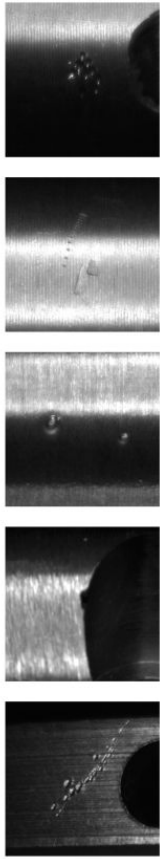
Synthetic Data for Defect Segmentation on Complex Metal Surfaces

Juraj Fulir, Lovro Bosnar, Hans Hagen, Petra Gospodnetić

CVPR 2023 - VISION Workshop

Introduction

- Defects are diverse and rare → Data shortage



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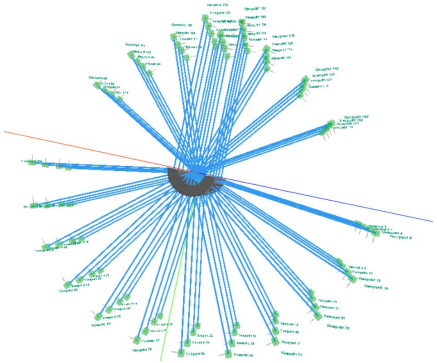

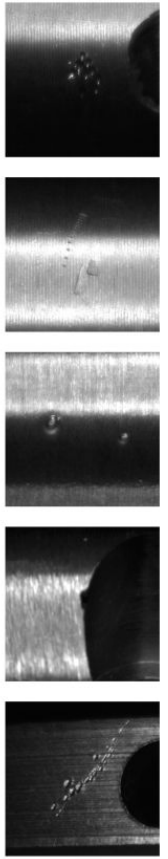

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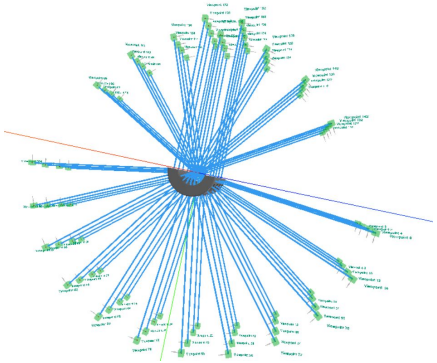
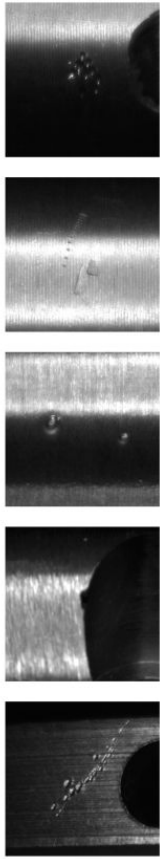
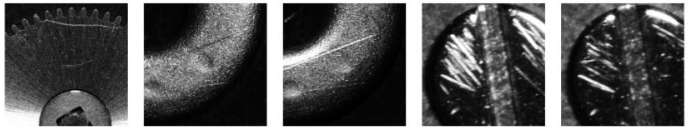
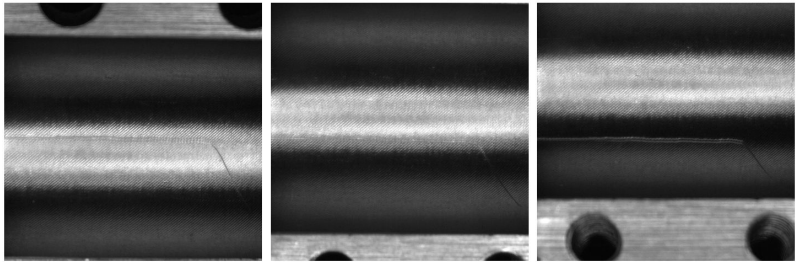
- Complex geometry → Complex inspection setups
- Textured metal surfaces are challenging





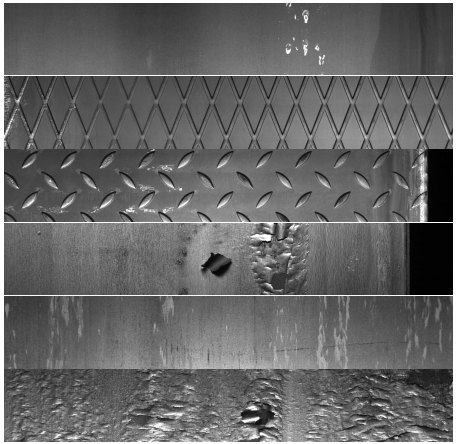


Honzátko, D. et.al.: Defect segmentation for multi-illumination quality control systems (2021)



Existing research

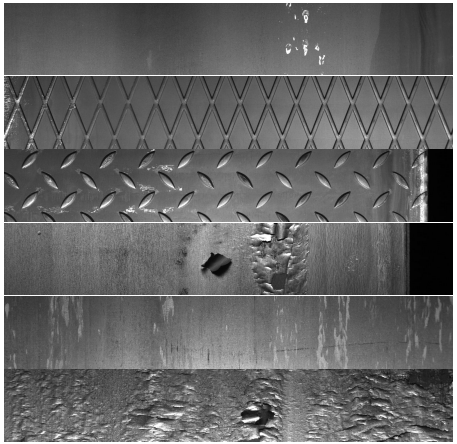
- Large datasets, but planar geometry



PAO Severstal: Severstal: Steel defect detection (2019)

Existing research

- Large datasets, but planar geometry
- Curved geometry, but uncontrolled environment



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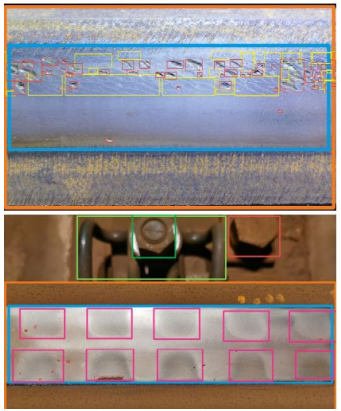
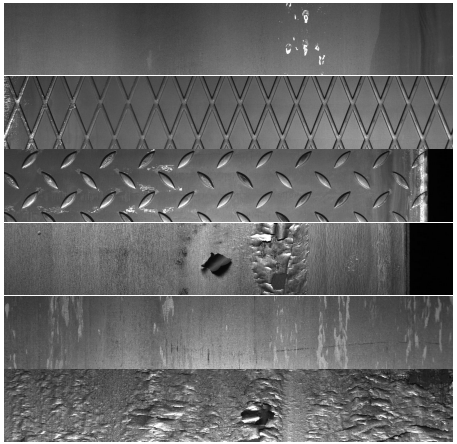


Zhang Z. et. al.: Rail-5k: a Real-World Dataset for Rail Surface Defects Detection (2021)

Existing research

- Large datasets, but planar geometry
- Curved geometry, but uncontrolled environment
- Complex geometry, but flat surface texture



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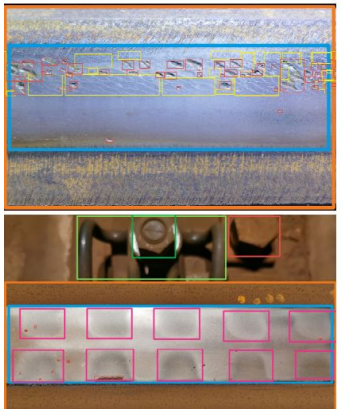

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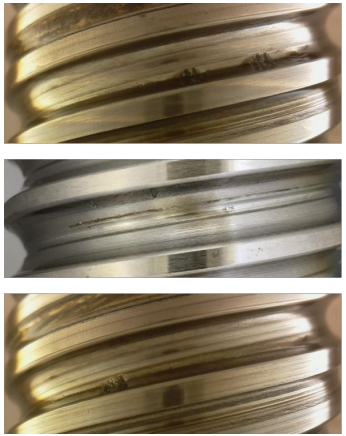
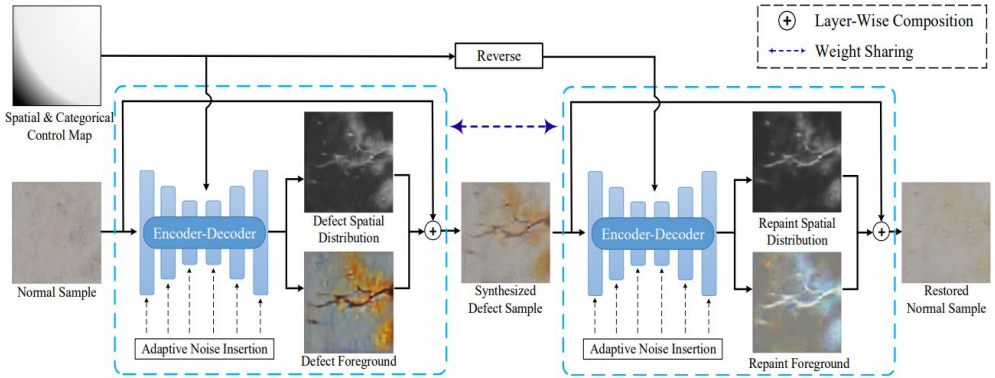


Schlagenhauf T. et. al.: Industrial Machine Tool Component Surface Defect Dataset (2021)

Existing research

- Trained generative models for data generation is problematic:
  - Requires data with a lot of variety
  - Difficult to guarantee image quality
  - Difficult to extend support while preserving existing

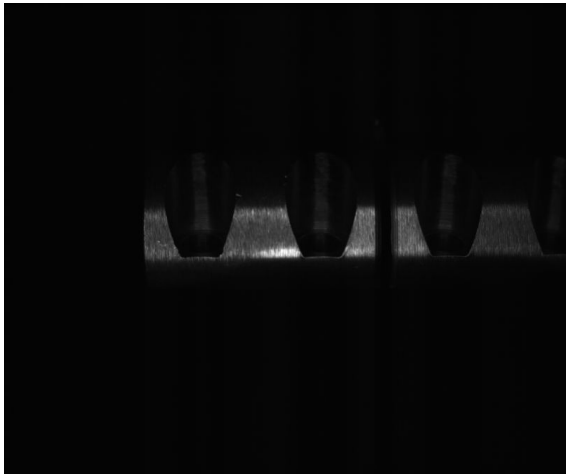


Zhang G. et. al.: Defect-GAN: High-Fidelity Defect Synthesis for Automated Defect Inspection (2021)

Our contributions

- New dataset for defect recognition → complex surface geometry and texture

Real data →



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- Synthetic dataset equivalent → using recent procedural methods by Bosnar et.al.

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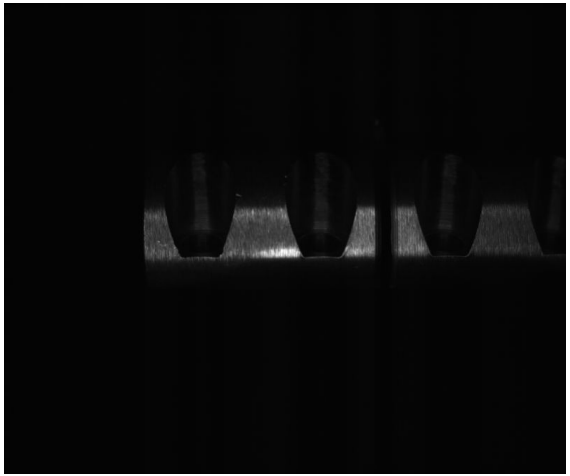

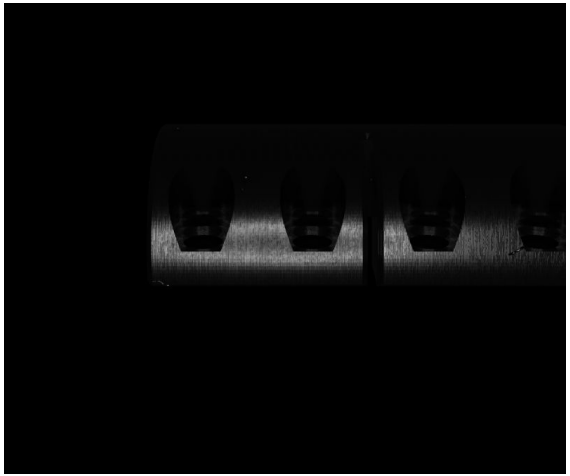

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- Comparative study: custom synthetic data or similar datasets

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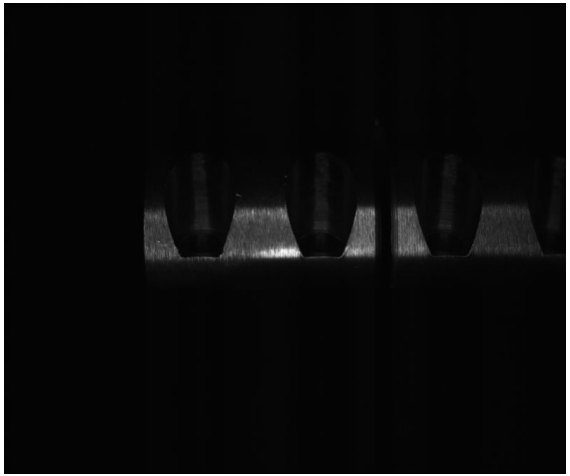

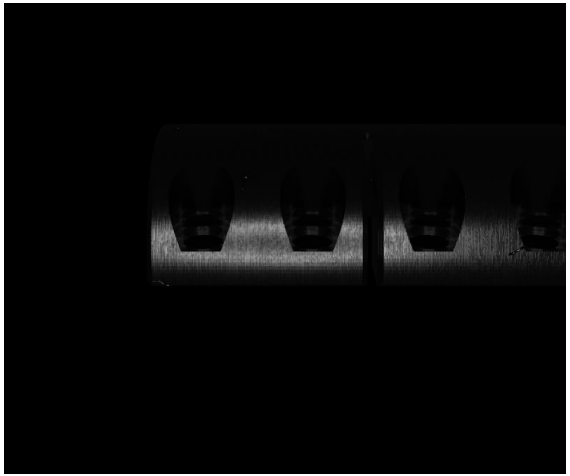

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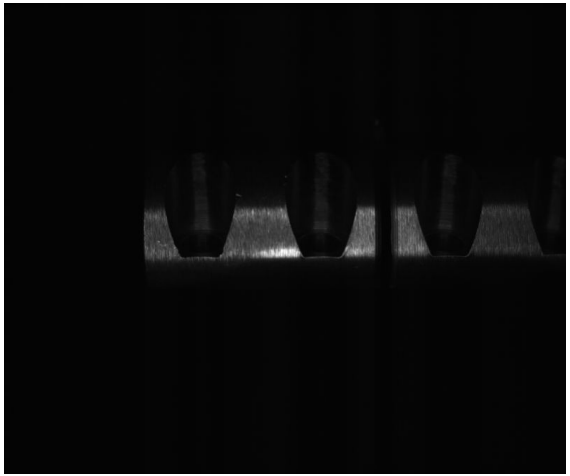
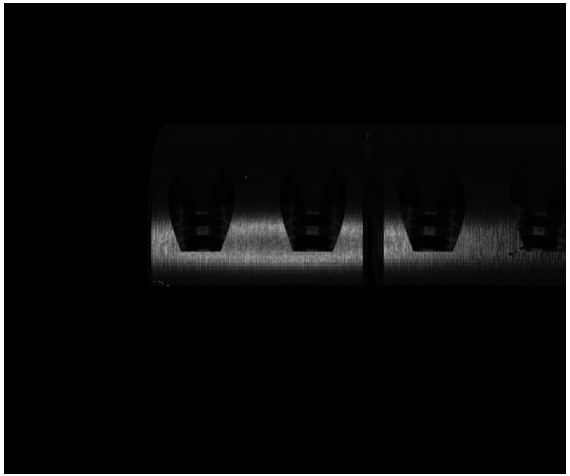
- Comparative study: custom synthetic data or similar datasets
- Methods for improving model performance

Real data →





← Synth data

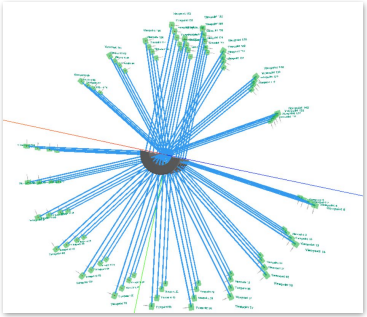
RealClutch dataset

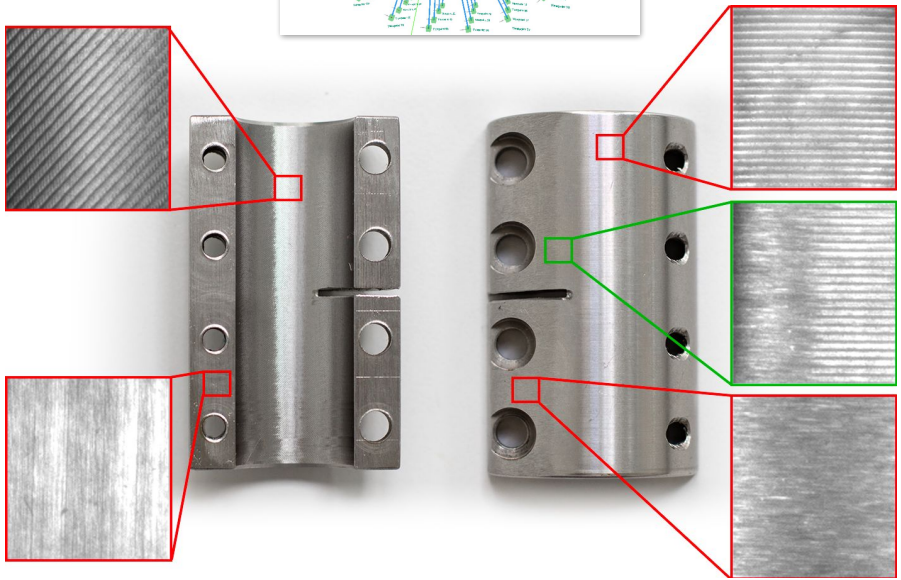
Description

- 6 objects, 3 manually defected
- 4 distinct surface textures
- 2 variations of inner milling texture
- Acquisition in dark environment
- 516 images (grayscale)
- Manually annotated only significant defects

Goal

- Image segmentation of significant defects





Random cropping

Image sample 1

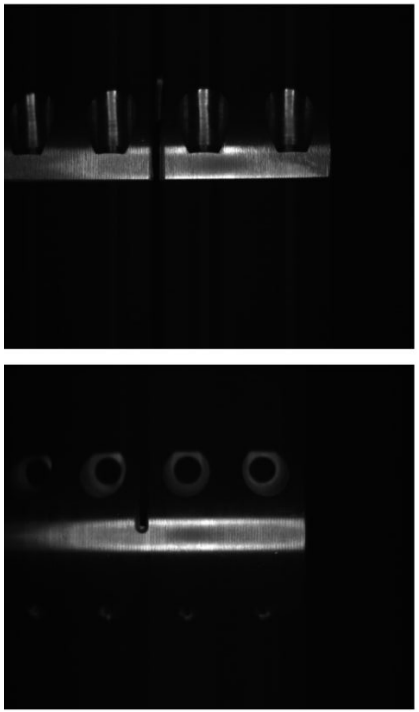
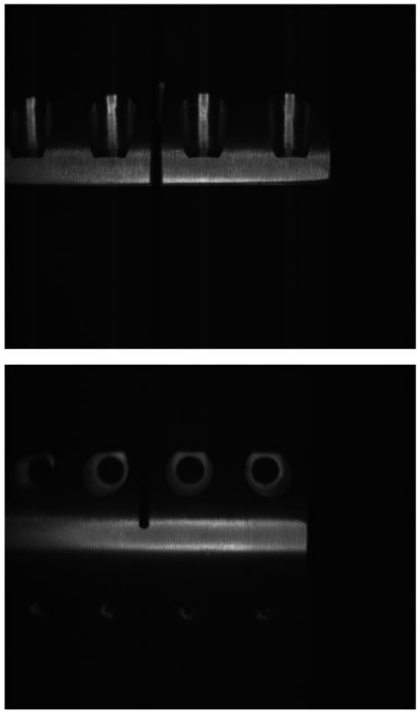


Image sample 2



- Large images (halved to 1224x1025)

Random cropping

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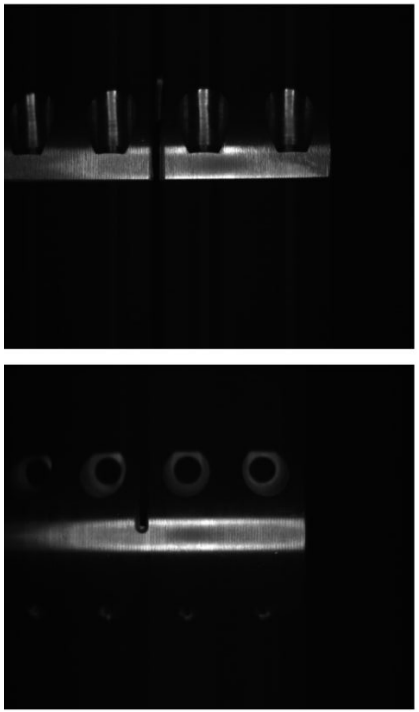

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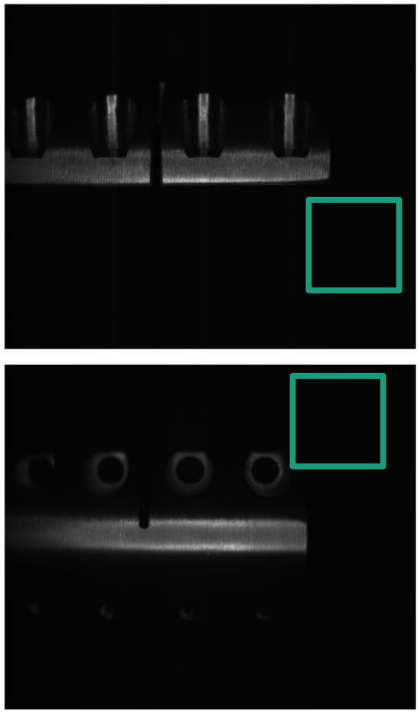
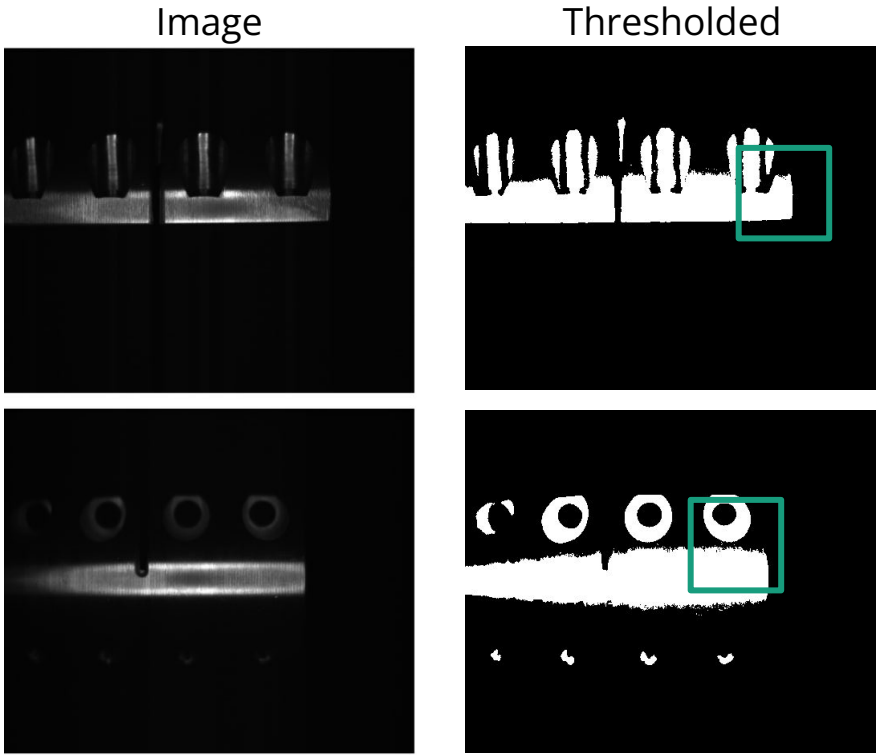


- Large images (halved to 1224x1025)
- Many random crops end up in dark regions (background)

Random cropping



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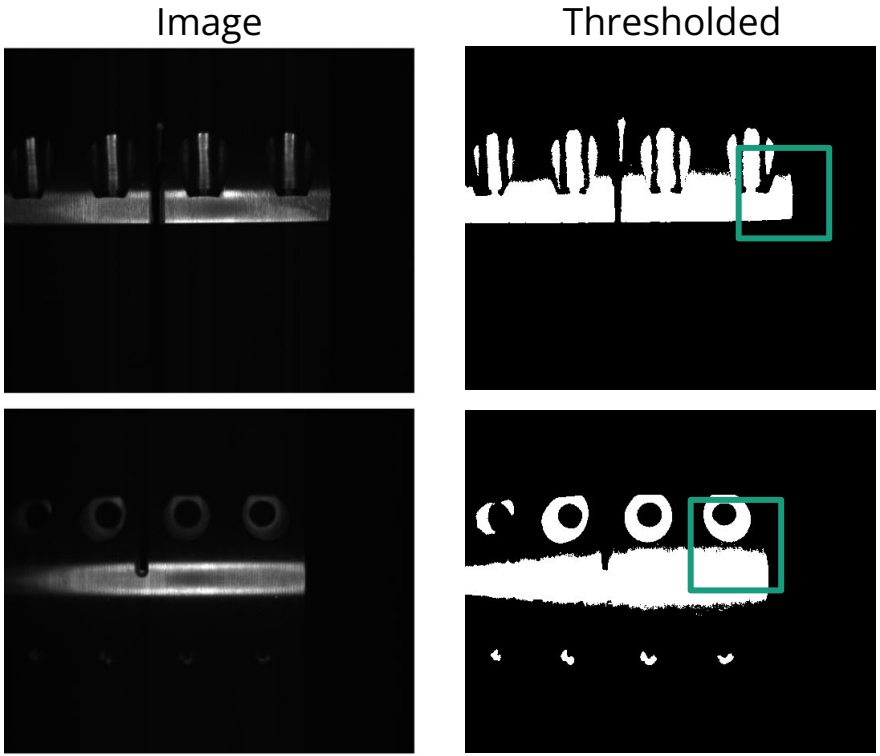
- Bias cropping to higher intensities

Random cropping



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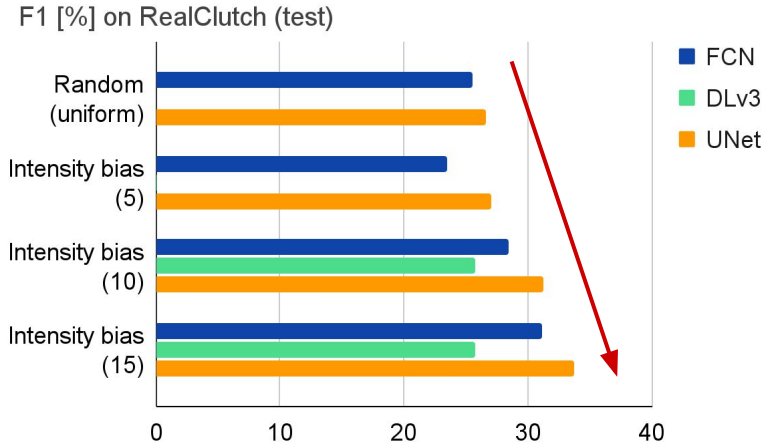
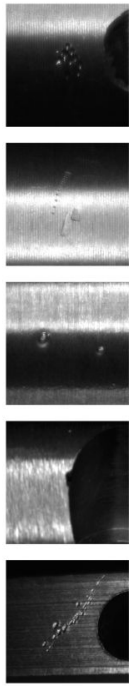
- Higher performance and stability



Comparative study

Comparative study

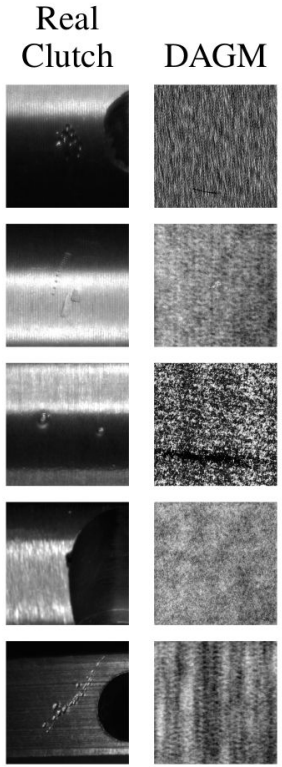
Real Clutch



Similarities:

- Defect shapes and material
- Surface material
- Shadowing effect of curved surfaces
- Complex geometry and multiple textures
- Defect visibility changes
- Similar geometry and acquisition setup

Comparative study - DAGM



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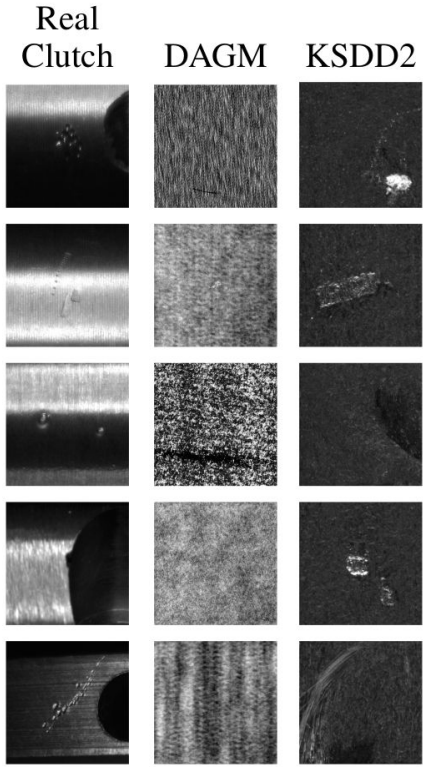
Wieler M. et. al.: Weakly supervised learning for industrial optical inspection (2007)

Comparative study - Kolektor Surface Defects Dataset v2



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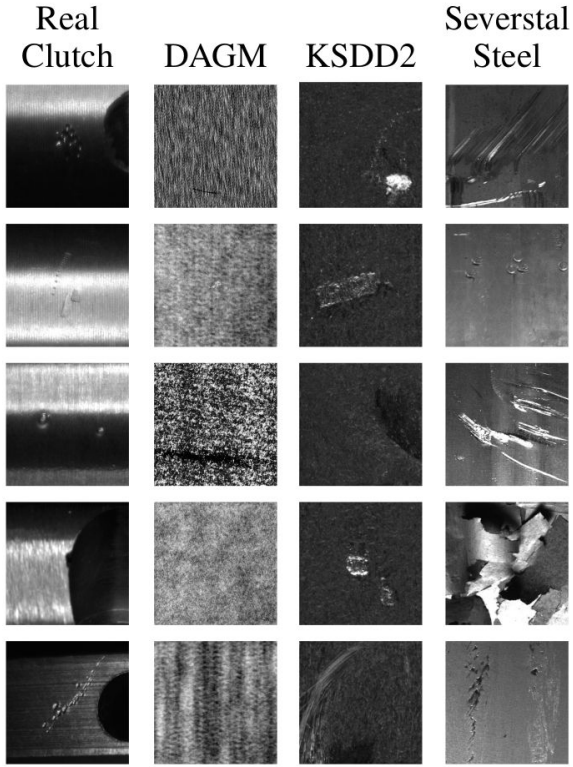
Božič J. et. al.: Mixed supervision for surface-defect detection: from weakly to fully supervised learning (2021)

Comparative study - Severstal Steel dataset



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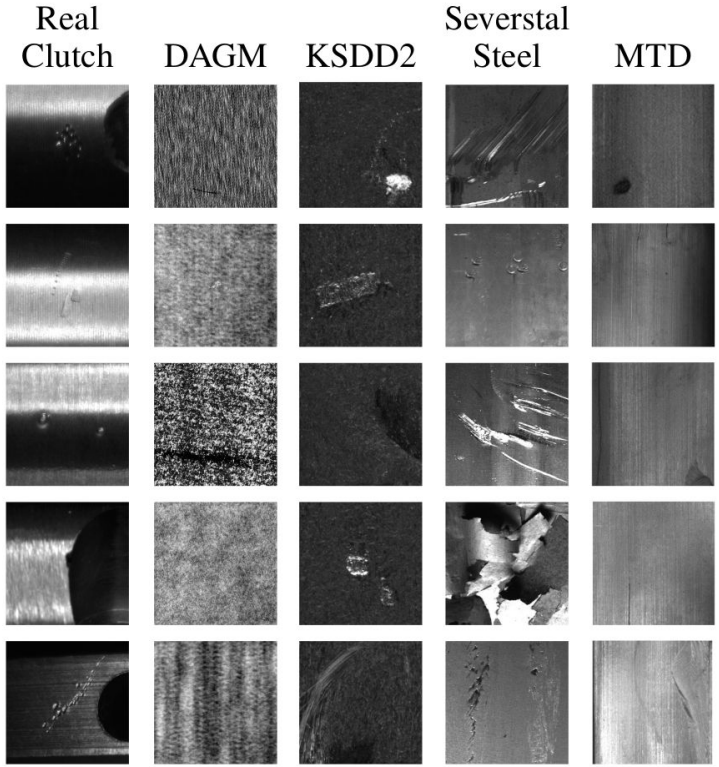
PAO Severstal: Severstal: Steel Defect Detection (2019)

Comparative study - Magnetic Tile Defects dataset



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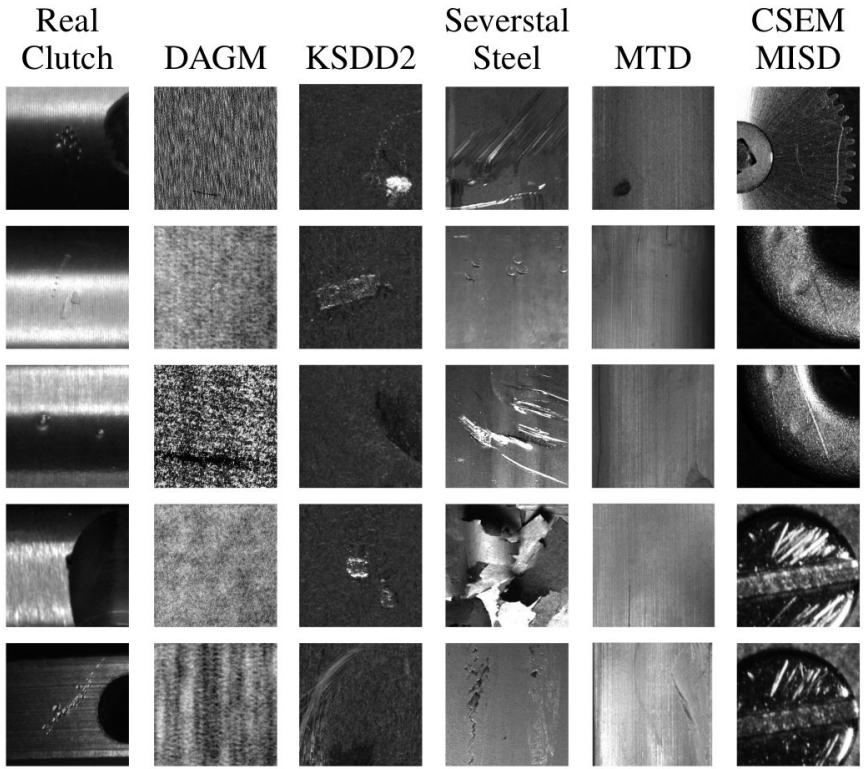
- Similar geometry and acquisition setup

Huang Y. et. al.: Surface defect saliency of magnetic tile (2018)

Comparative study - CSEM Multi Illumination Surface Defect detection dataset



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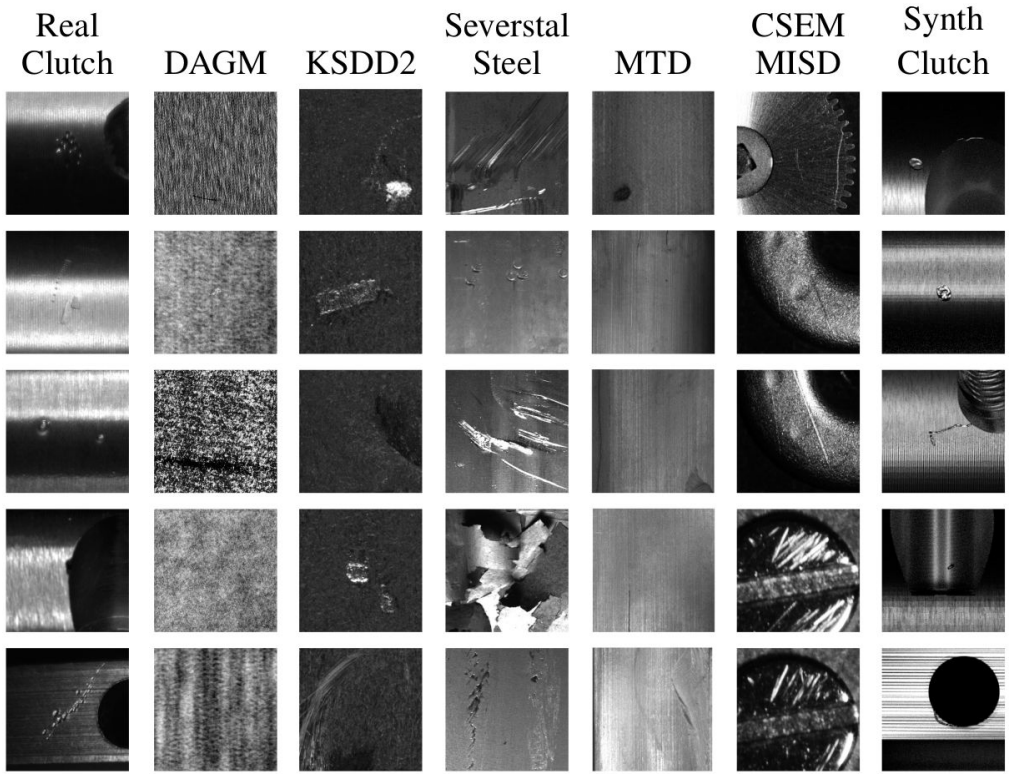
Honzátko, D. et.al.: Defect segmentation for multi-illumination quality control systems (2021)

Comparative study - SynthClutch



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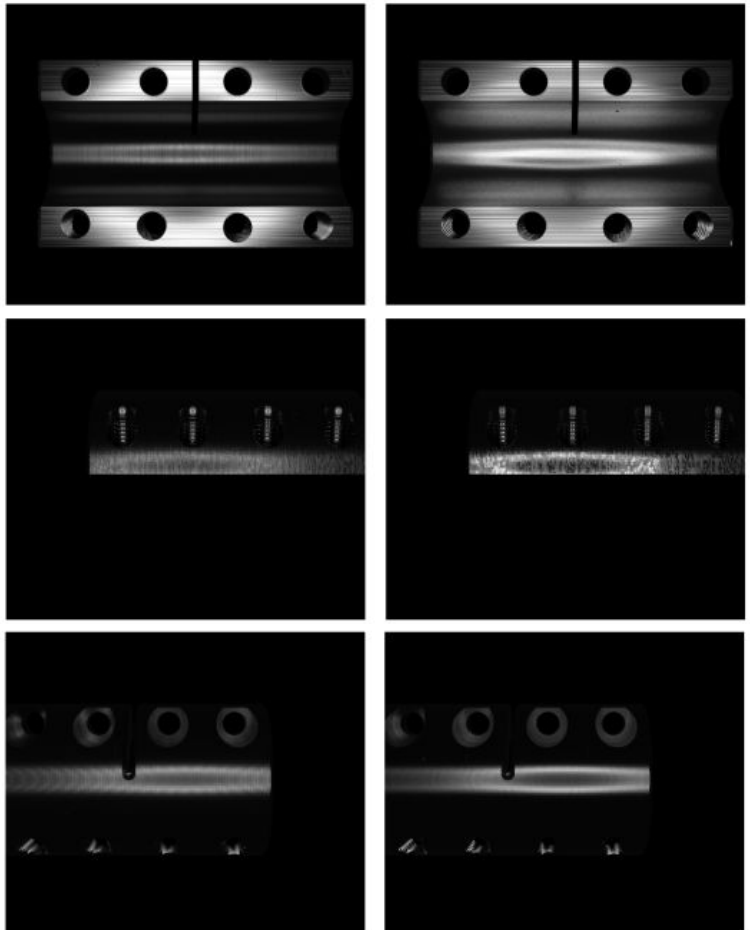
SynthClutch dataset

Description

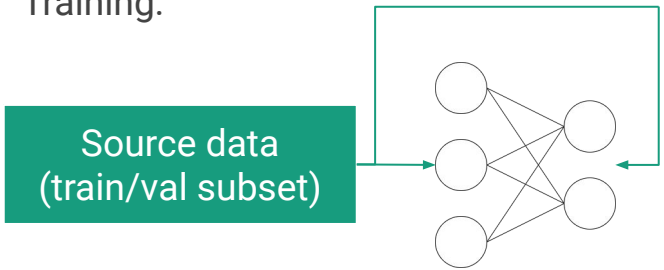
- 40 objects, procedurally defected and textured CAD model
- Defect, material and texture parameters sampled within specified ranges
- 3440 rendered images (grayscale)
- Rendered with segmentation annotations



L. Bosnar et.al.: Image synthesis pipeline for surface inspection (2020)
L. Bosnar et.al.: Texture synthesis for surface inspection (2022)
L. Bosnar et.al.: Procedural defect modeling for virtual surface inspection environments (2023)

Results

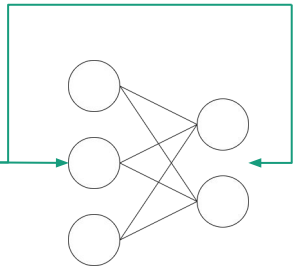
Training:



Results

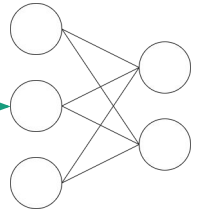
Training:

Source data
(train/val subset)



Testing:

RealClutch
(test subset)



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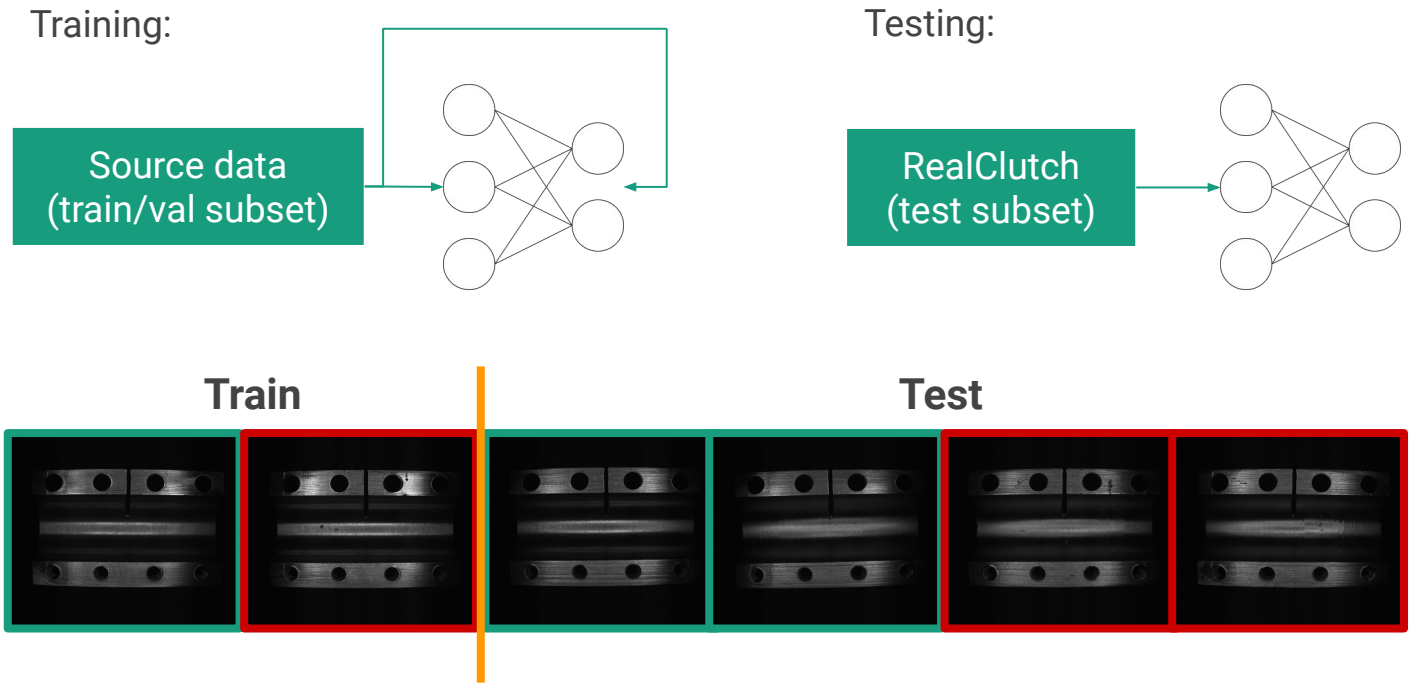
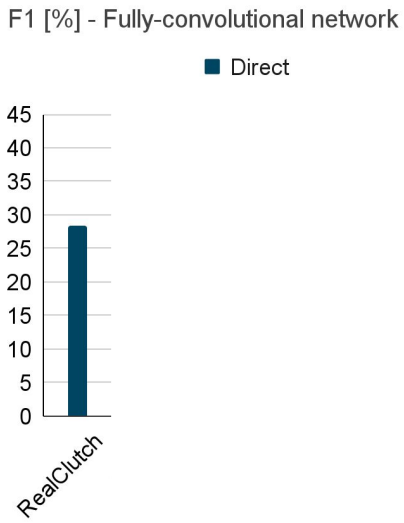
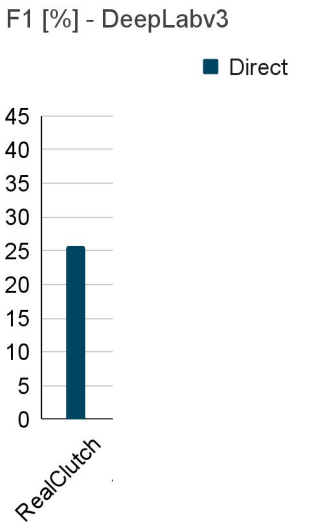
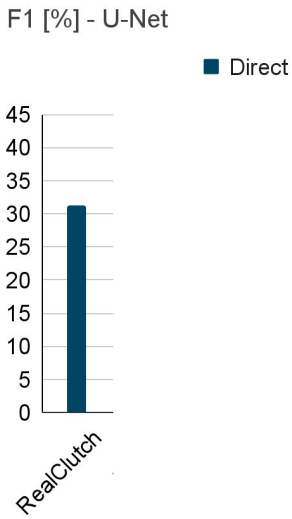


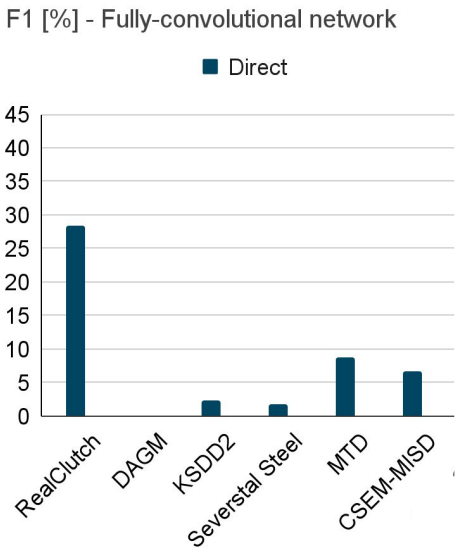
Results - Baseline

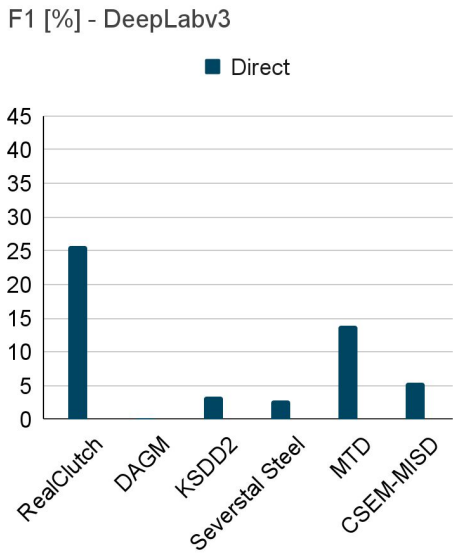


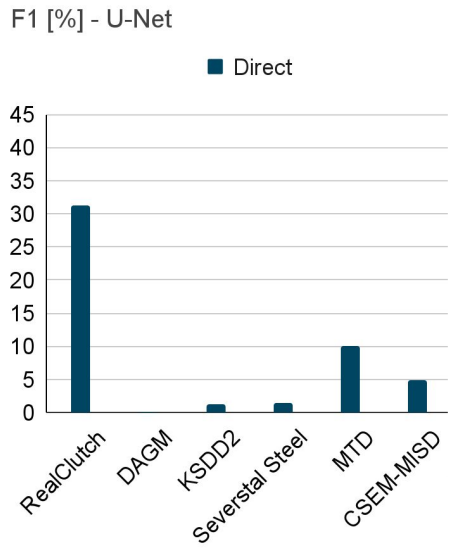




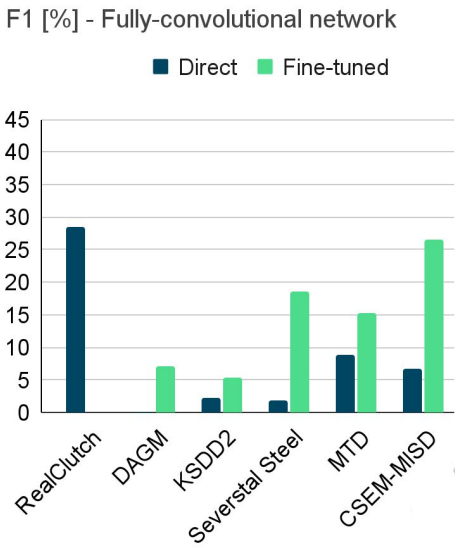
Results - Related datasets

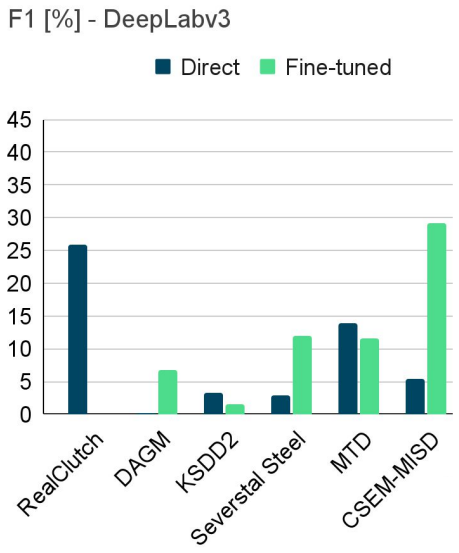


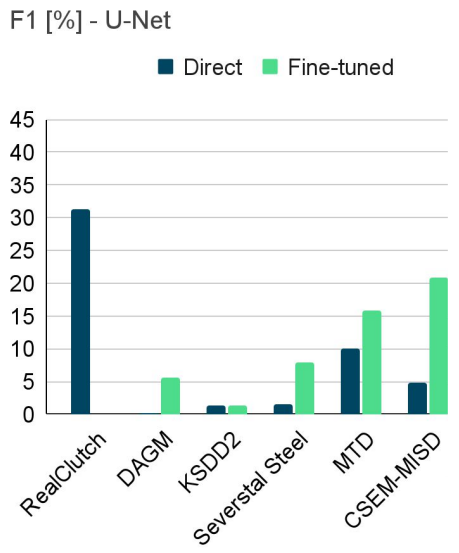




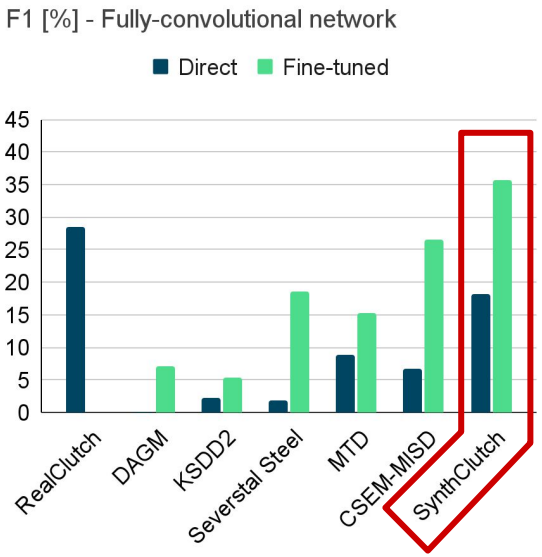
Results - Related datasets + Fine-tuning

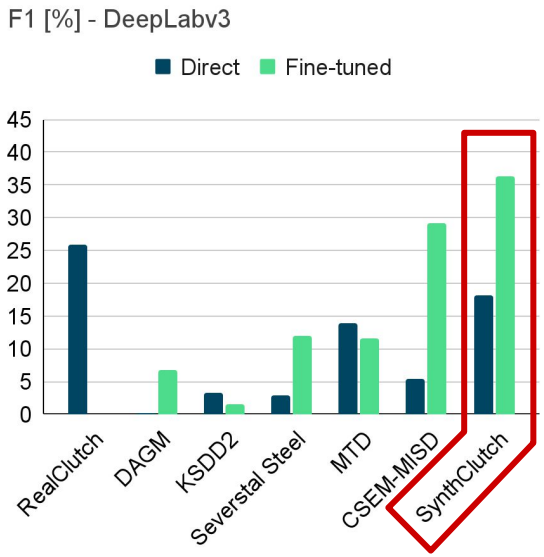


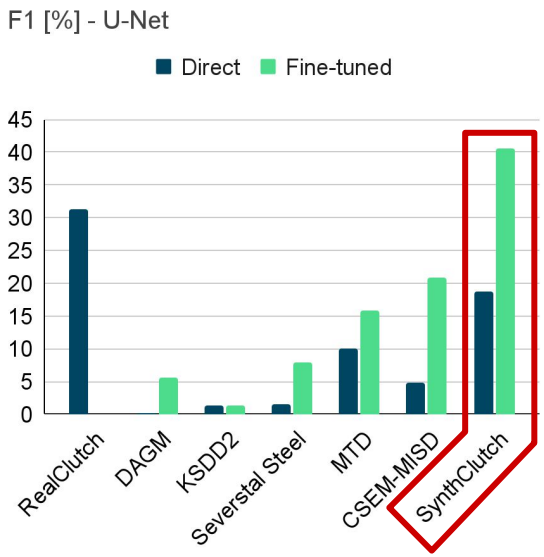




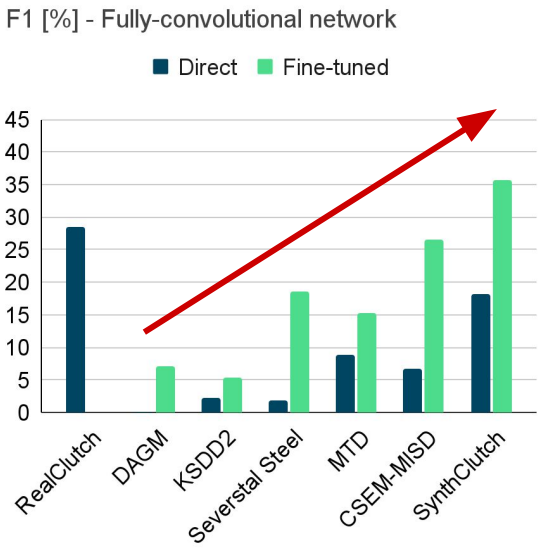
Results - SynthClutch

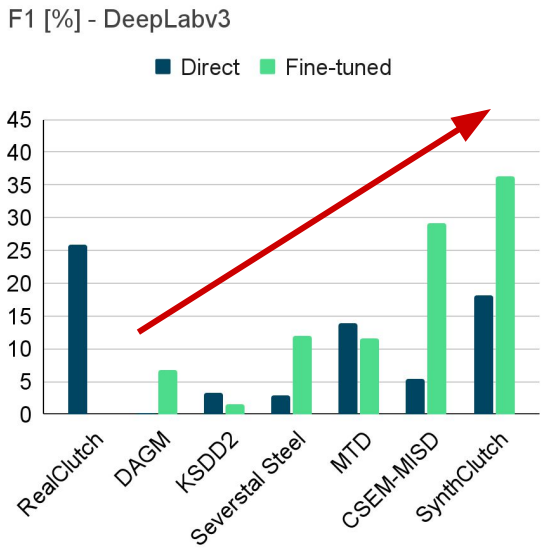


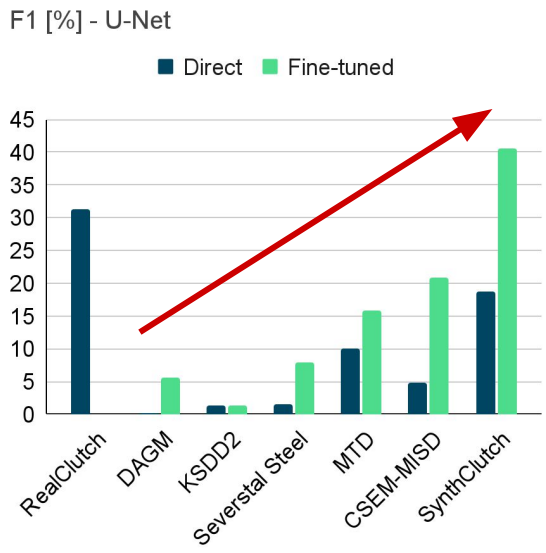




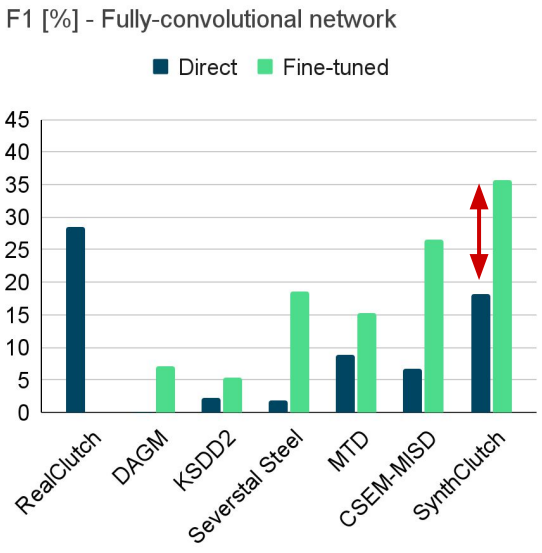
Results - Performance trend

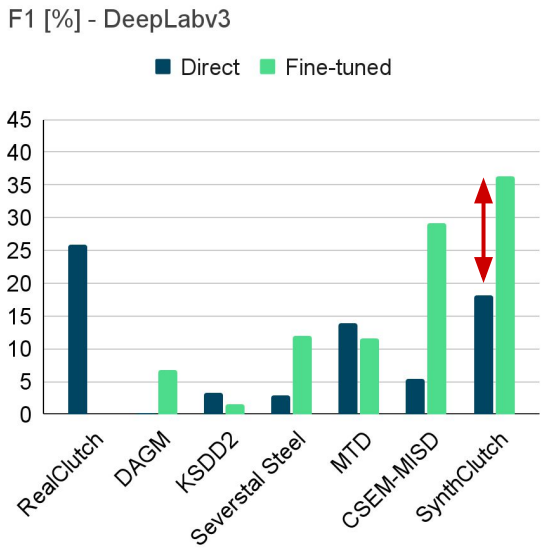


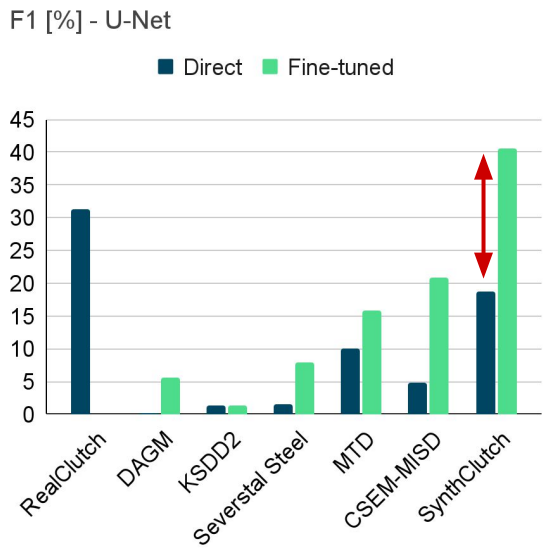




Results - Domain gap

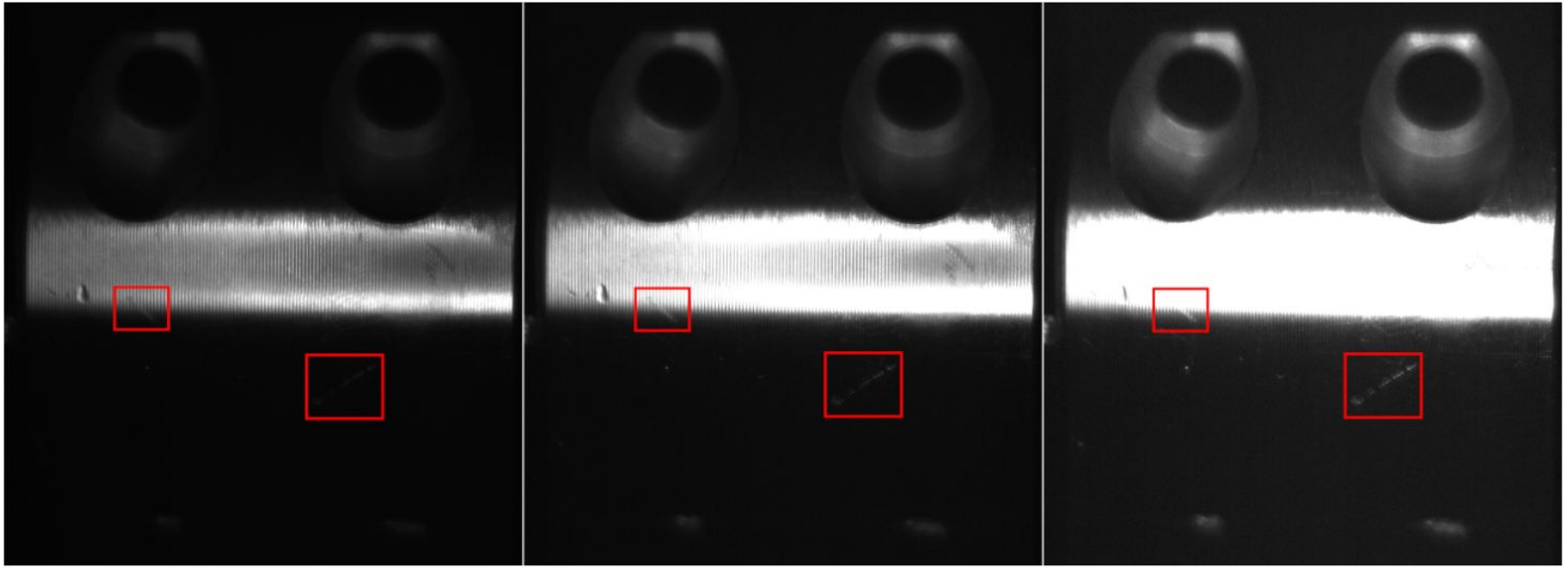






Exposure stacking - Defect appearance change

Original | Exposure 1 | Exposure 2



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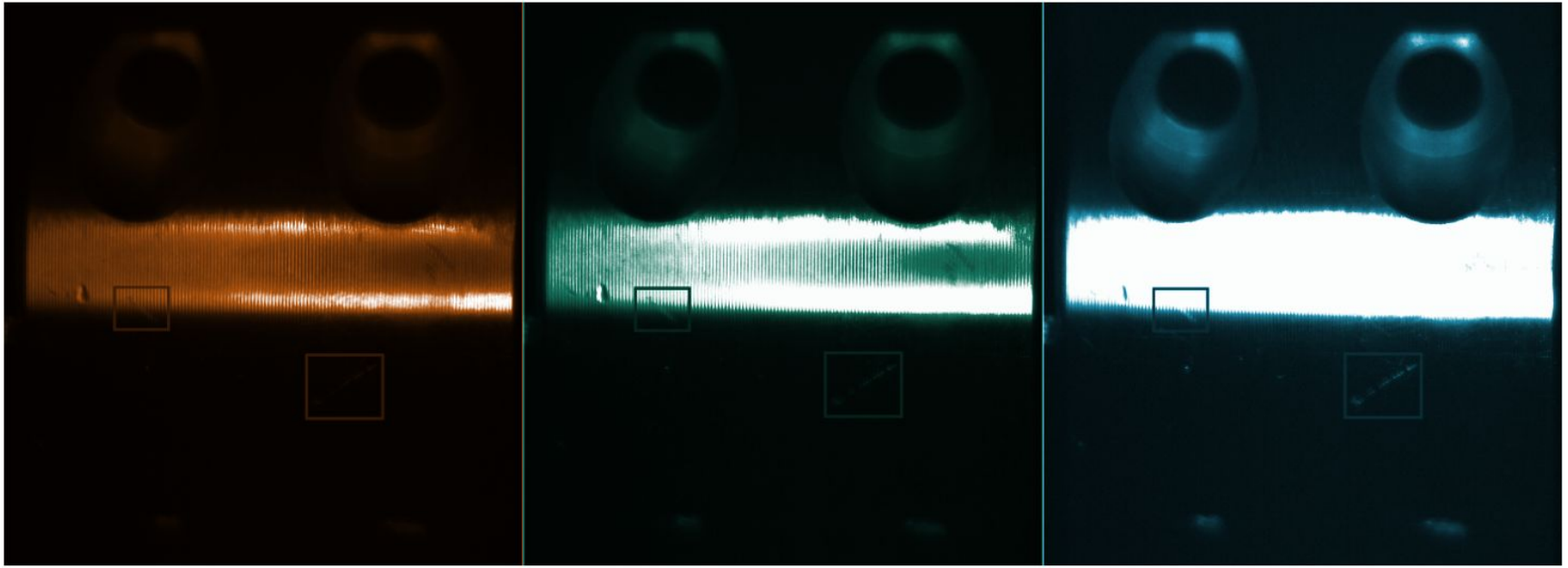
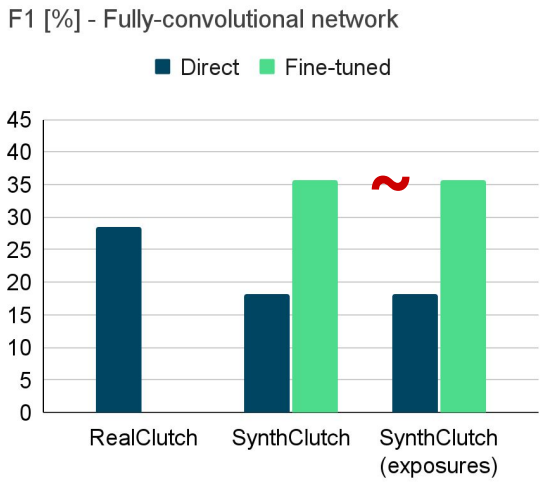
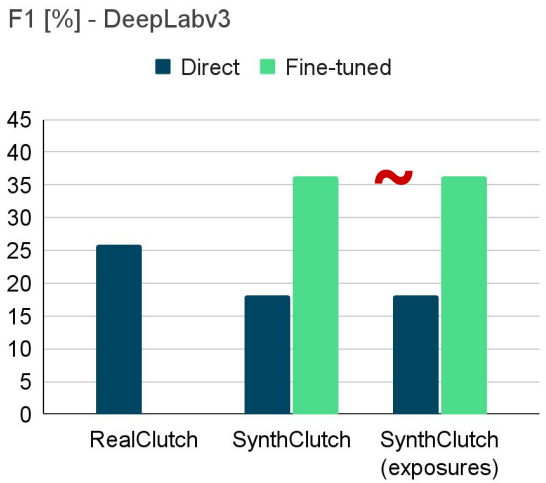
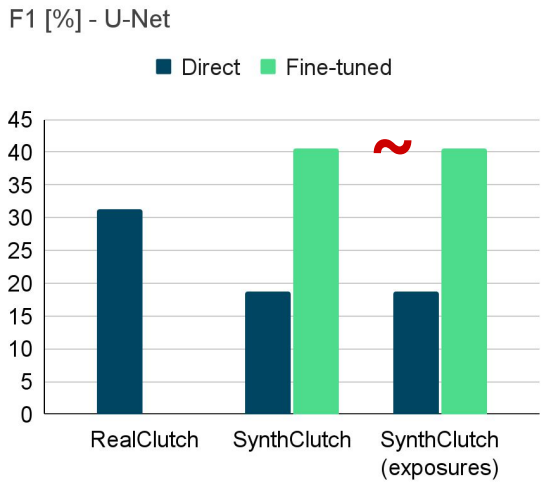


Exposure stacking - Results







Conclusions

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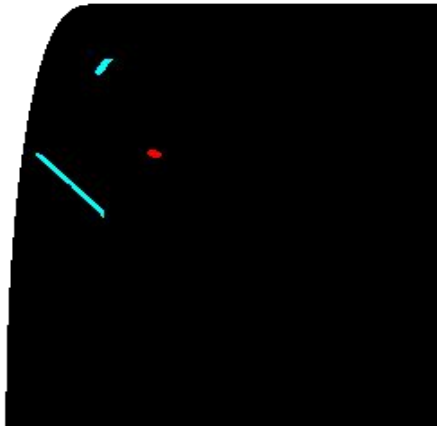
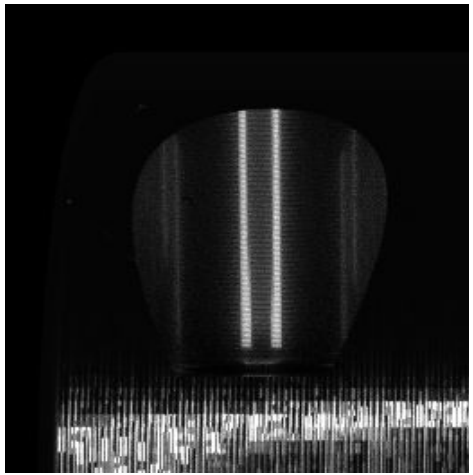
- Intensity biased cropping benefits the learning process
- Stack of modified exposures does not increase model performance

Limitations and further research

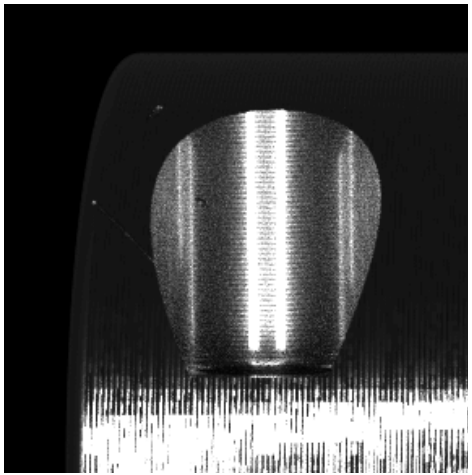
- Synthetic masks are over-labeling



Mask



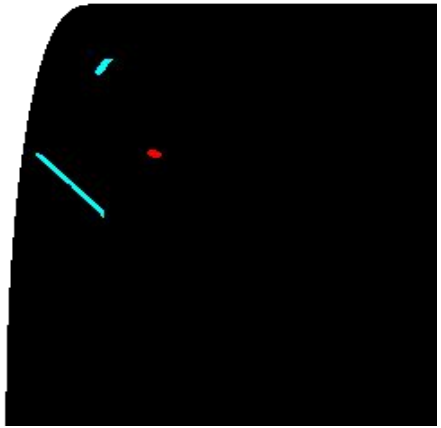
Image



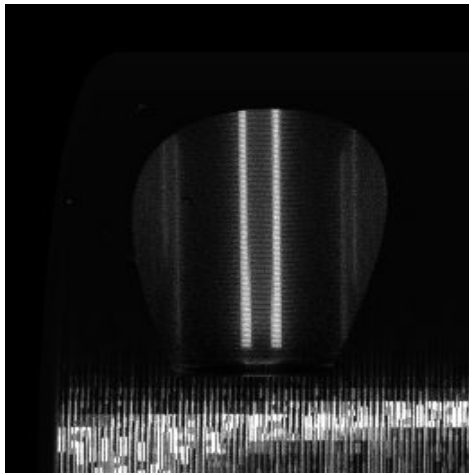
Overexposed image

Limitations and further research

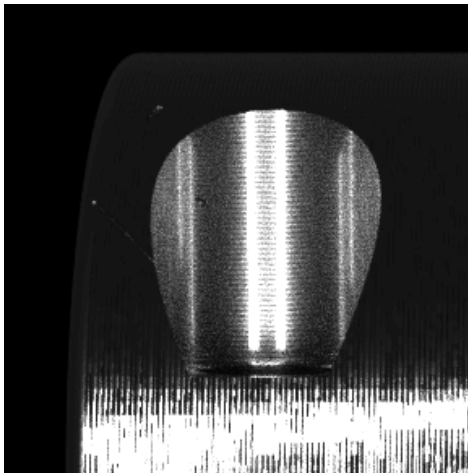
- Synthetic masks are over-labeling
  - Problem of defect visibility



Mask



Image



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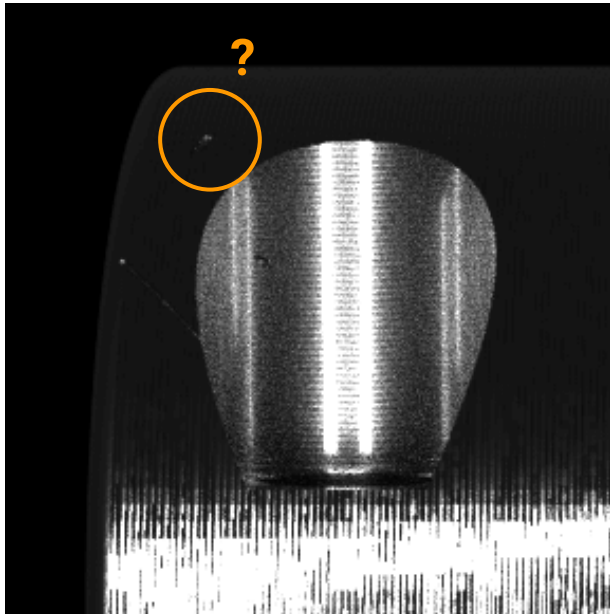
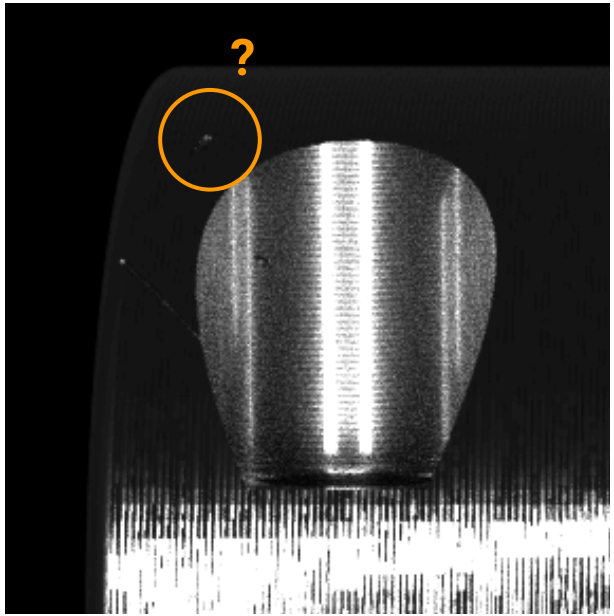


Limitations and further research

- Synthetic masks are over-labeling
  - Problem of defect visibility
- Decision making based on single image
- Exploring the possibilities of procedural synthetic data in different industrial inspection setups



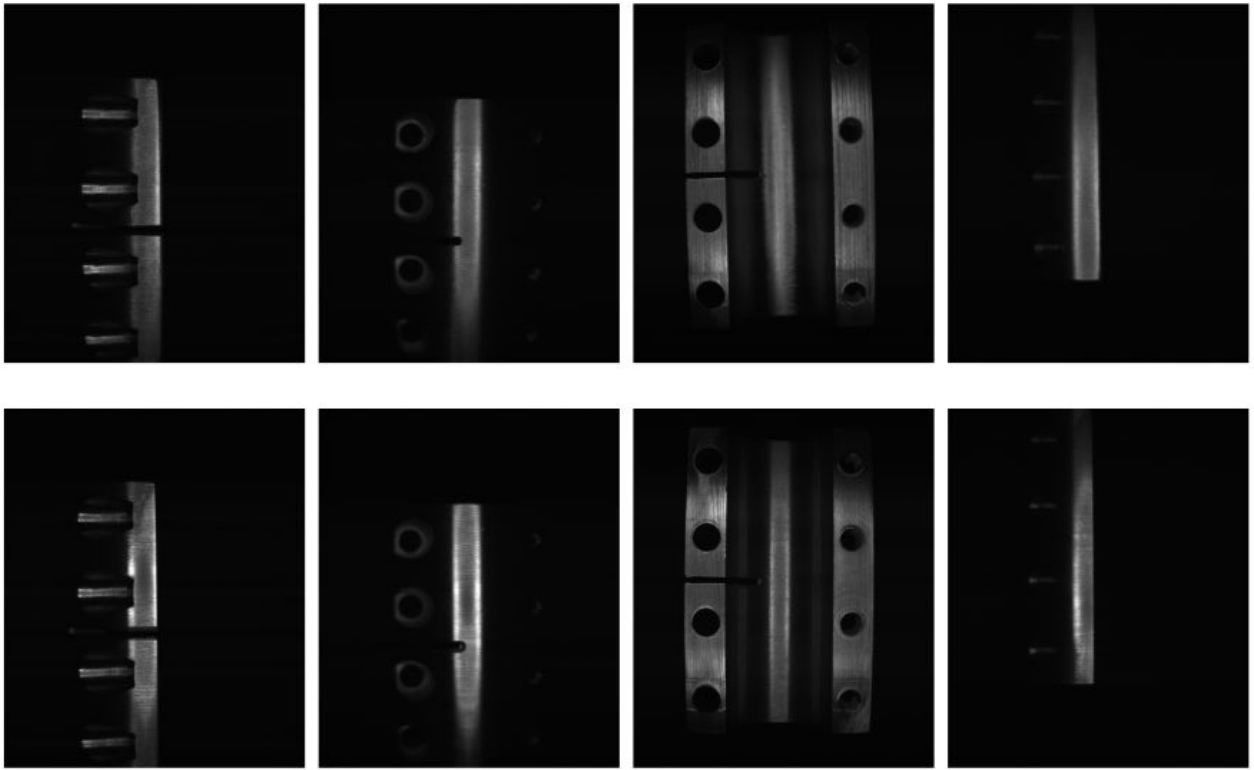
Thank you for listening!

This work was supported by Fraunhofer ITWM and the German Federal Ministry of Education and Research (BMBF) [grant number 01IS21058B (SynosIs)].

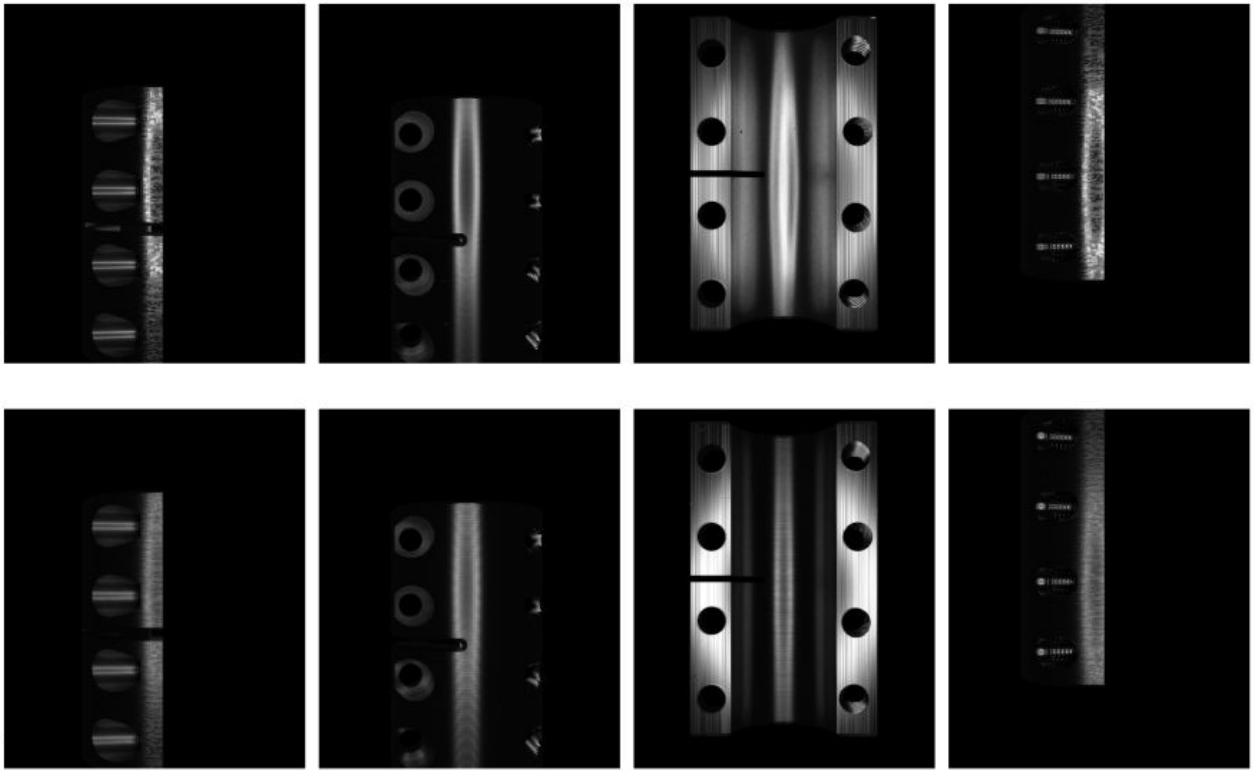
We thank Maedler for providing us with the correct object samples and consent to use them for research.

Extra slides

RealClutch dataset



SynthClutch dataset



Introduction

-

Defect recognition approaches	Expensive annotation	Requires lot of defect data	Requires lot of correct data
Supervised (detection, segmentation)	+	+	+
Weakly-supervised (class activation maps)	-	+	+
Anomaly detection	-	-	+