Dynamic tracking of lithium volume in a lithium-ion battery, using synchrotron X-ray tomographic microscopy

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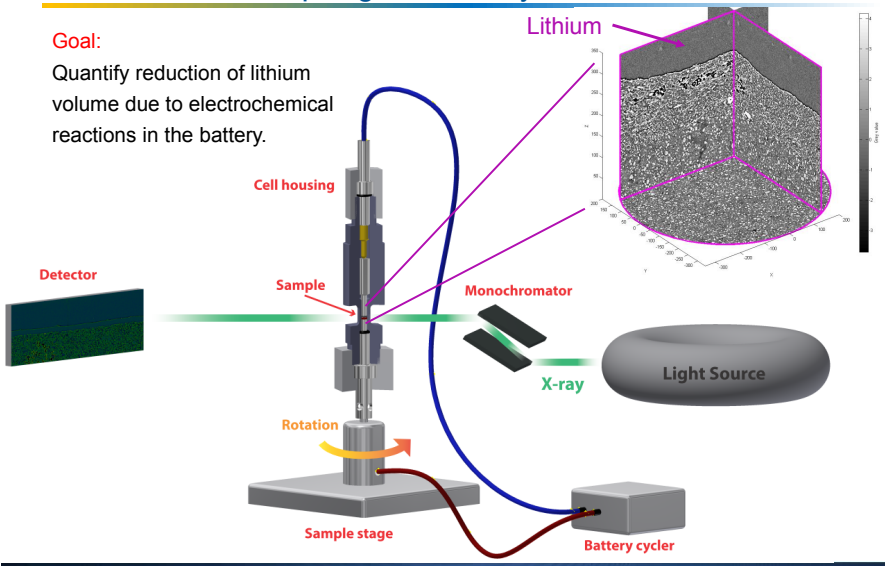
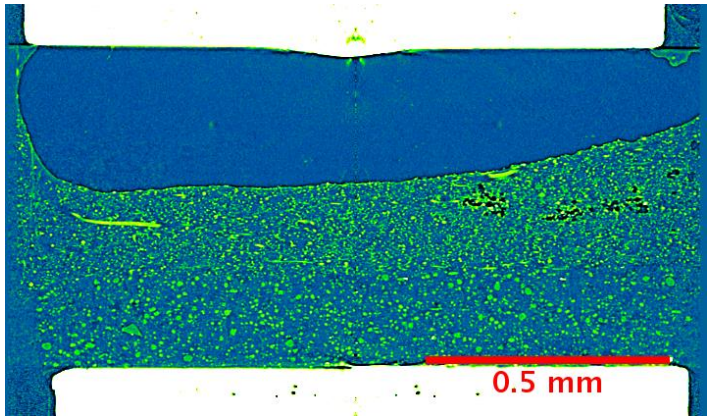
Measurement setup & goal of analysis

Goal:

Quantify reduction of lithium volume due to electrochemical reactions in the battery.



Cross sectional view through battery



⇒ 48 tomographic datasets, each with 1024x1024x600 voxels

⇒ Used Matlab for image processing

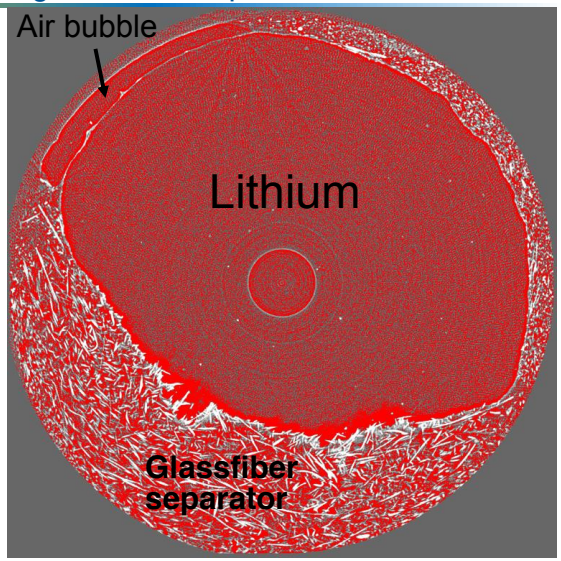
Standard threshold segmentation impossible

Attempt standard thresholding…

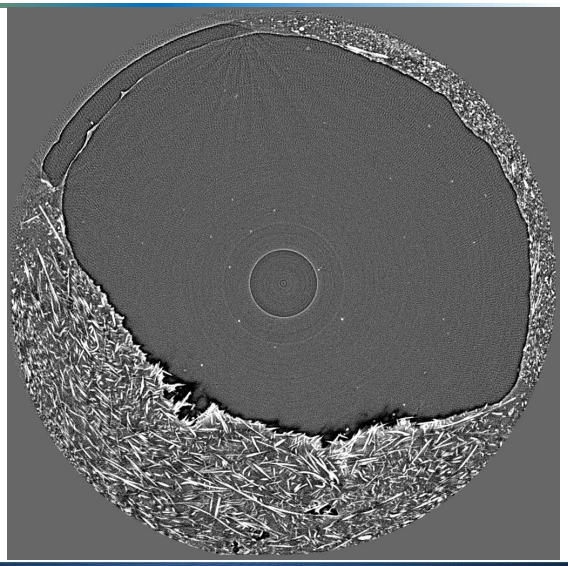
=> No chance

Strategy (exploit edge enhancement):

1) Segment the edges
2) Enhance the edges to form a closed contour
3) Select only the enclosed domain
4) Clean remaining artifacts



Raw data



Wiener filter

Function:

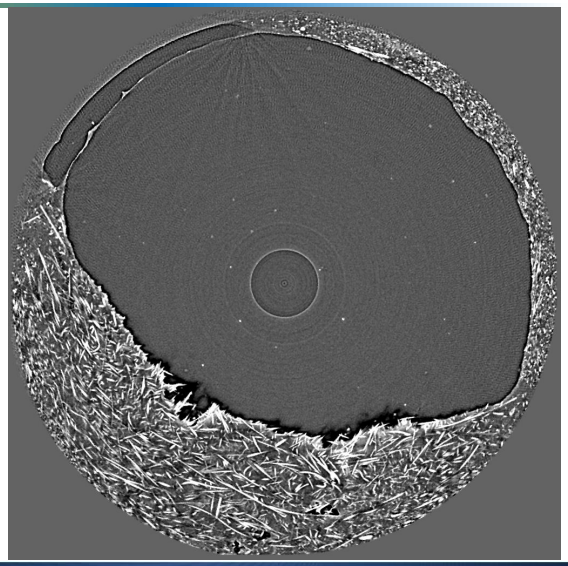
wiener2

Goal:

reduce noise while keeping all important edge structures

Parameters:

3x3 neighborhood



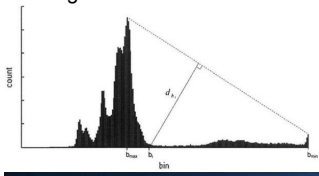
Triangle thresholding

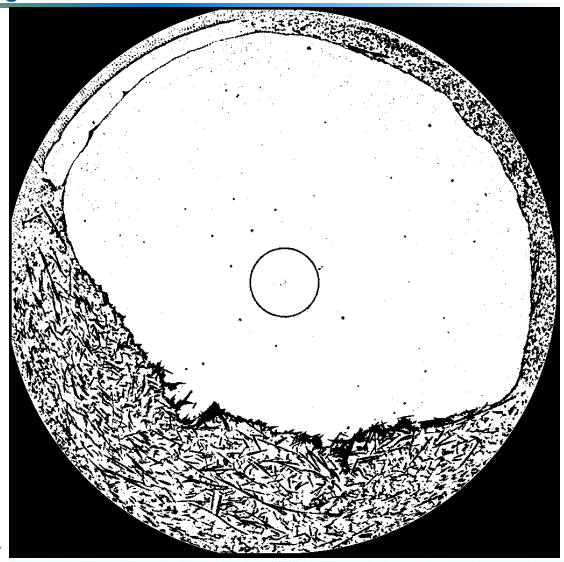
Function:

Self-written based on «*Zack G.W. et al., Journal of Histochemistry & Cytochemistry, 1977*»

Goal:

Segment as closely as possible above the grey value of lithium to keep all edge structures





Remove small connected domains («clean»)

Function:

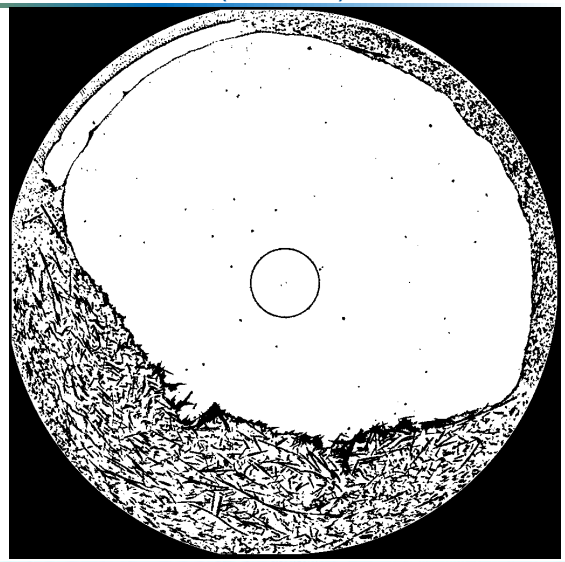
Bwareaopen

Goal:

Avoid merging of undesired domains in the next step

Parameters:

Remove black domains with less than 5 connected voxels



Erode

Function:

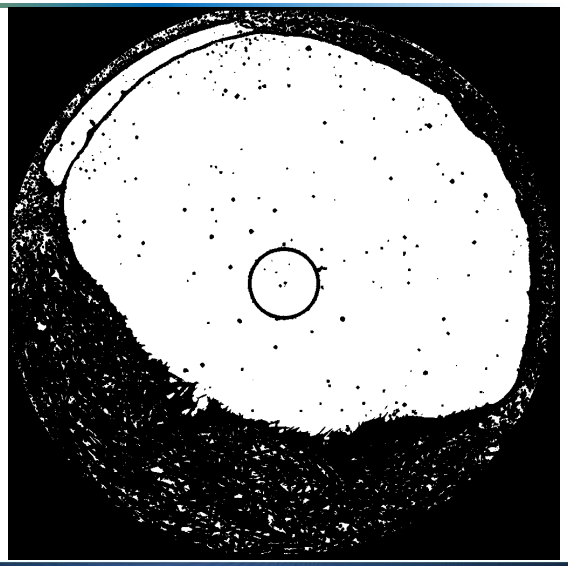
imerode

Goal:

Merge disjoint boundaries

Parameters:

Structuring element: 3D ball with radius 2



Remove small connected domains («clean»)

Function:

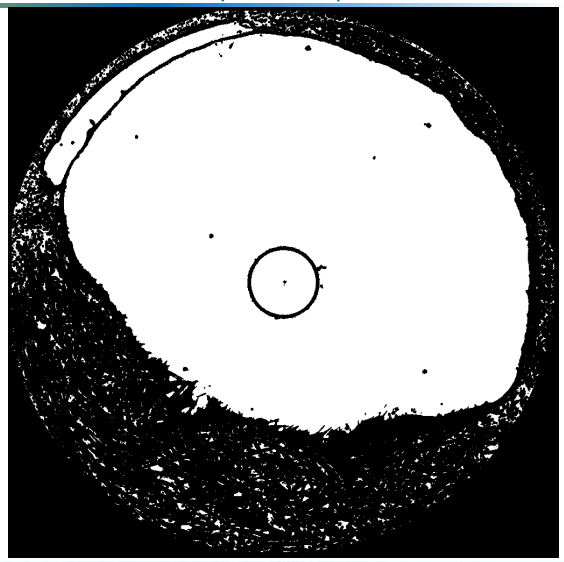
Bwareaopen

Goal:

Avoid merging of undesired domains in the next step

Parameters:

Remove black domains with less than 400 connected voxels



Erode

Function:

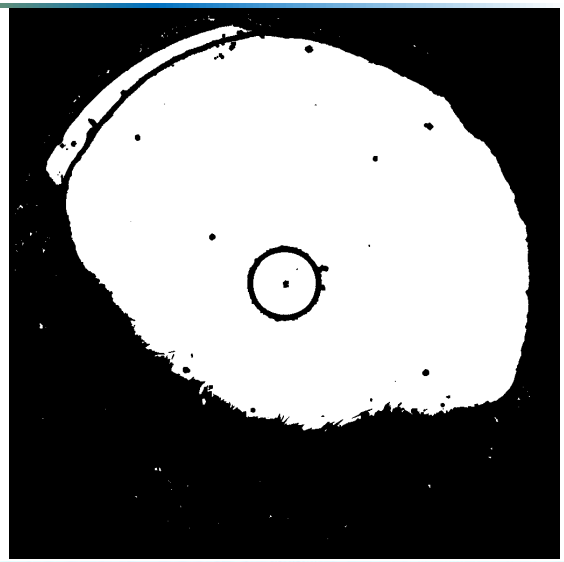
Imerode

Goal:

Merge disjoint boundaries

Parameters:

Structuring element: 3D ball with radius 2



Remove small connected domains («clean»)

Function:

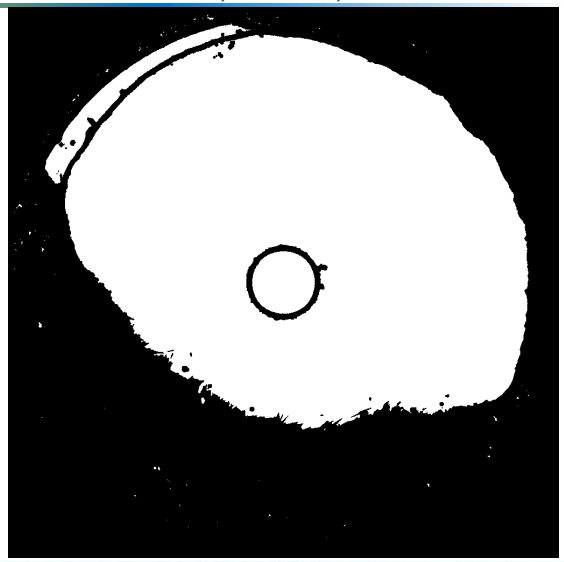
bwareaopen

Goal:

Avoid merging of undesired domains in the next step

Parameters:

Remove black domains with less than 8000 connected voxels



Erode

Function:

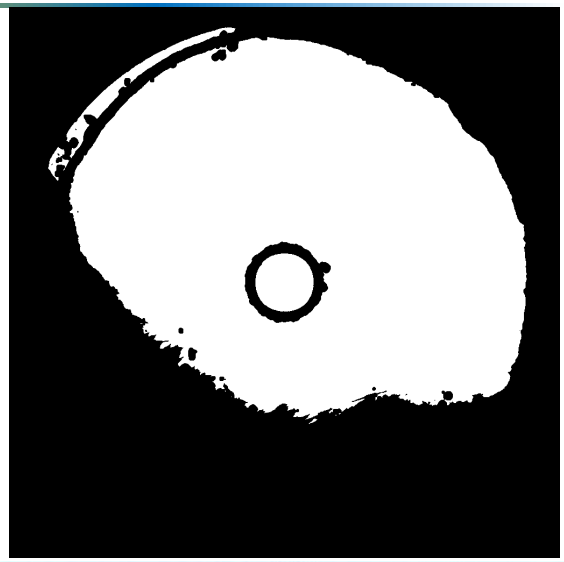
imerode

Goal:

Merge disjoint boundaries

Parameters:

Structuring element: 3D ball with radius 4



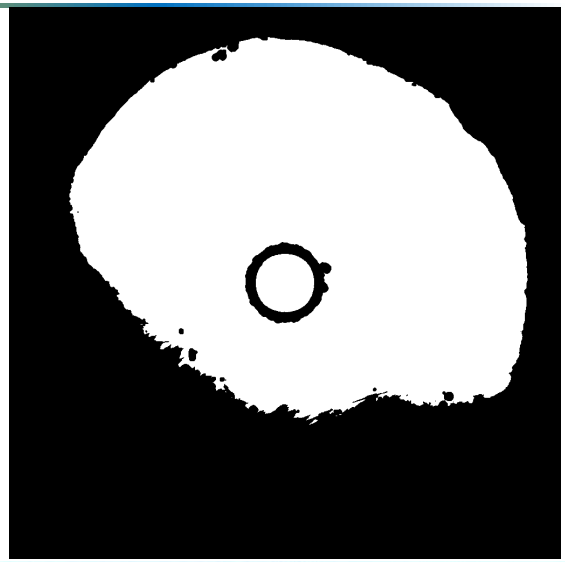
Pick only biggest connected domain in 3D

Function:

bwareaconncomp

Goal:

Identifiy the biggest domain (which corresponds to lithium)



Dilate

Function:

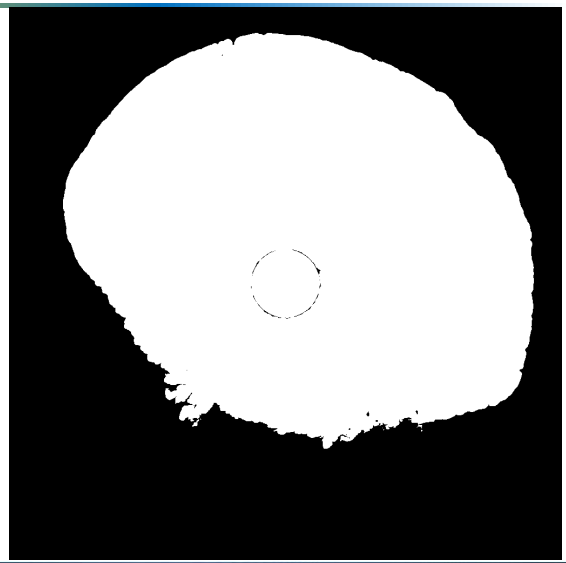
Imdilate

Goal:

Dilate segmented domain back to original size

Parameters:

Structuring element: 3D ball with radius 2+2+4=8



Remove rings

Function:

remove_rings

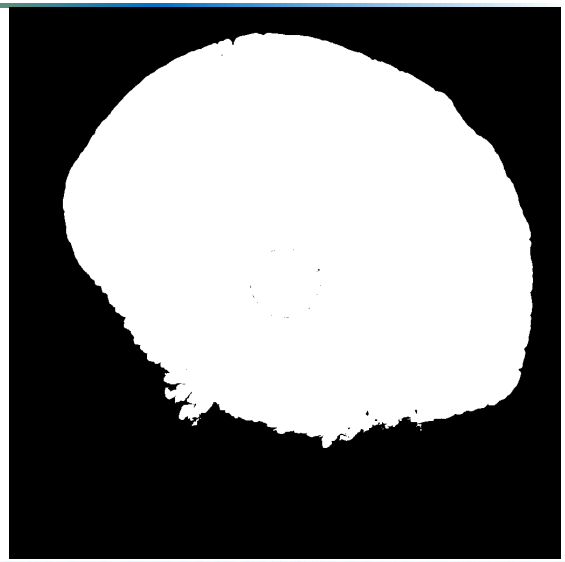
Custom function from id19 at ESRF (Lauridsen, Johnson, Tafforeau)

Goal:

Remove remaining artifacts

Parameters:

Threshold: 0.5



Remove remaining holes

Function:

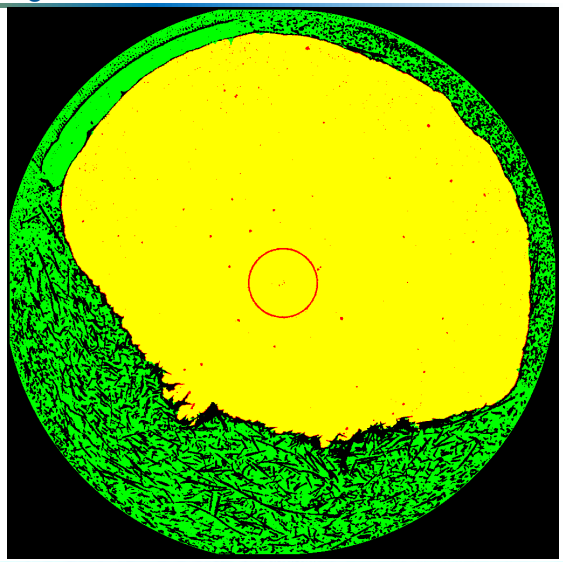
imfill

Goal:

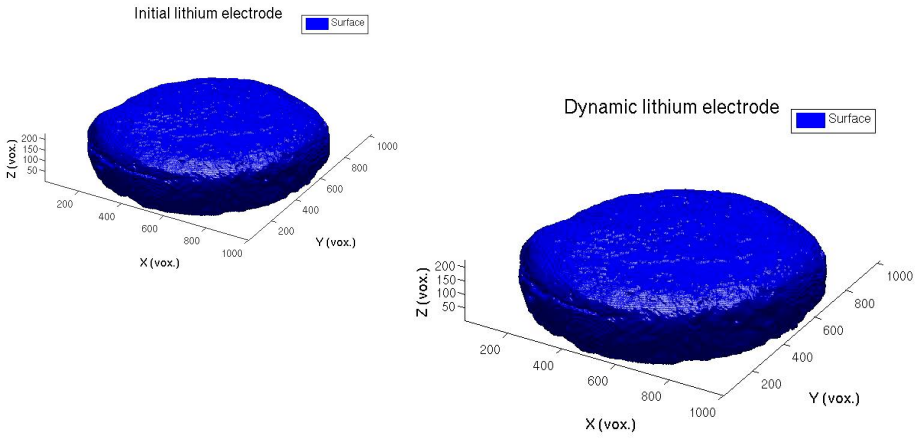
Remove remaining enclosed domains

Overlay result with segmentation

Overlay result with the original segementation to check the quality of the results



3D rendering: Electrochemical shrinking of lithium electrode



Compare result to coulomb counting from battery charger

Charge «stored» in the lithium is related to the volumetric shrinking via

$$Q(t) = -\frac{F * \rho_{Li}}{M_{Li}} * (V_{Li}(t) - V_{Li}(0))$$

Fairly good agreement to electrochemical data!