Image Processing for Materials Characterization: Issues, Challenges and Opportunities

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Outline

1. Motivation
2. Material images
3. Challenges and opportunities
4. The special session
5. Conclusions
Periods in mankind’s history are often named after specific materials:

- stone age
- bronze age
- iron age
Motivation

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Industrial breakthroughs remain related to particular material

- steel
- silicon
Motivation

Today’s applications

- Semi-conductors
- Sensors,
- Drug carriers,
- Catalysts, etc.

- Materials technology is evolving from materials discovered in Nature by chance to designed materials, that repair themselves, adapt to their environment, capture and store energy or information, help elaborate new devices and sensors, etc.

- Materials are now designed from scratch with initial blueprints, starting from atoms and molecules. Example: Graphene.
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The traditional, human, vision-based interpretation of material images misleading...

Scanning electron microscopy: Polymer-charged concrete (©F. Moreau, IFPEN)
The traditional, human, vision-based interpretation of material images misleading...

Scanning electron microscopy: Polymer-charged concrete (©F. Moreau, IFPEN)

Taking physical properties into account...

... is at the heart of successful image analysis in material science
Catalysts at a coarse level of observation

Catalysts with metallic palladium crust (©IFPEN).

Optical microscopy
Catalysts at a coarse level of observation

Catalysts with metallic palladium crust (©IFPEN).

**Goals**
- measure the crust thickness (avoids invasive probe techniques)
- related with the efficiency of catalysts, to improve the conversion of hydrocarbons into chemical products.

Optical microscopy
Catalysts

Scanning electron microscopy: catalyst section.

Atomic structure of a ceria nanoparticle (©Rhodia).
Catalysts

Scanning electron microscopy: catalyst section.

Goals

1\textsuperscript{st} image: characterization of the area in black (cracks), the round shapes (pores) and the white dots (zeolite inclusions)

2\textsuperscript{nd} image: segmentation into pores, ceria, silica

Atomic structure of a ceria nanoparticle (©Rhodia).
Filled rubber’s microstructures (©Michelin)

Composite material with elastomer matrix (©EADS).
Rubber

Filled rubber’s microstructures (©Michelin)

Composite material with elastomer matrix (©EADS).

Goal
- deduce physical properties from 3D microstructure simulations
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Classical material image analysis pipeline

Image acquisition → Preprocessing (Filtering, Registration) → Segmentation or Classification or Analysis → Modeling (i.e. stochastic) → 3D Reconstruction → Attributes (shape, distribution... → 3D Reconstruction → 3D Reconstruction → 3D Reconstruction
Segmentation

Image acquisition

Preprocessing
  Filtering, Registration

Segmentation or Classification or Analysis

Modeling
  i.e. stochastic

3D Reconstruction

Attributes
  (shape, distribution...)

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Segmentation – blob-shaped objects

(a) Optimal threshold;  (b) Watershed;  (c) Graph cuts;  (d) Continuous maximum flows

Segmentation – thin objects

Issue and technic

- Issue: Segmenting elongated objects such as fibers is complicated
- Technic: Continuous Max Flows [Appleton, Talbot, PAMI 2006]
Analysis

Issue and technic

- **Issue**: contours of the objects to segment (nanostructured ceriasilica composite catalysts) not well defined
- **Technic**: Morphological approach [Moreaud et al., J. of Microscopy 2008]
Modeling

- Image acquisition
- Preprocessing: Filtering, Registration
- Segmentation or Classification or Analysis
- Modeling: i.e. stochastic
- Attributes (shape, distribution...)
- 3D Reconstruction
Motivation

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Conclusions

Modeling

Image acquisition

Preprocessing
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Segmentation or Classification or Analysis

Modeling i.e. stochastic

3D Reconstruction

Attributes (shape, distribution...)

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Microstructure stochastic modeling

Issue and technic

- Issue: Extract physical properties such as conductivity from rubber images
- Technic: multiscale microstructure modeling [Jean et al., J. of Microscopy 2010]
Multi-modality

Energy Dispersive Spectroscopy

Scanning Electron Microscopy

Related to works in hyperspectral imaging [Noyel, Angulo, Jeulin: Morphological segmentation of hyperspectral images, Image Anal. Stereol, 2005]
Pre-processing

Image acquisition

Preprocessing
Filtering, Registration

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Pre-processing

- Image acquisition
- Preprocessing: Filtering, Registration
- Segmentation or Classification or Analysis
- Modeling: i.e. stochastic
- 3D Reconstruction
- Attributes: (shape, distribution...)

Modeling and segmentation, followed by filtering, registration, and classification, then analysis and modeling of stochastic attributes, leading to 3D reconstruction.
Parallel computing

Issue and technic

- **Issue**: Tomographic acquisitions lead to noisy images and large data volumes to filter
- **Technic**: Fast 3D bilateral filter on the GPU [Cokelaer and Moreaud, ECS 2013] Speed gain using GPUs: $60 \times$ faster than quad-core CPU implementations
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An overview of the special session

   - 2D texture image synthesis

2. Image Processing In Experiments On, And Simulations Of Plastic Deformation Of Polycrystals Fast Fourier Transform, Edge Detection
   - Peaks segmentation in 2D diffractogram images to reconstruct 3D objects

   - Analogy between physics of interfaces and MRF segmentation of 2D images

4. Morse theory and persistent homology for topological analysis of 3D images of complex materials Skeletonisation, Watershed transform
   - Topologically accurate joint skeleton and 3D watershed segmentation

5. Volume-Based Shape Analysis for Internal Microstructure of Steels Image-based Shape Analysis, Multi-labeled Volumes
   - 3D segmentation and classification
Conclusions

Summary

- Material images acquired by indirect devices, subject to noise, lead to large data volumes to analyse
- Material science is an interesting field of application for image processing methods
- Possible interaction between the two domains is wide
- The goal of this special session is to draw the image processing community attention to these new possibilities