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M&M 2024:

Framework for Generative Artificial Intelligence Enhanced Microscopy Image Analysis Automation of Metallic Materials: a Case Study

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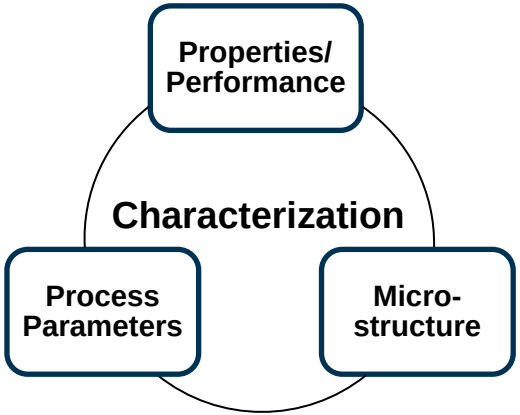
Quantitative microstructure analysis

Quantitative microstructural data



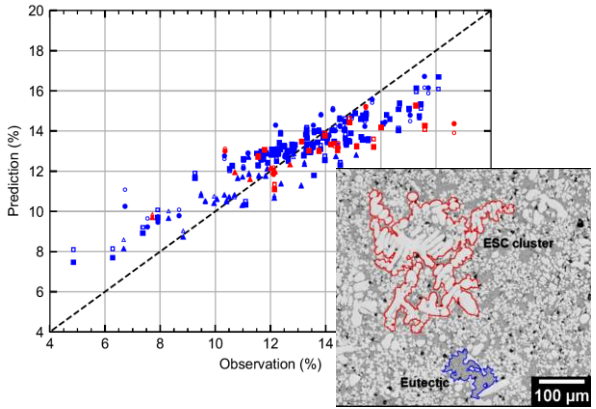
Data quality

Data quantity

AI model

Automation

AI casting*
Elongation: observation vs. prediction



Our goal:
To establish process-structure-property relation to reduce application development cost

*A.Gariepy et al. NADCA 2022

AI-driven automated microstructure analysis

Challenges in current analysis workflow

Structure difficult to quantify

Large number of images to analyze

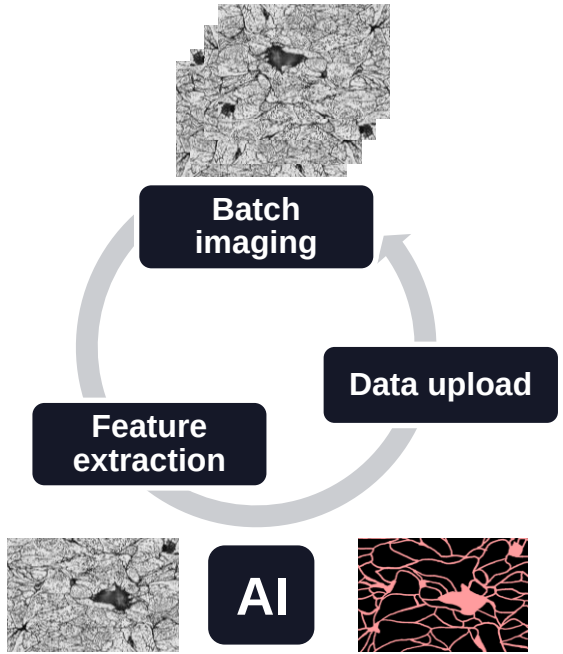
Various preparation and imaging conditions

AI answer to the challenges

AI models trained on expert annotation

AI models that performs automatic segmentation

Generative AI models to enhance images



Case study: cold spray
Deposition quality evaluation by microstructure

Selection of process parameters

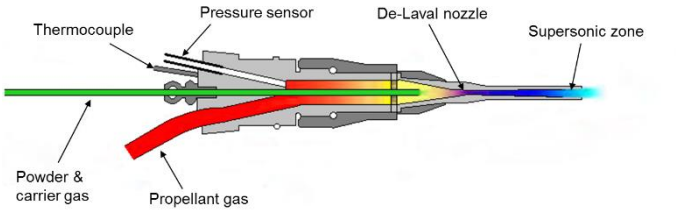
- High dimensional space
- Costly mechanical testing

Variation of deposition quality

- Intrinsic variation
- Local variation on edges, corners…

Cold spray process parameters

Gas pressure, gas temperature, standoff distance, spray angle, gun traverse speed, nozzle shape + material, particle shape, size, material, substrate material, surface condition + surface temperature



Microstructure is essential for evaluation of deposition quality of cold spray

Characterization of cold spray materials

Deep learning model developed to isolate particle boundaries

Convolutional neural network model

Input: raw CSAM micrographs

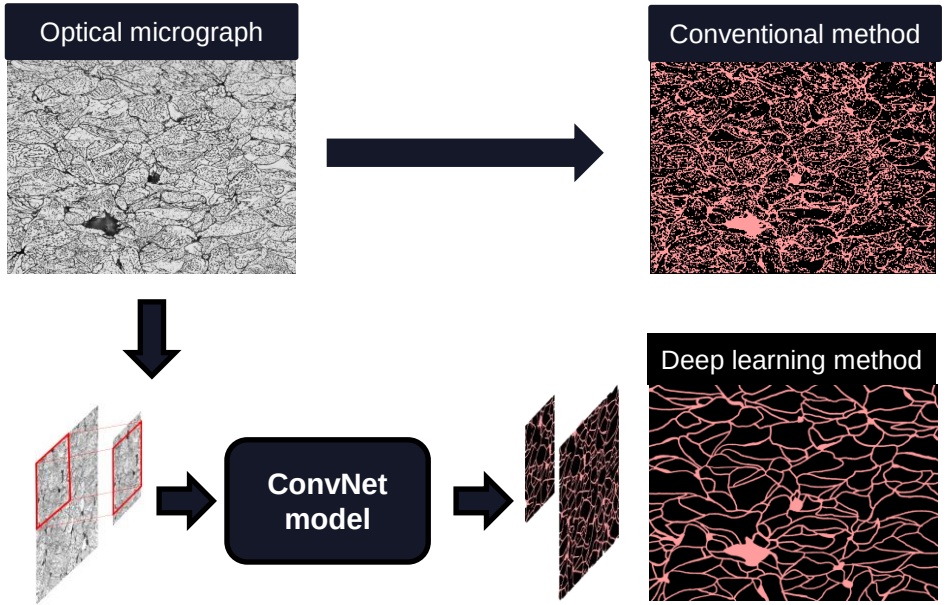
Output: binary images

Particle features output such as

Particle area

Particle morphology

Grouped particle statistics



Tu, S., Vo, P. Microstructural Feature Extraction by a Convolutional Neural Network for Cold Spray of Aluminum Alloys. *J Therm Spray Tech* **33**, 540–550 (2024).

Model robustness to different image quality

Factors that changes the nature of image

Alloy type

Etching level (preparation)

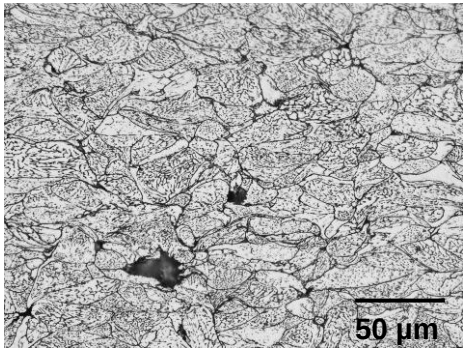
Imaging conditions

Possible solutions

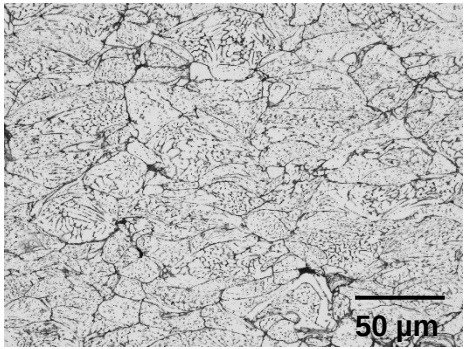
Unified sample preparation and imaging (hard)

More data to train the model (expensive)

Generative AI to enhance the input data



Properly etched



Under etched

Result improvement on enhanced mask

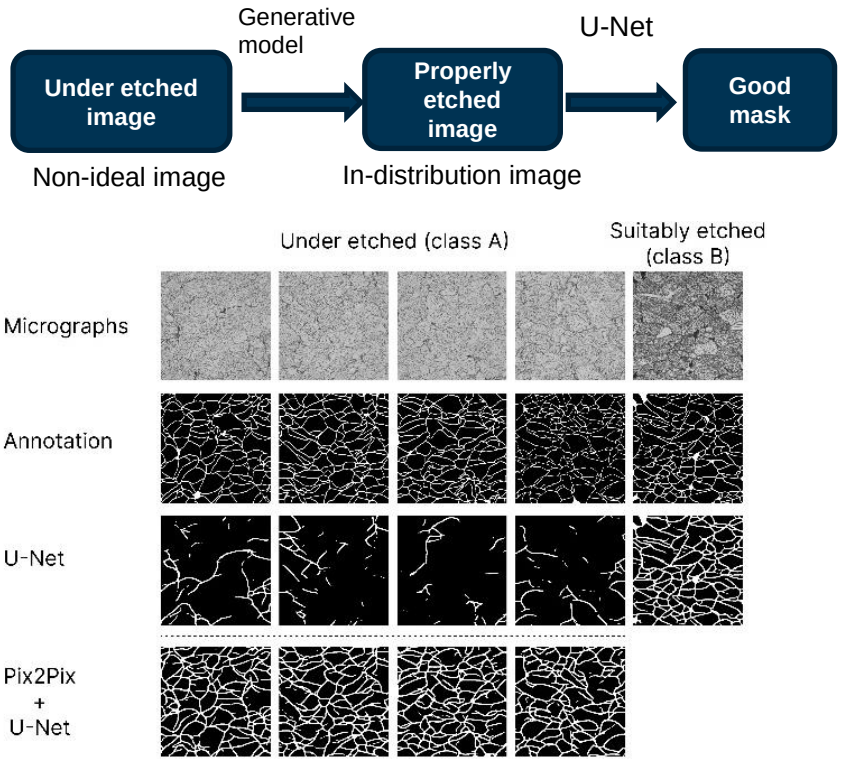
Pre-trained U-Net works poorly with under-etched images

Samples were etched with Keller's reagent

U-Net model were trained using 20 images with data augmentation

The performance of the U-Net model is influenced by the etching level of the sample

Enhance image with Pix2Pix for better U-Net performance



Our strategy: populate and train

Model to populate the training dataset

Conditional generative adversarial network (CGAN)

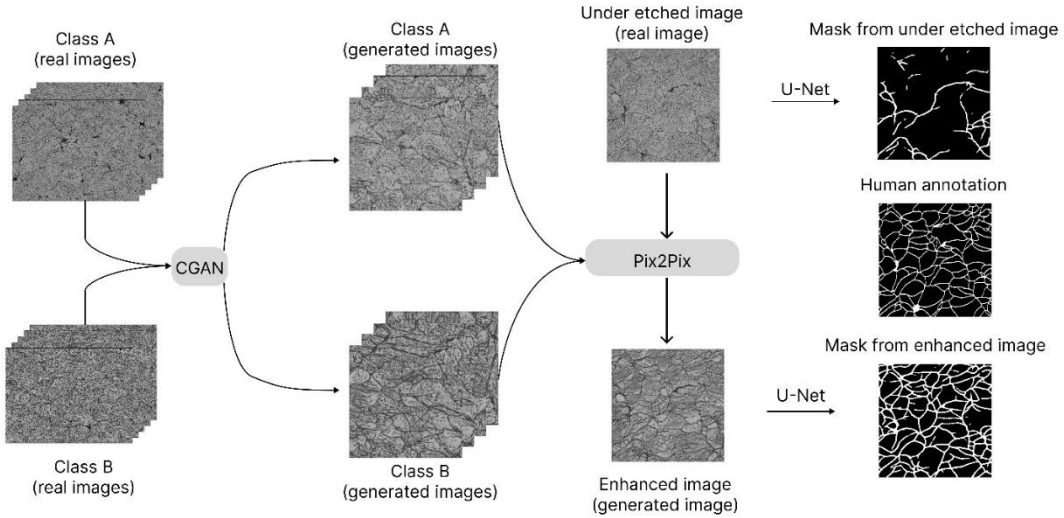
Under etched images (Class A)

Suitably etched images (Class B)

Model to enhance border contrast

Pix2Pix model trained on image pairs

Border enhanced image better for segmentation using pretrained U-Net model



Discussion on results and accuracy

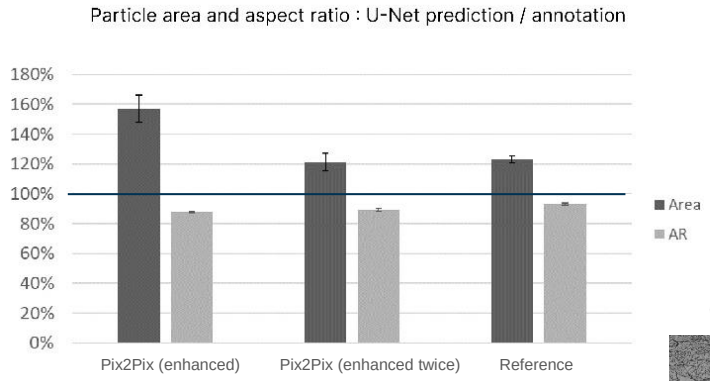
Particle area and aspect ratio (AR) measurements as ratios of U-Net prediction over annotation

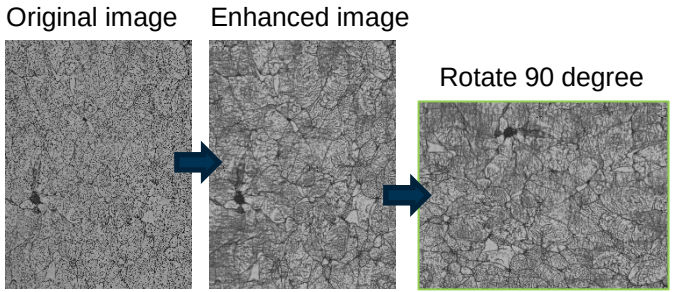
Applying the Pix2Pix model twice

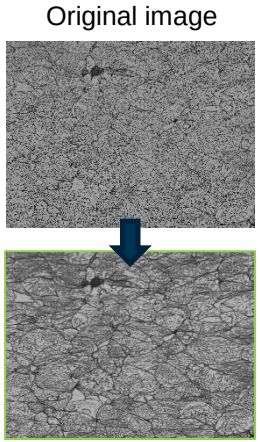
- Reduce the overestimation of area measurements
- Decrease the standard deviation.

These results suggest reliable measurements and manageable systematic errors.

Overfitting exist due to the nature of particle deformed horizontally

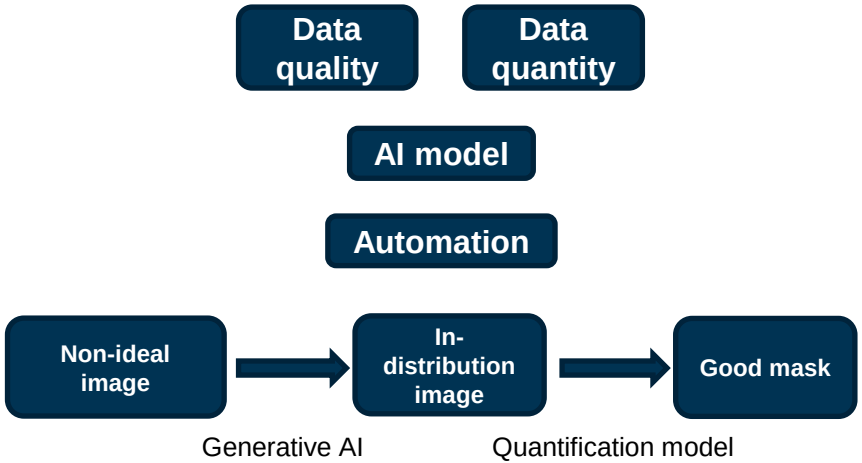






Summary and future work

Framework summary



Future work

- Optimize model with less overfitting
- Develop models for functionalities such as inpainting, deblur, etc.
- Accuracy assessment with property data
- Integration of intelligent characterization system

THANK YOU

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