Segmentation for 3D metrology by Computerized Tomography

by

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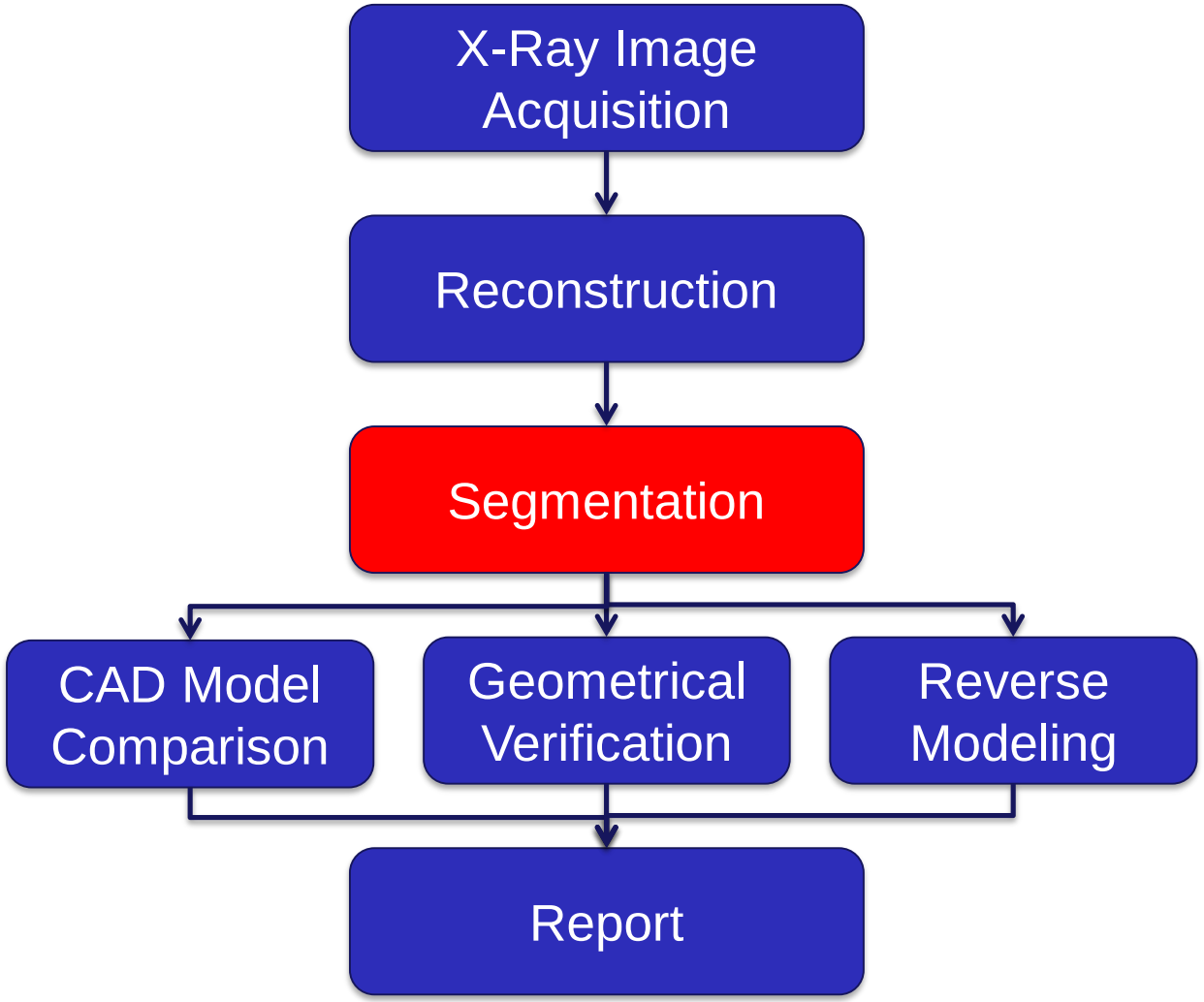
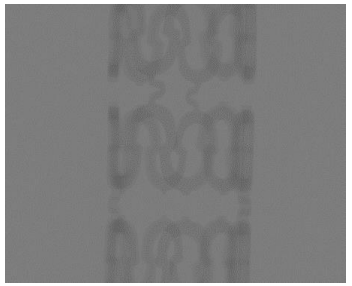
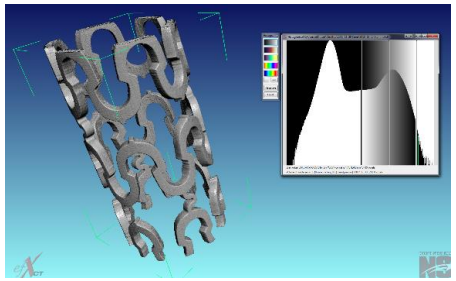
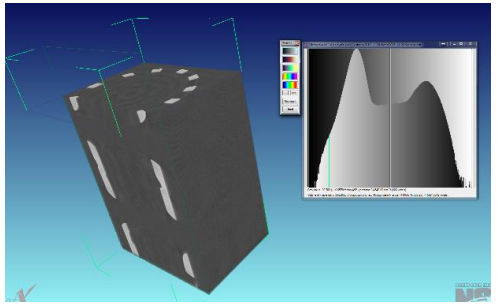
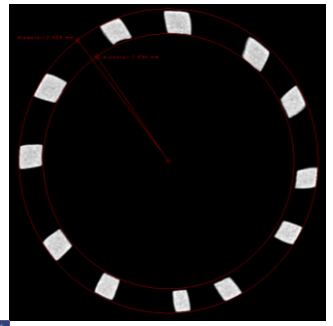
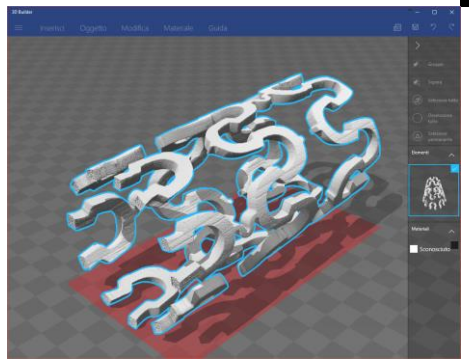

X-Ray Image Acquisition
Reconstruction
Segmentation
CAD Model Comparison
Geometrical Verification
Reverse Modeling
Report

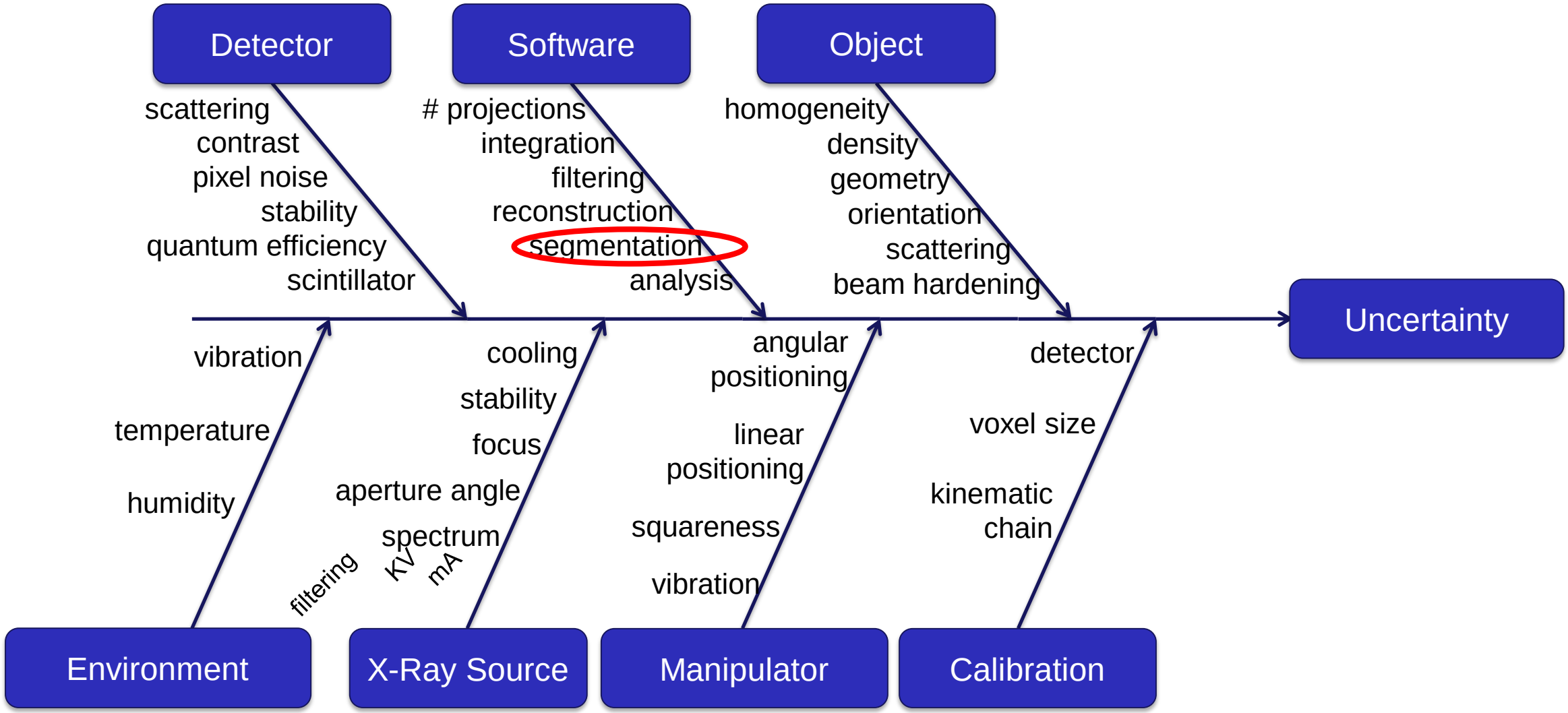


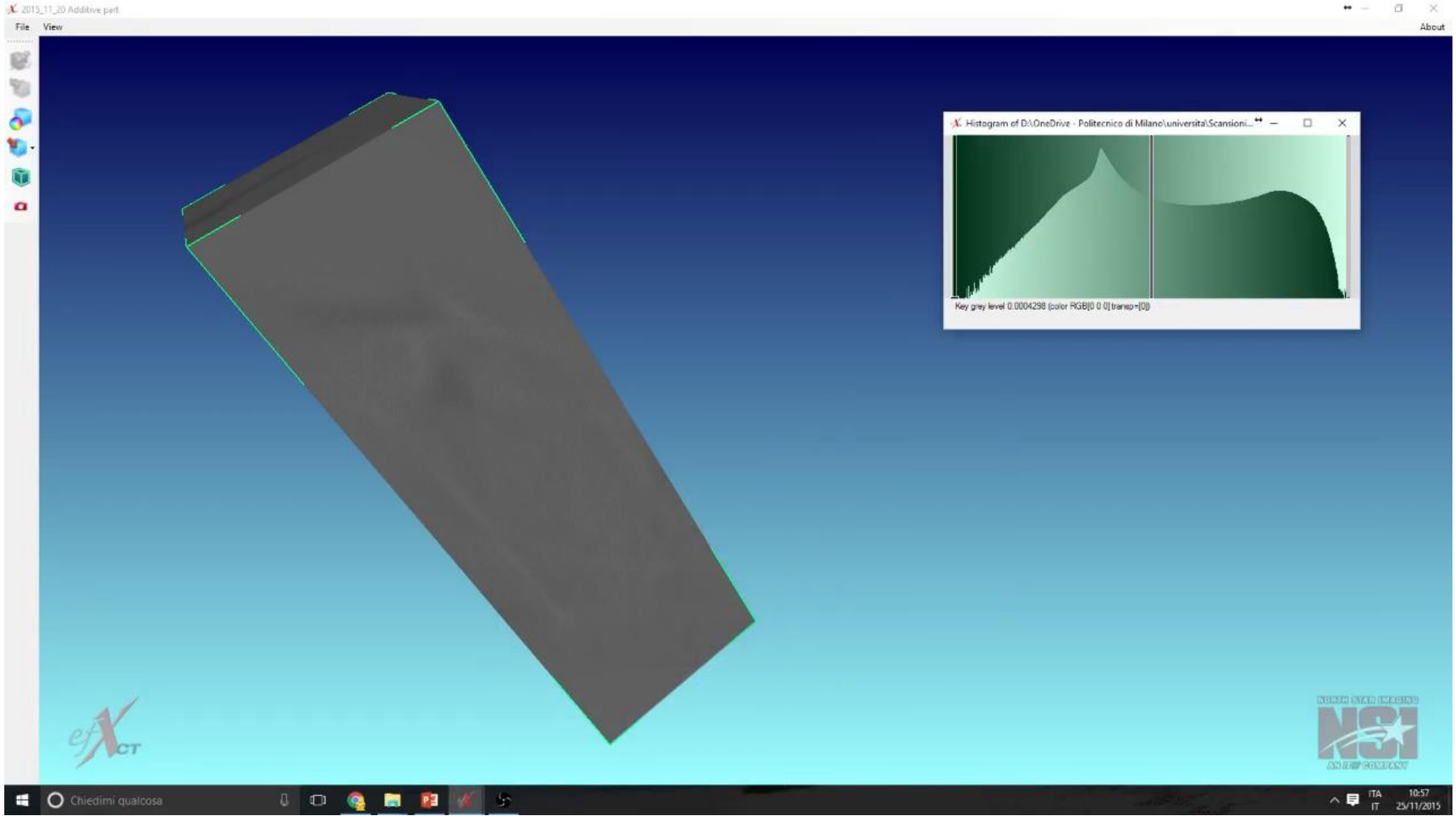









Detector
Software
Object
scattering
contrast
pixel noise
stability
quantum efficiency
scintillator
projections
integration
filtering
reconstruction
segmentation
analysis
homogeneity
density
geometry
orientation
scattering
beam hardening
Uncertainty
vibration
temperature
humidity
cooling
stability
focus
aperture angle
spectrum
KV
mA
filtering
angular positioning
linear positioning
squareness
vibration
detector
voxel size
kinematic chain
Environment
X-Ray Source
Manipulator
Calibration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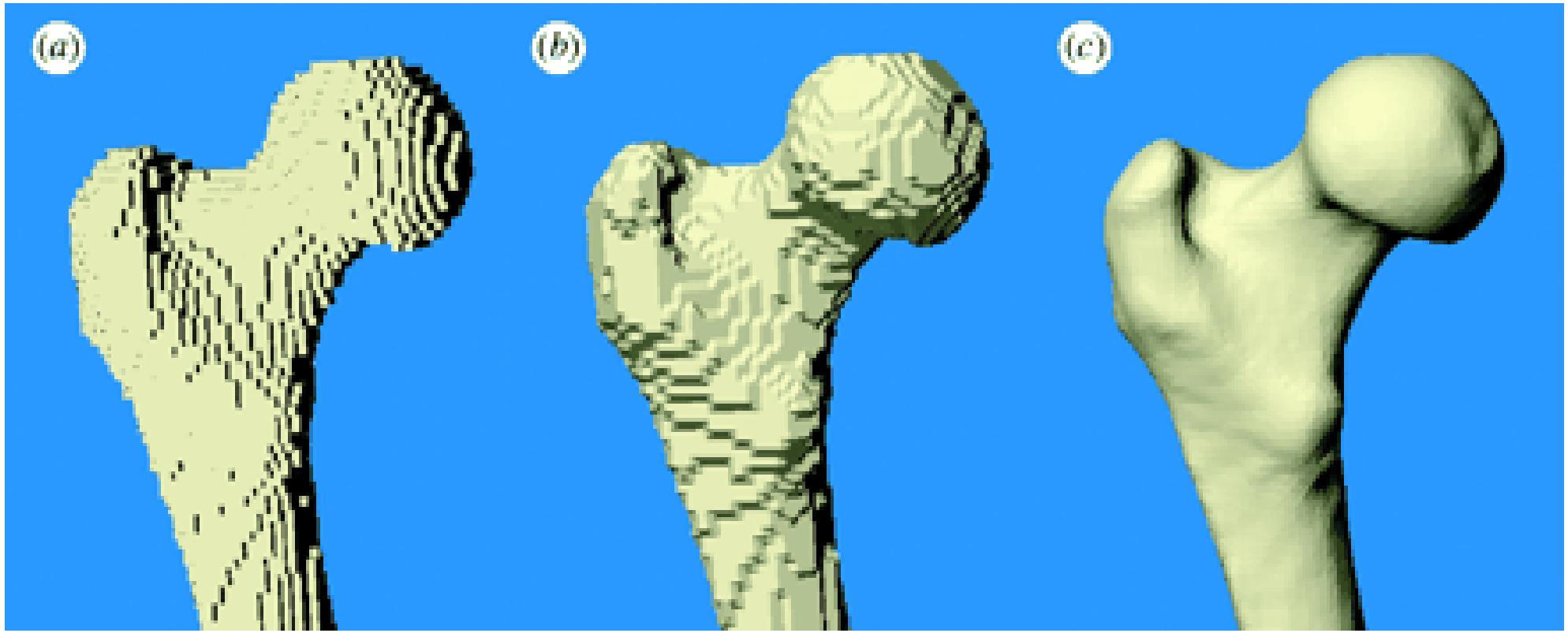
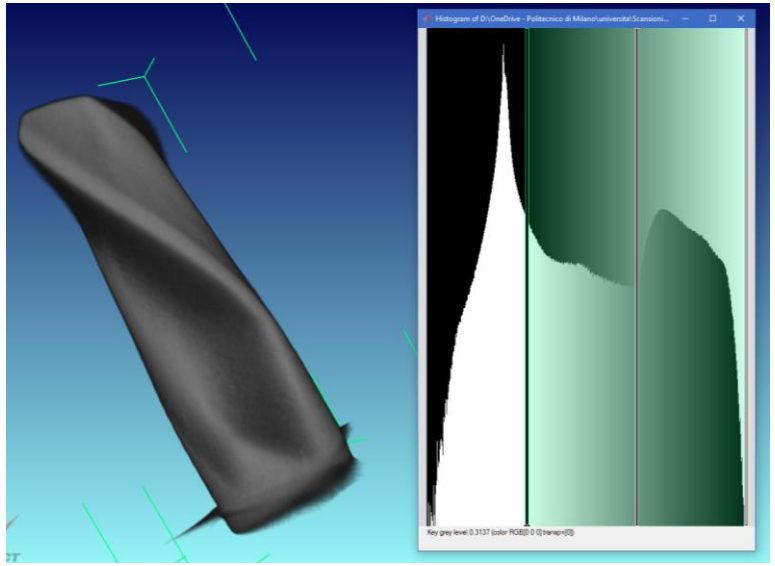
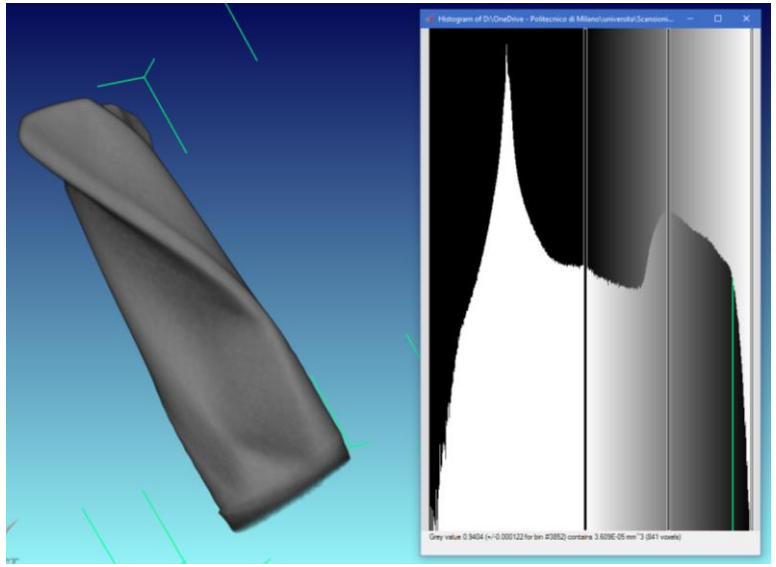
Even when a segmentation has been established, still issues remain about the optimal solution:

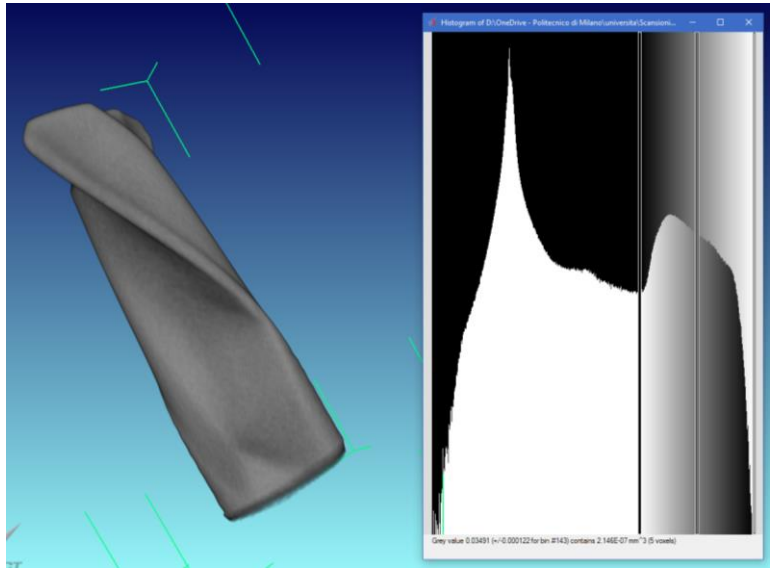
- Direct analysis of the voxel (is a segmentation really needed?)
- How can we extract a cloud of points form a voxel representation of a volume, while preserving the metrological traceability?

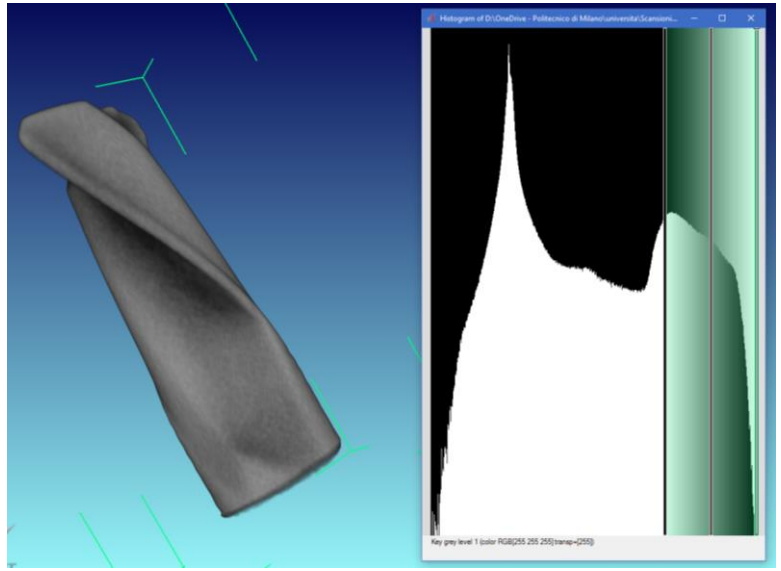


P.G Young, T.B.H Beresford-West, S.R.L Coward, B Notarberardino, B Walker, A Abdul-Aziz, An efficient approach to converting three-dimensional image data into highly accurate computational models (2008)









Global thresholding (requires an explicit definition of the threshold)

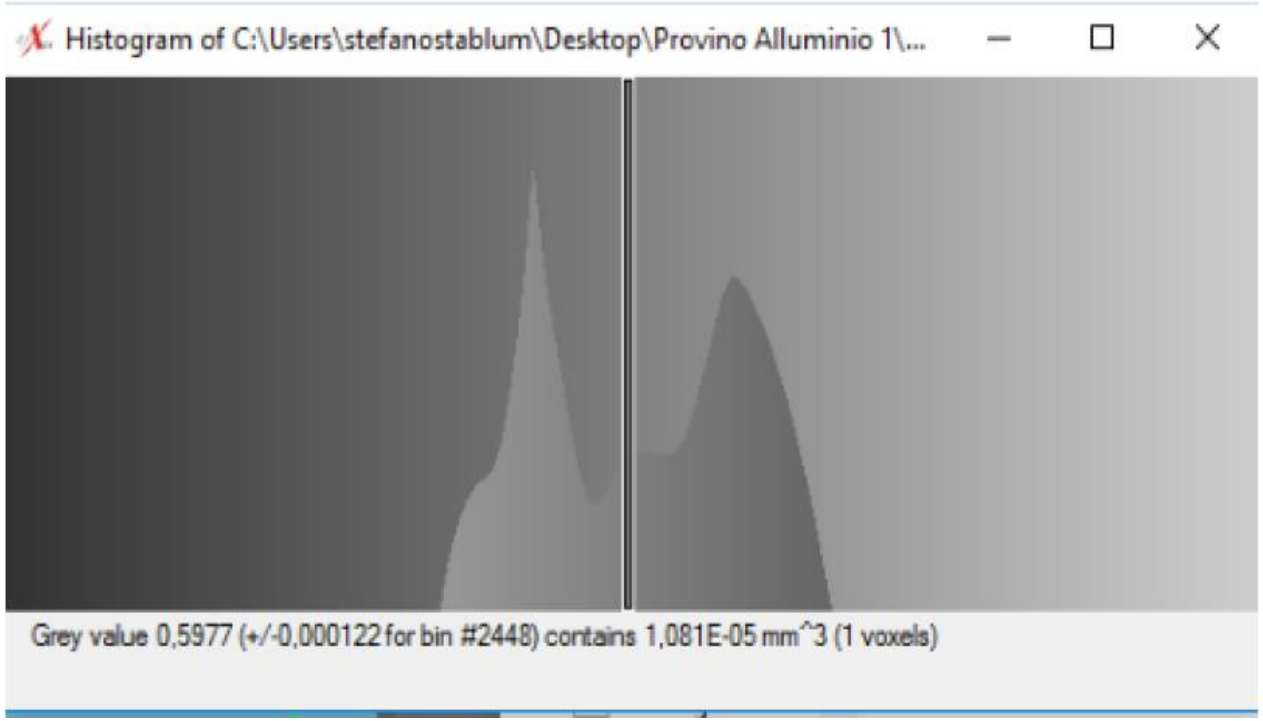
$$g(x) = \begin{cases} 1 \; if \; f(x) \geq \theta \\ 0 \; if \; f(x) < \theta \end{cases}$$

Local thresholding (requires an explicit definition of the threshold, in case changing point to point)

$$g(x) = \begin{cases} 1 \; if \; f(x) \geq \theta(x) \\ 0 \; if \; f(x) < \theta(x) \end{cases}$$

Where $\theta(x)$ can be defined in different ways

- Niblack Thresholding
  - W. Niblack, An introduction to image processing (1986)
- Mardia and Hainsworth
  - K.V. Mardia and T.J. Hainsworth, A Spatial Thresholding Method for Image Segmentation (1988)
- Indicator Kriging
  - W. Oh and W.Q. Lindqvinst, Image Thresholding by Indicator Kriging (1999)

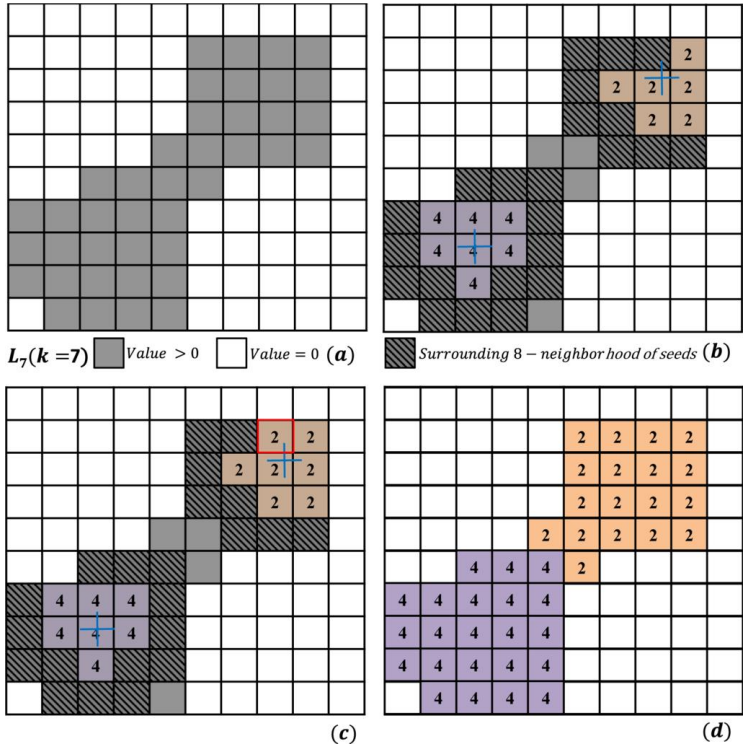


Hysteresis thresholding (requires a double explicit definition of the threshold)

$$g(x) = \begin{cases} 1 \; if \; f(x) \geq \theta_1 \\ 1 \; if f(x) \geq \theta_2 \; \wedge \exists x' | f(x') \geq \theta_1, x' is \; adjacent \; to \; x \\ 0 \; else \end{cases}$$

Region Growing (tries to autonomously define the threshold)

```
1  funct RegGrow(seed) ≡
2  ⌜
3     region.empty()
4     region.add(seed)
5     while region.HasNeighbour() do
6           x := PopNeighbour(region)
7           if M(x)
8              region.add(x)
9           fi
10    od
11    return(region)
12 ⌟.
```



The criterion $M(x)$ can be defined in several different ways

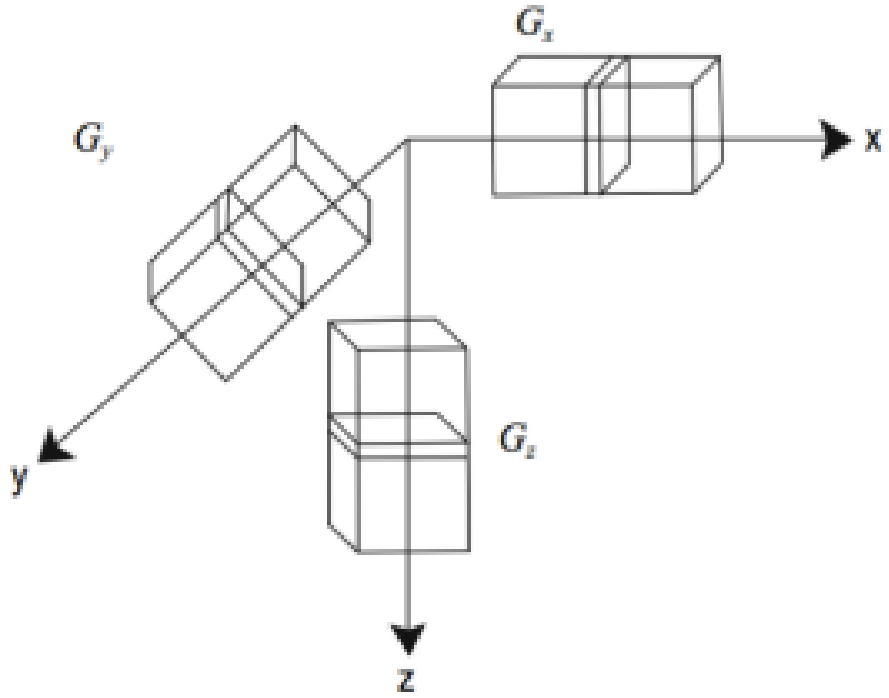
- R. Adams and L. Bischof, Seeded region growing (1994)
- C. Revol and M. Jourlin, A new minimum variance region growing algorithm for image segmentation (1997)

Sobel operator 3D (requires the definition of a threshold on the gray level gradient)

$$S_x(:,:,-1) = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

$$S_x(:,:,0) = \begin{bmatrix} -2 & 0 & 2 \\ -4 & 0 & 4 \\ -2 & 0 & 2 \end{bmatrix}$$

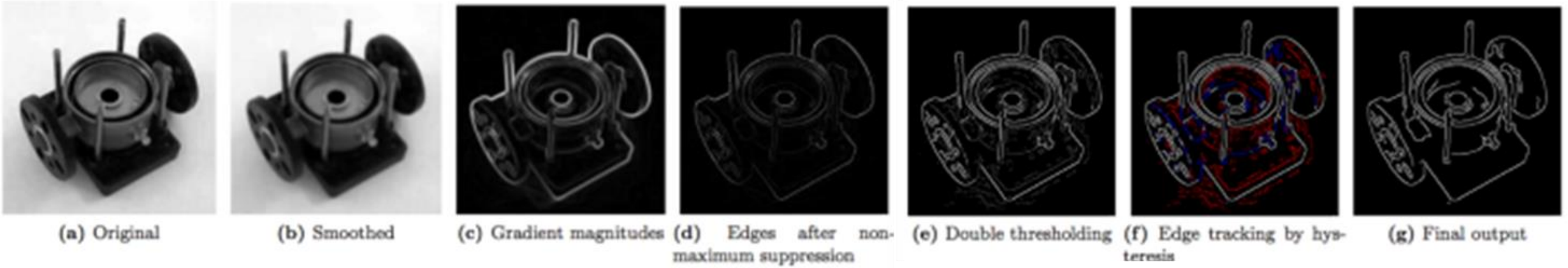
$$S_x(:,:,1) = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$



Sobel operator 5D: modification of the previous which tries to better take into consideration the slope along directions differing from the main directions (requires the definition of a threshold on the gray level gradient)

Canny algorithm (1986, variant of Sobel, requires the definition of a threshold on the gray level gradient)

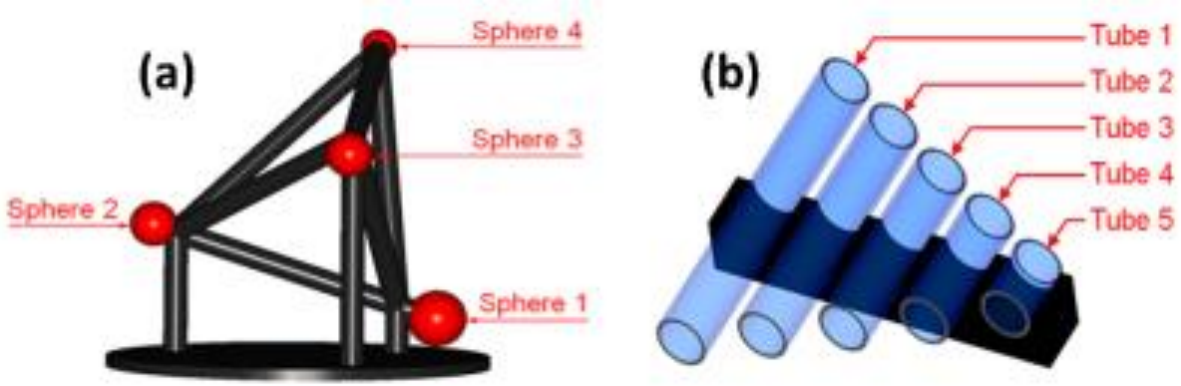
1. (Gaussian) smoothing
2. Calculation of the gradient (e.g. Sobel) and thresholding on the gradient
3. Non-maximum suppression
   - Sharpens the borders by removing blurred pixels
4. Double Thresholding
   - Eliminates fake borders generated by the noise the in the scan

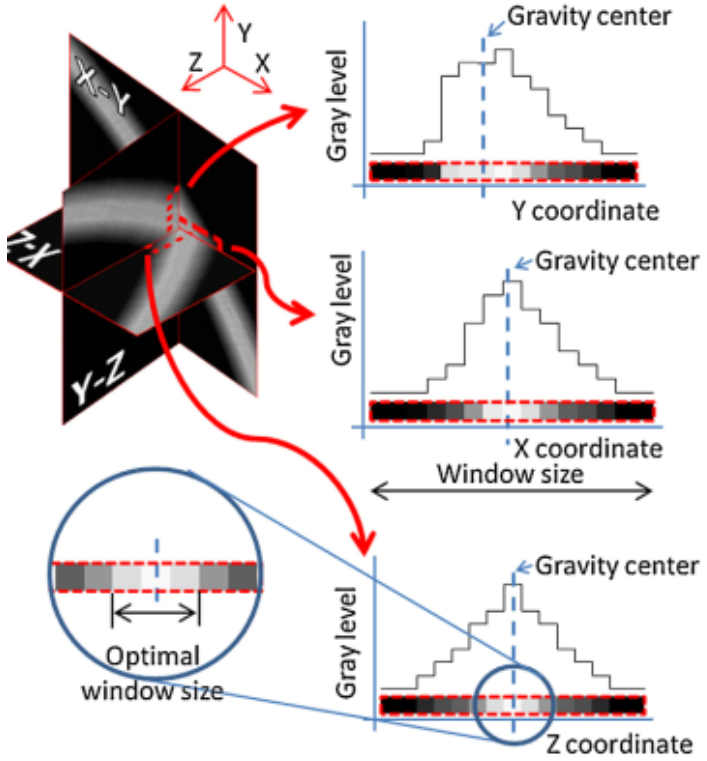


(a) Original (b) Smoothed (c) Gradient magnitudes (d) Edges after non-maximum suppression (e) Double thresholding (f) Edge tracking by hysteresis (g) Final output

Canny adapted (Yagüe-Fabra et al., CIRP Annals 2014)

1. Canny algorithm
2. Sub-voxeling by gravity center calculation
3. Measurement (from the extracted cloud of points)
4. (Optional) measurement correction (partial measurement on an additional system required)





The authors report a bias “below 0.5%” of the nominal size. At the same time, they report an uncertainty ranging from 0.8% to 0.1%. Is this adequate?

Aluminum experimental set-up

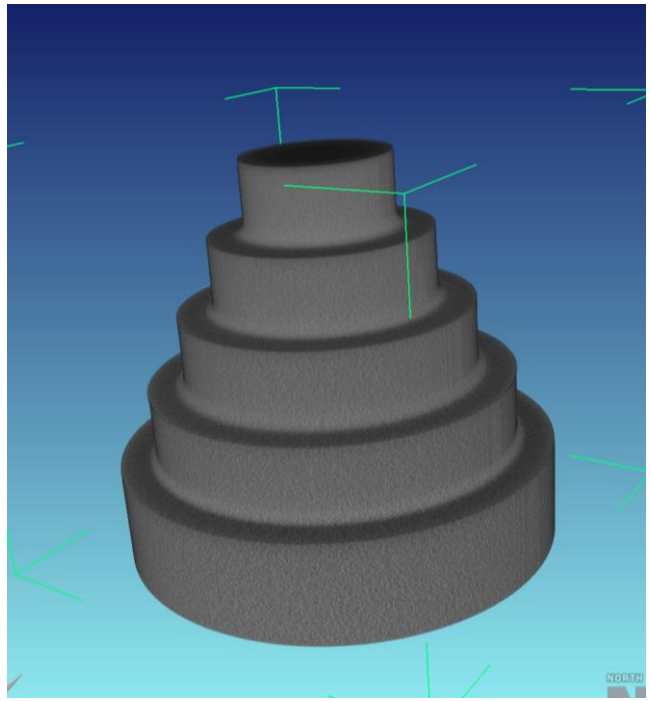
- Nominal size: 8-12-16-20-24-28 mm
- Voltage: 90-60 KV
- Physical filter: yes-no
- Calibration uncertainty: <1 µm

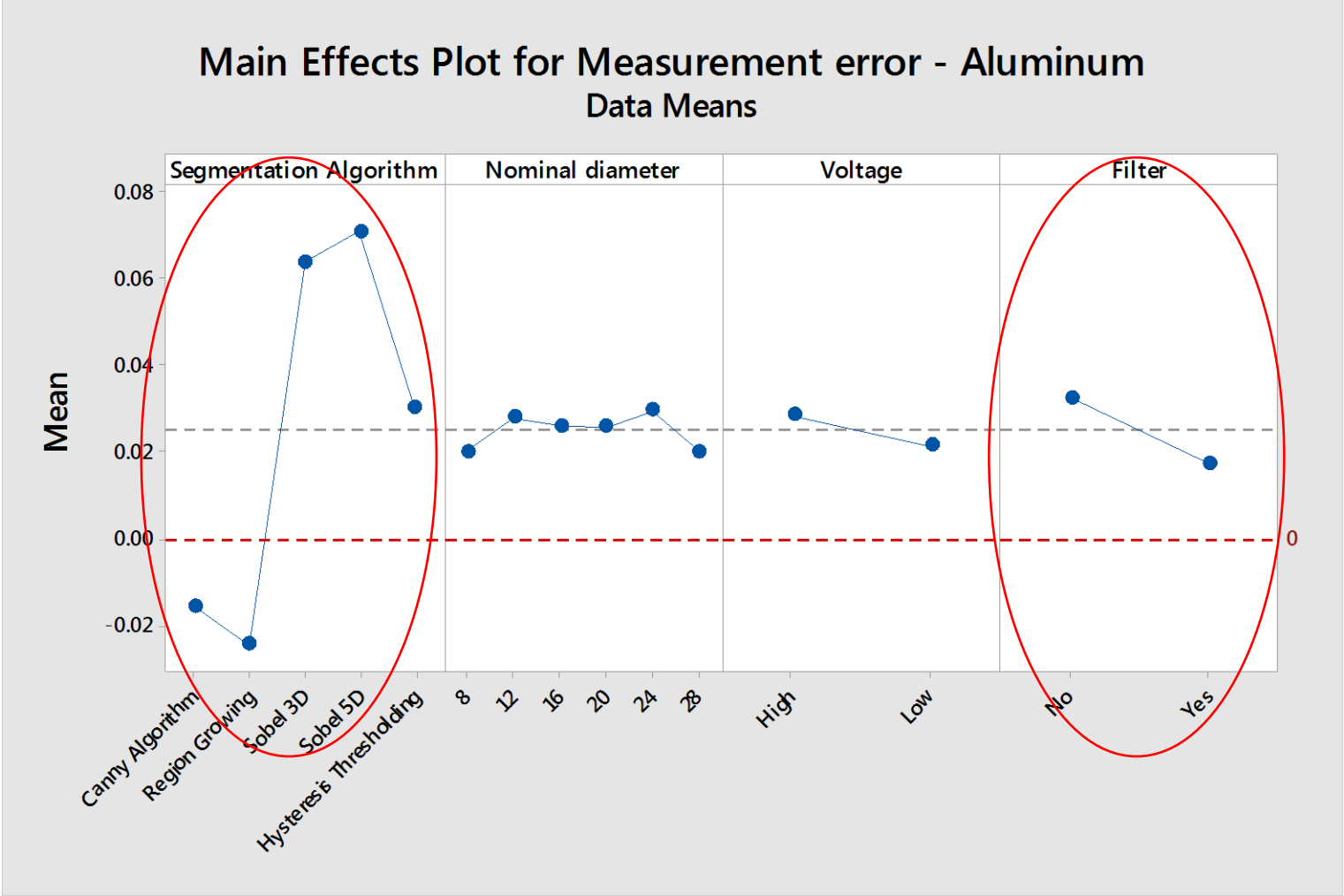
Tot. 240 experimental data

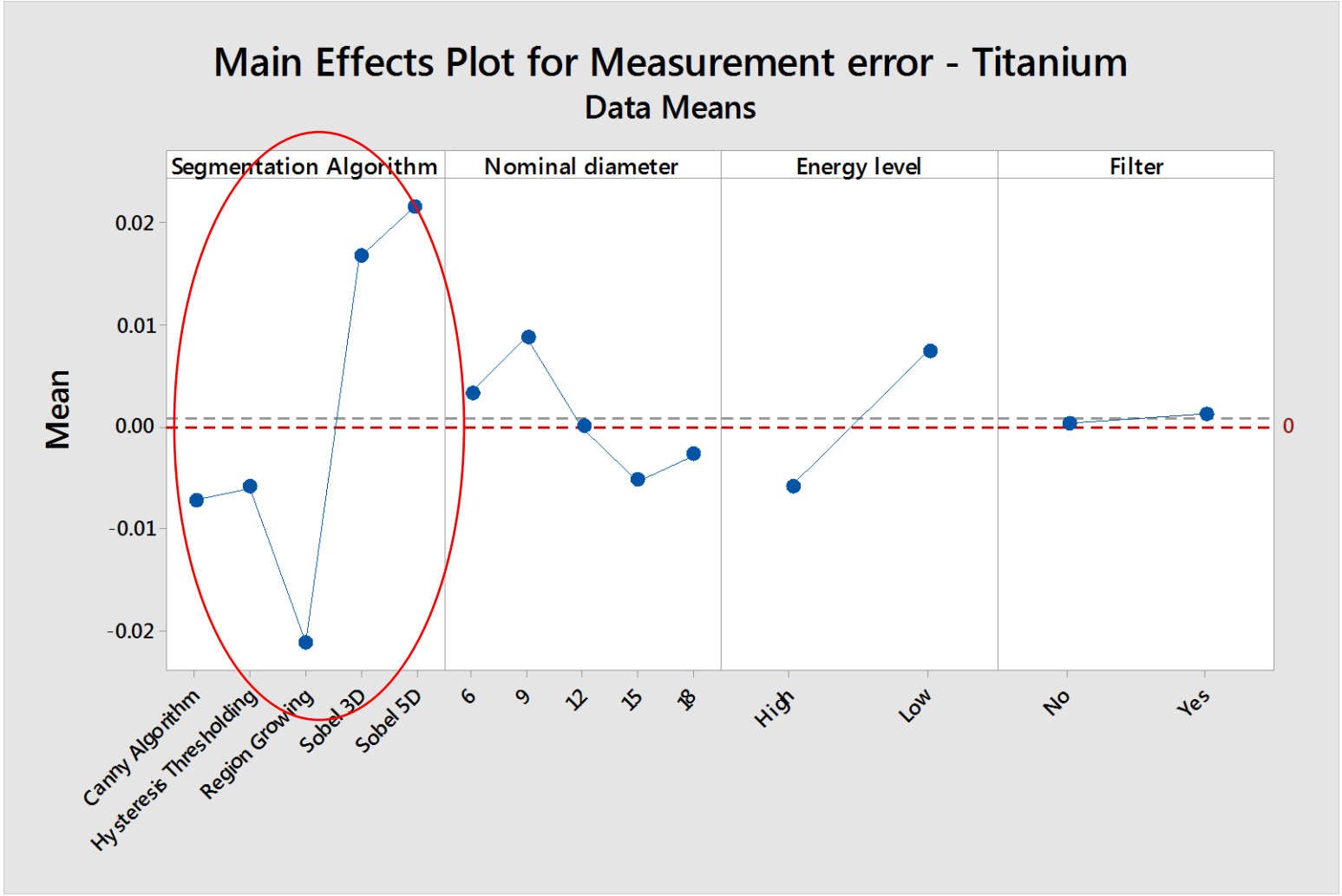
Titanium experimental set-up

- Nominal size: 6-9-12-15-18 mm
- Voltage: 160-100 KV
- Physical filter: yes-no
- Calibration uncertainty: <1 µm

Tot. 200 experimental data




Main Effects Plot for Measurement error - Aluminum
Data Means
Segmentation Algorithm
Nominal diameter
Voltage
Filter
Mean
0.08
0.06
0.04
0.02
0.00
-0.02
0
Canny Algorithm
Region Growing
Sobel 3D
Sobel 5D
Hysteresis Thresholding
8
12
16
20
24
28
High
Low
No
Yes


Main Effects Plot for Measurement error - Titanium
Data Means
Segmentation Algorithm
Nominal diameter
Energy level
Filter
Mean
0.02
0.01
0.00
-0.01
-0.02
0
Canny Algorithm
Hysteresis Thresholding
Region Growing
Sobel 3D
Sobel 5D
6
9
12
15
18
High
Low
No
Yes

- Can the knowledge af the X-ray absorption curve improve the definition of the part surface? Current approaches do not include this information.
- Is there a reference software (reconstruction algorithm + segmentation/thresholding + fitting) for testing X-ray CT scanners?
- Should the thresholding be task-specific, i.e. different approaches should be chosen depending on the measurement task?
- Can CT simulation help in the choice of the optimal segmentation?
- Is a guideline database available for the operator, in order to make CT really applicable at industrial level?
- Is segmentation required, i.e. can we directly fit voxels?

Segmentation for 3D metrology by Computerized Tomography

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Thank You for Your Kind Attention

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