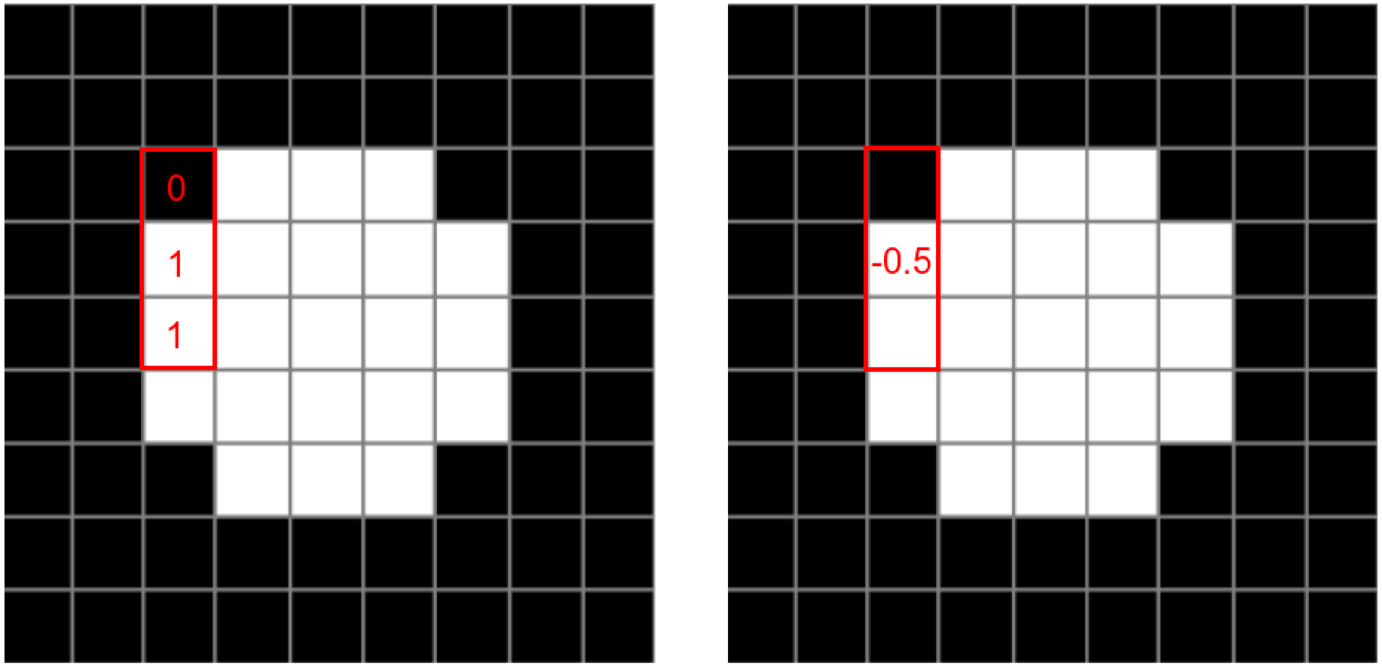


Correlation



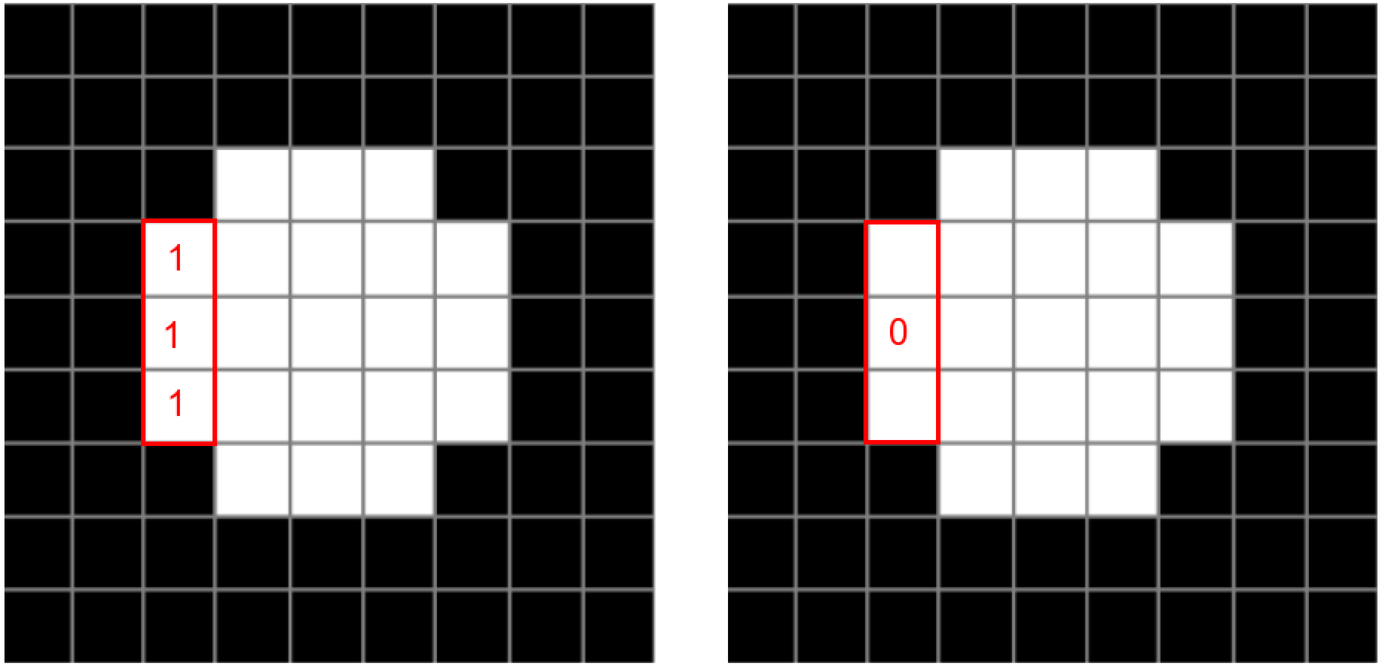
Surface Roughness

$$\frac{\Delta I(x,y)}{\Delta x} = \frac{I(x+1,y) - I(x-1,y)}{(x+1)-(x-1)} = \frac{0-1}{2} = -0.5$$



Surface Roughness

$$\frac{\Delta I(x,y)}{\Delta x} = \frac{I(x+1,y) - I(x-1,y)}{(x+1)-(x-1)} = \frac{1-1}{2} = 0$$



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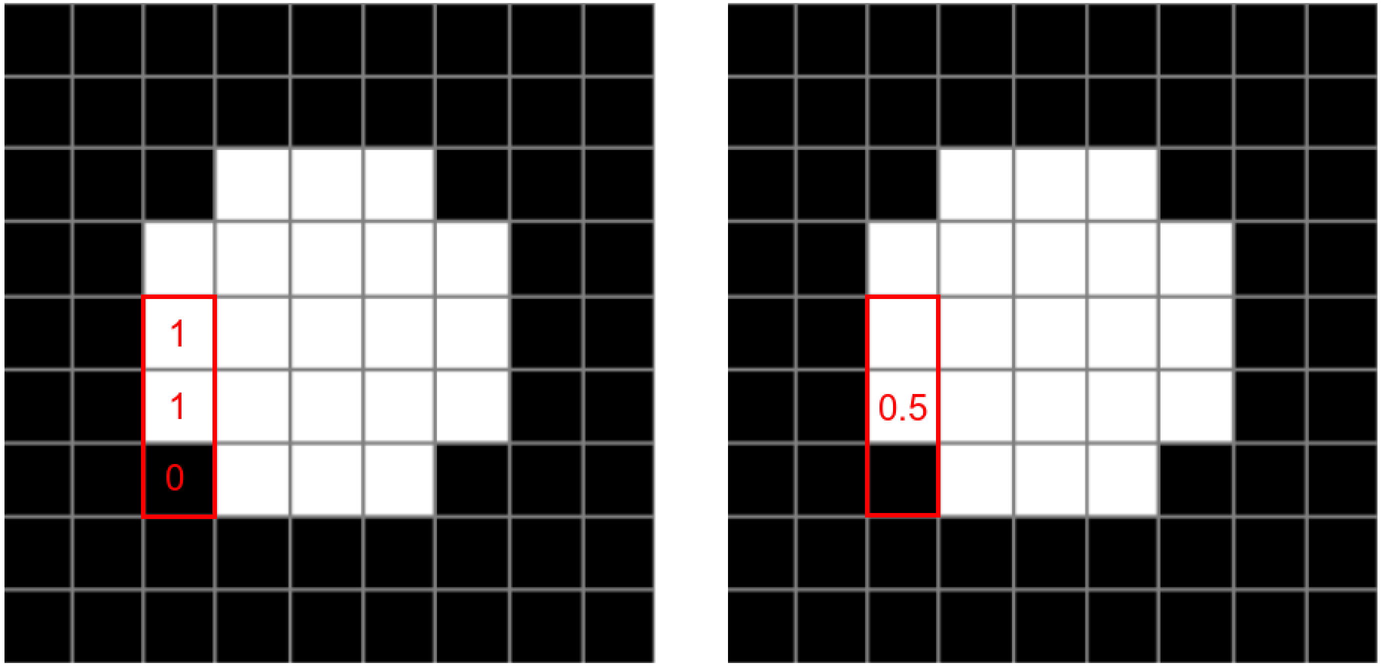

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