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20/10/2021

Deep Semi-supervised Learning of Dynamics for 3D Defect Mapping in Laser Powder Bed Fusion

IBSim-4i conference

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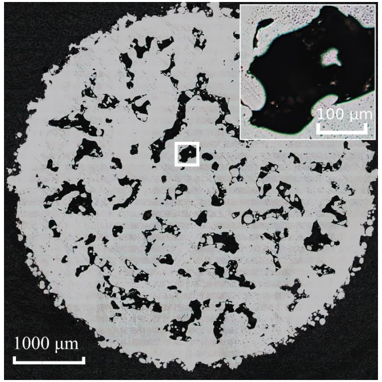
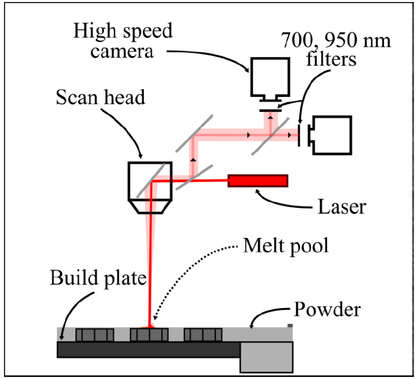
Presentation overview

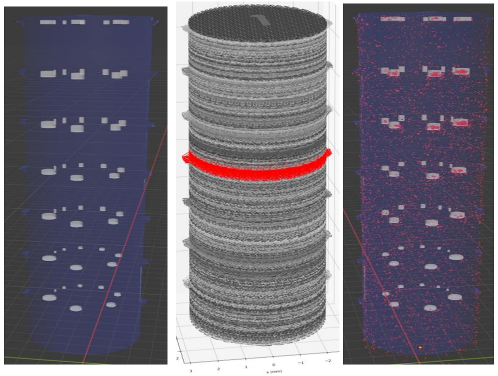
Part 1: Defect sources



Part 2: Defect detection



Part 3: Defect mapping



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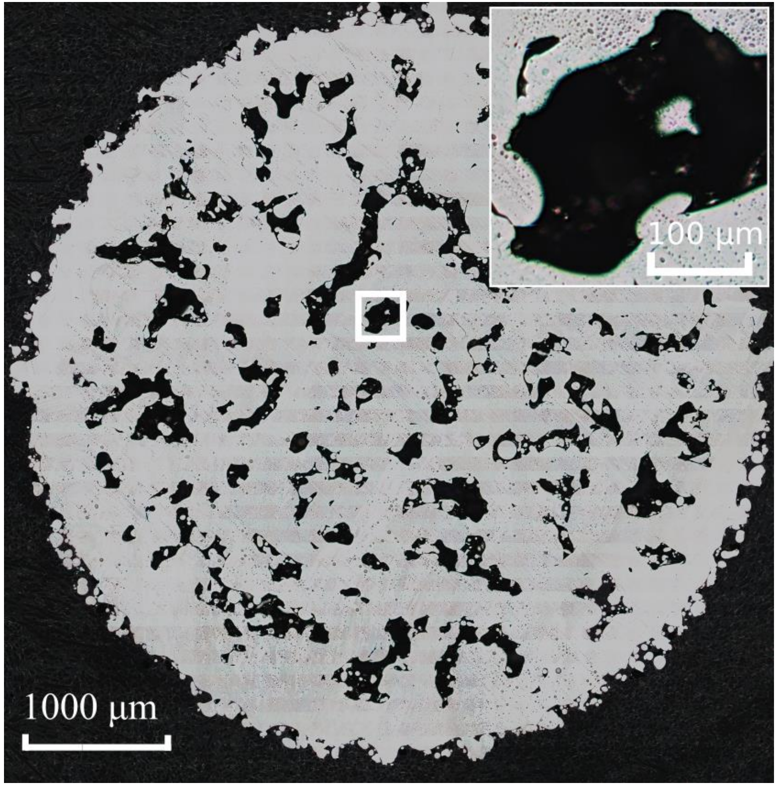

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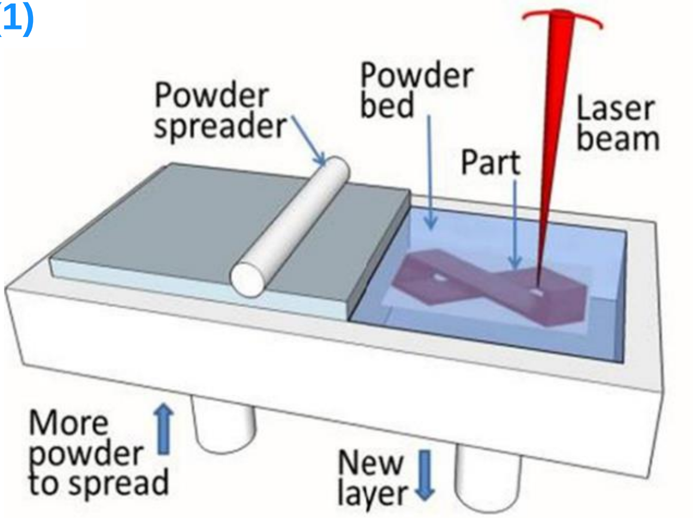
L-PBF process

(1)



[1] – DebRoy et al. (2017) - Additive manufacturing of metallic components – Process, structure and properties
[2] - Fraunhofer Institute
[3] – Dall'Ava et al. (2019) - Comparative analysis of current 3D printed acetabular titanium implants
[4] Tan et al. (2020) - Design and additive manufacturing of novel conformal cooling molds

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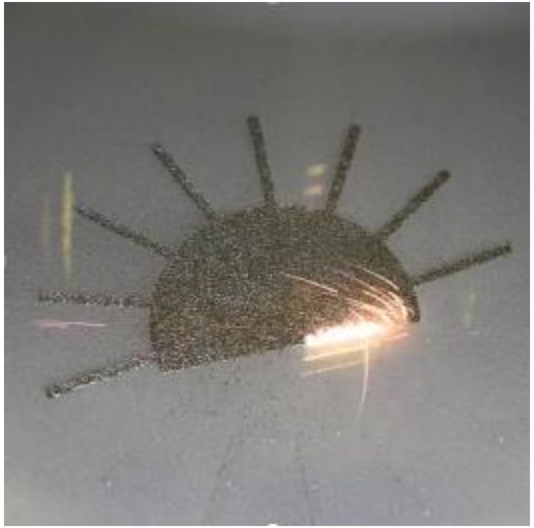
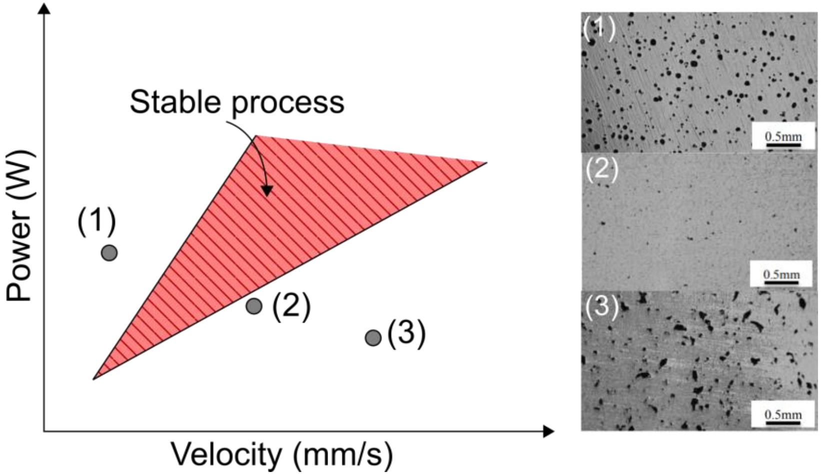
Why do defects occur?



Laser Powder Bed Fusion process (Franhofer)



Process window showing varying types of defects.
Section images: Gong H et al. (2013) "Defect morphology in Ti–6Al–4V parts fabricated by selective laser melting and electron beam melting"

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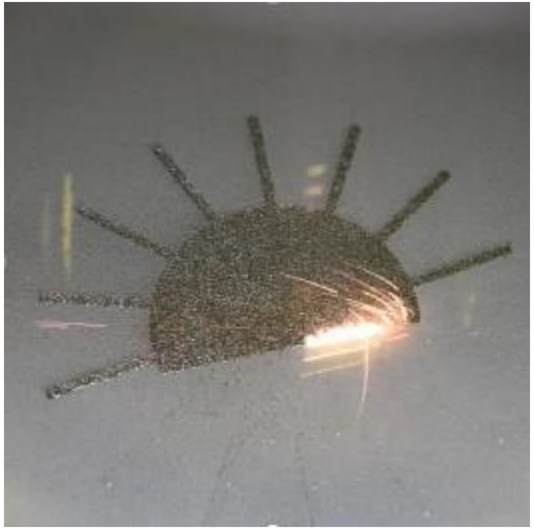
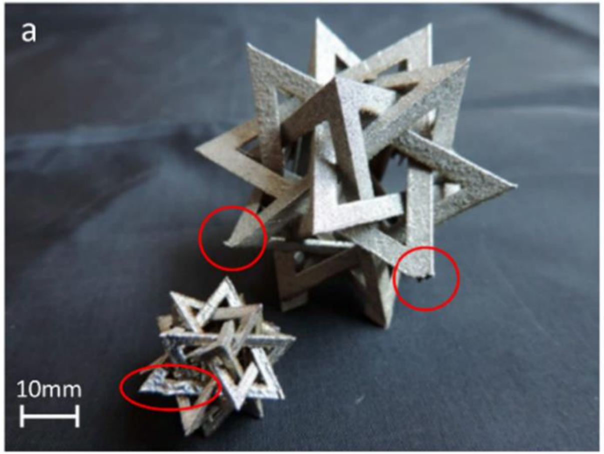
Geometric induced (pre-build)



Laser Powder Bed Fusion process (Franhofer)



Grasso M et al. (2016) “In-process monitoring of selective laser melting: spatial detection of defects via image data analysis”

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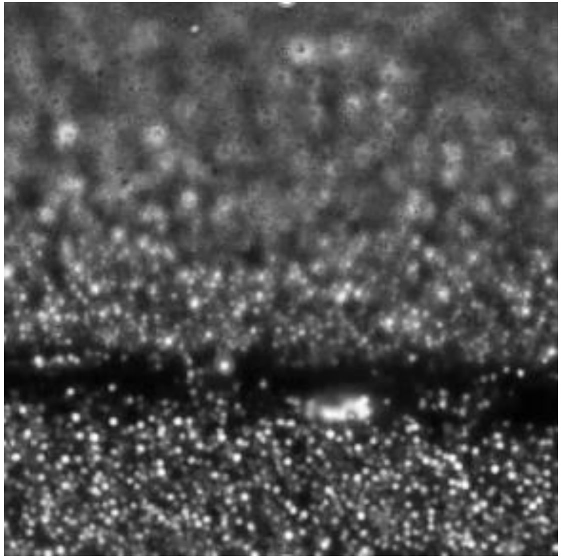
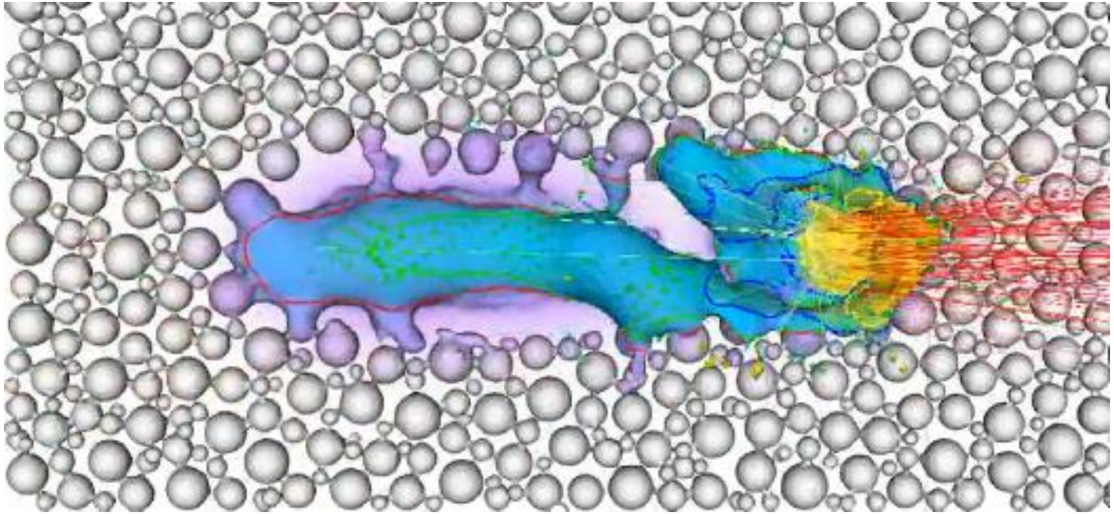
Variability induced (in-situ)





Video credits: Khairallah et al. (2020) “Controlling interdependent meso-nanosecond dynamics and defect generation in metal 3D printing”

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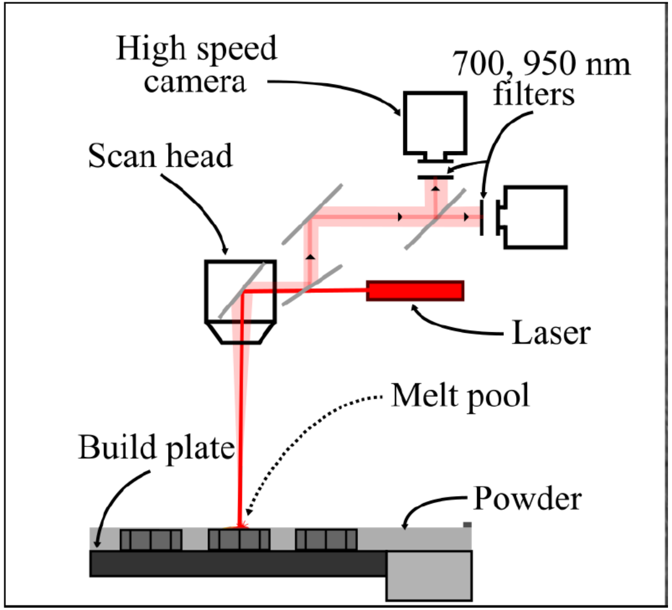
Part 2: Defect detection



Larsen & Hooper (2021) - [Deep semi-supervised learning of dynamics for anomaly detection in laser powder bed fusion]

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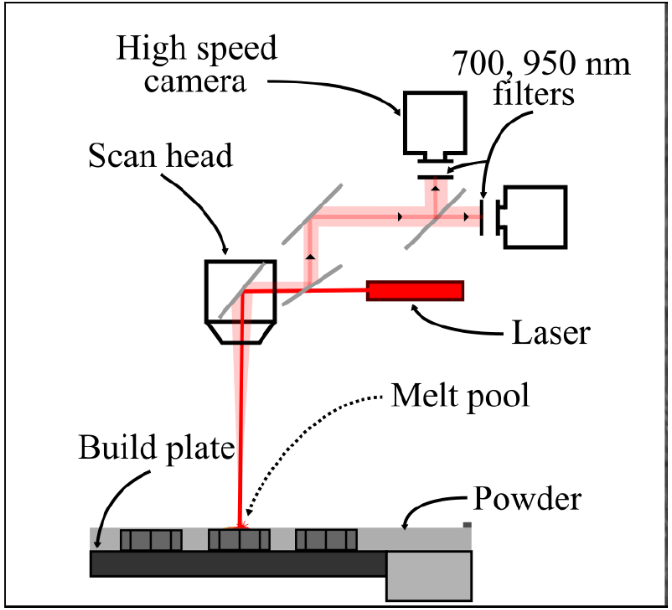
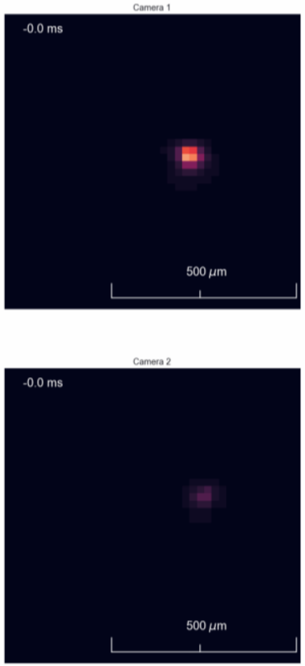
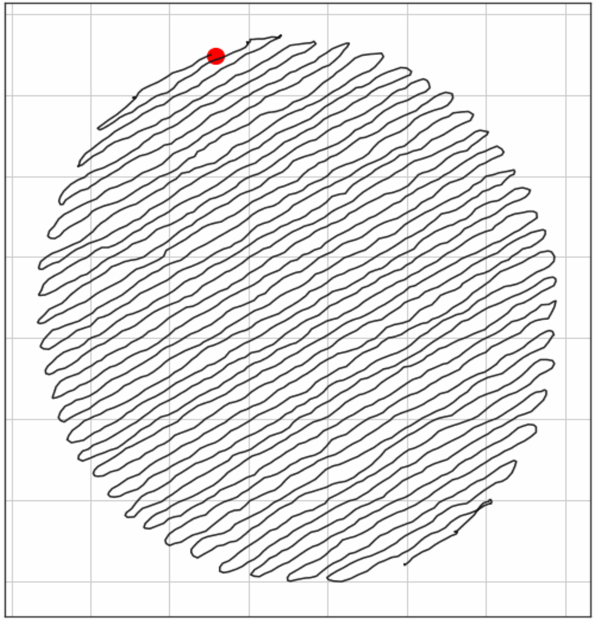
Melt pool monitoring







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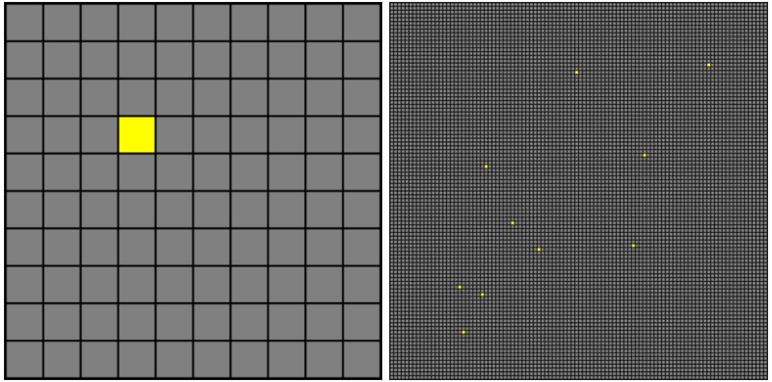
The challange of False Positives (FP)

- False positive rate, $\mathrm{FPR} = \frac{\mathrm{FP}}{\mathrm{FP+TN}}$
- 10x10 grid
- 0.01 FPR = 1 FP/layer
- 100x100 grid
- 0.001 FPR = 10 FP/layer
- One $25\ \mathrm{mm}^2$ layer may have in the region of 10,000 measurements at 100 kHz.
- 100s of layers results in many FPs



Example of a component layer

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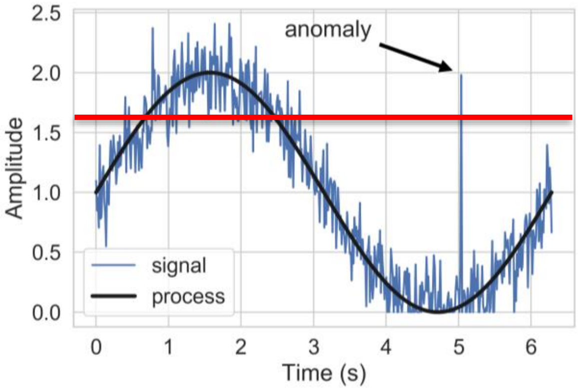
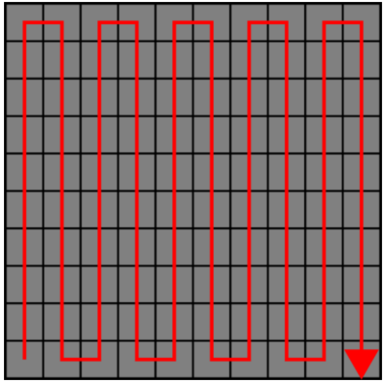
Autocorrelation

- One cause of high FP: sequential data often has correlations
- This can cause defects to be obscured in the process
- Results in large amounts of false positives (FP)
- Hence modelling the process allows defects to be detected by reduced FP



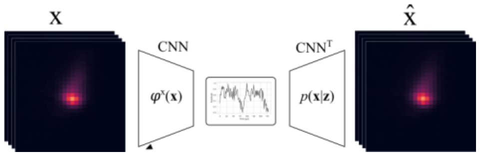


Laser scan path

Melt pool monitoring with FlawNet

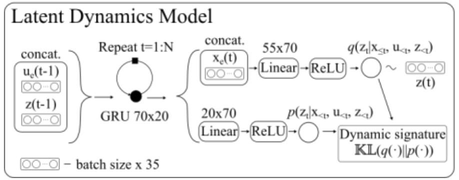
(a) Dimensionality reduction

Input: high speed image data
Output: extracted features



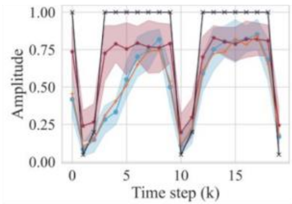
(b) Latent dynamics model

Input: melt pool state at time, t
Output: melt pool state at time, t+1



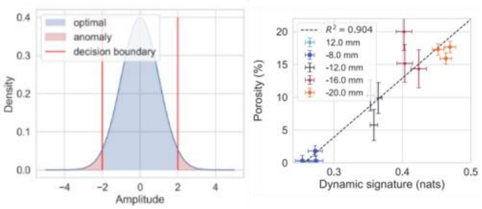
(c) Data fusion of dynamics

Measure dynamic signature
Combine local correlations



(d) Linear classification and regression

Local prediction of defect
Layerwise porosity



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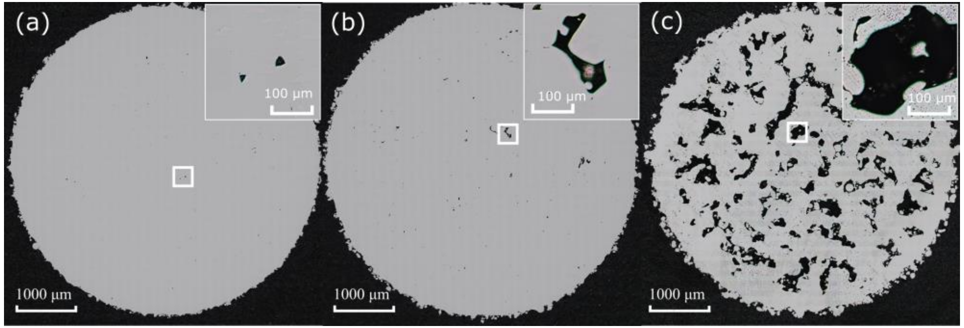
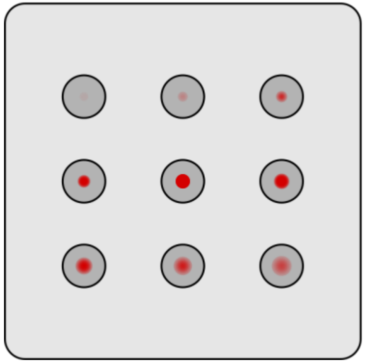
Case study: detecting part-wide porosity

3 builds:

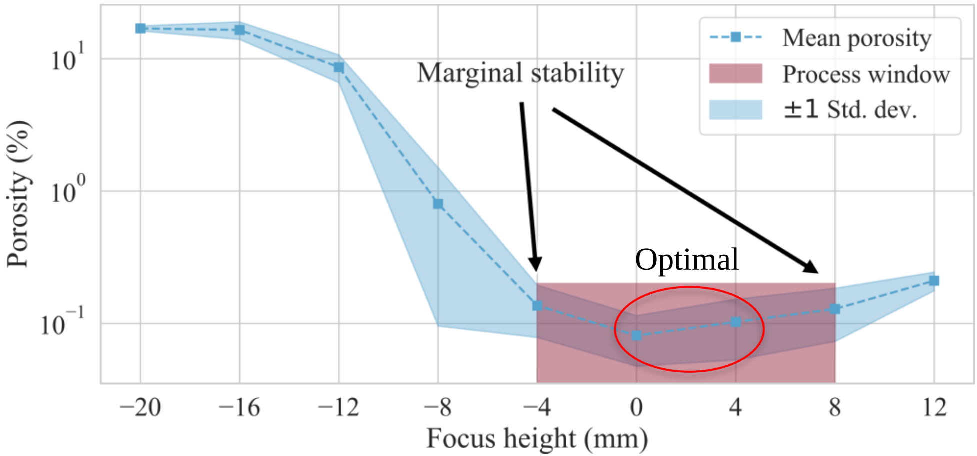
- 9x Ø5 mm cylinders
- 9x focus heights
- -20 to 12 mm



Three example qualities: (a) optimal: 0 mm, (b) unstable: -8 mm, (c) unstable: -12 mm

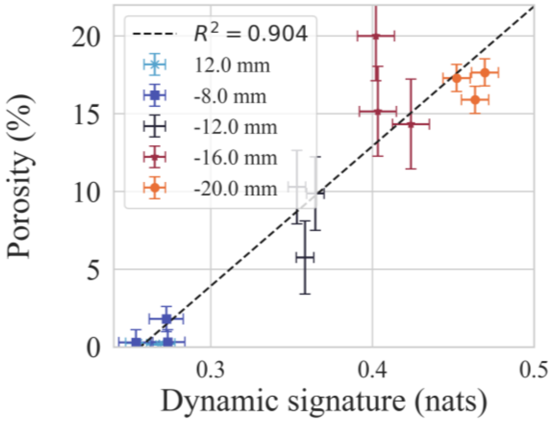


Build plate with cylinder setup

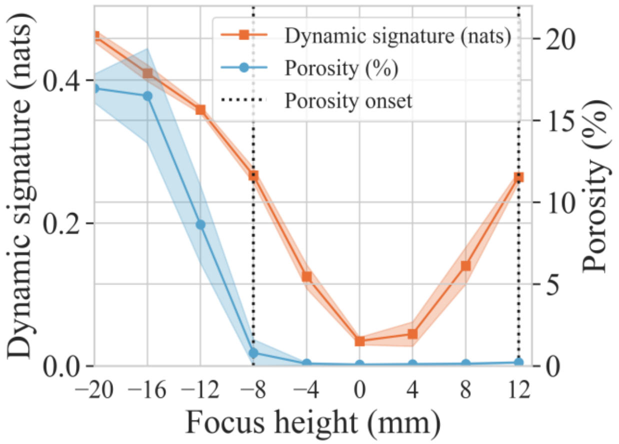


Focus height vs. porosity indicating process window

Results 1: Correlating with global porosity



Porosity vs mean dynamic signature over one layer.



Focus height vs. porosity and dynamic signature.

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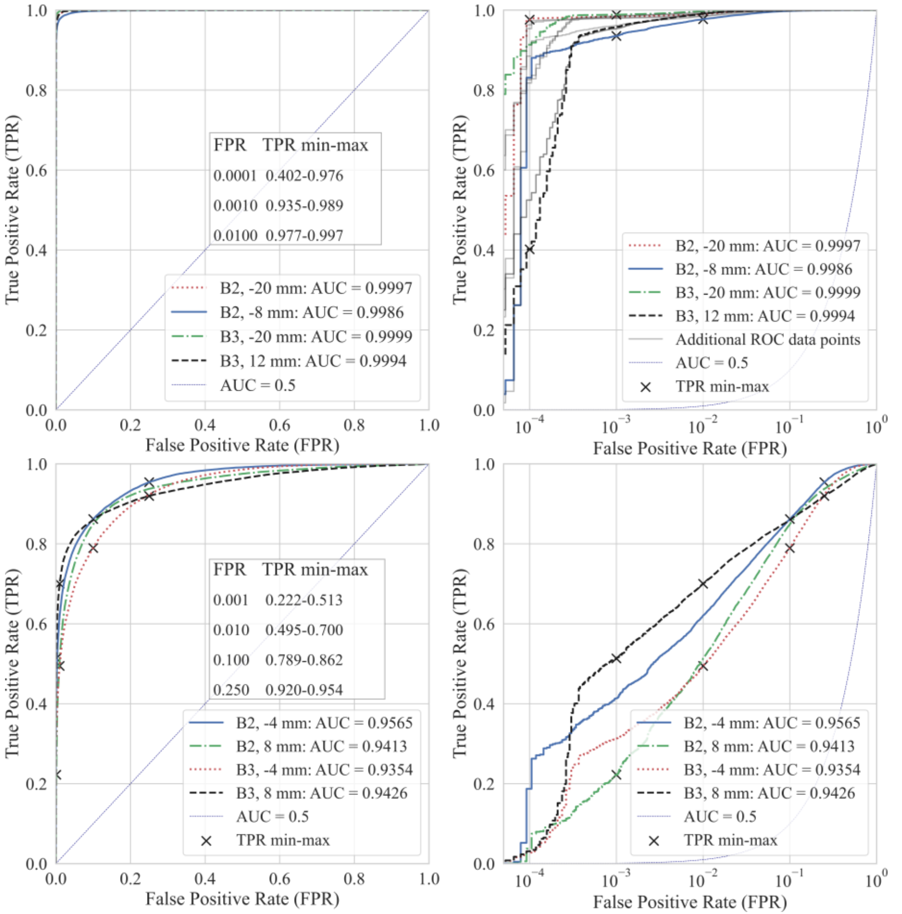
Results 2: Localised defect detection (9 frames)

- Optimal vs. unstable
  - 14 samples
  - ROC AUC = 0.999 ± 0.001
  - Porosity = $8.93 \pm 8.73\%$
- Optimal vs. marginal
  - 4 samples
  - ROC AUC = 0.944 ± 0.013
  - Porosity = $0.14 \pm 0.07\%$
- Worst case:
  - ROC AUC = 0.935
  - Porosity = 0.07%



Receiver operating characteristic (ROC) for optimal (0,4mm) vs. rest of focus heights

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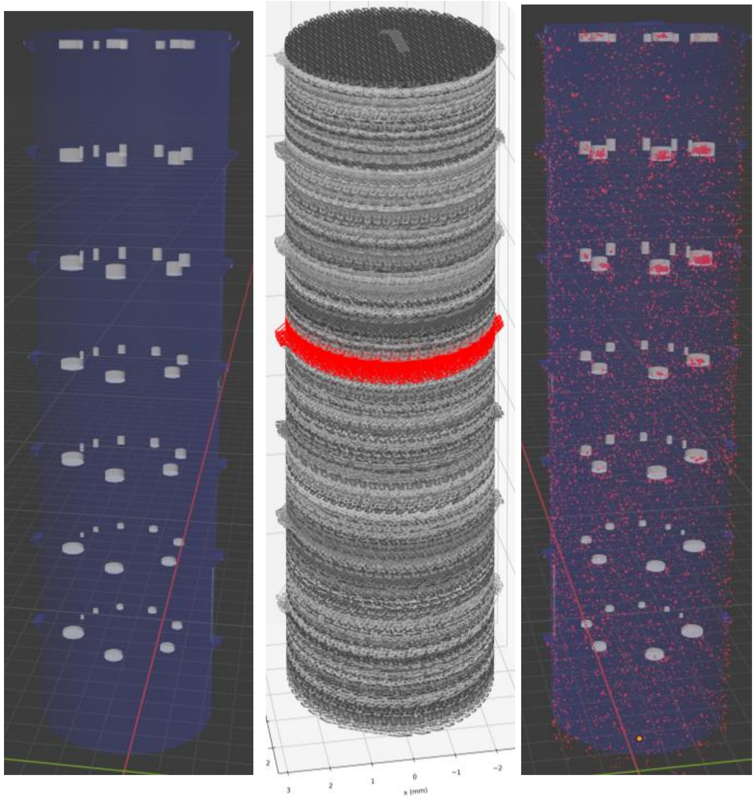
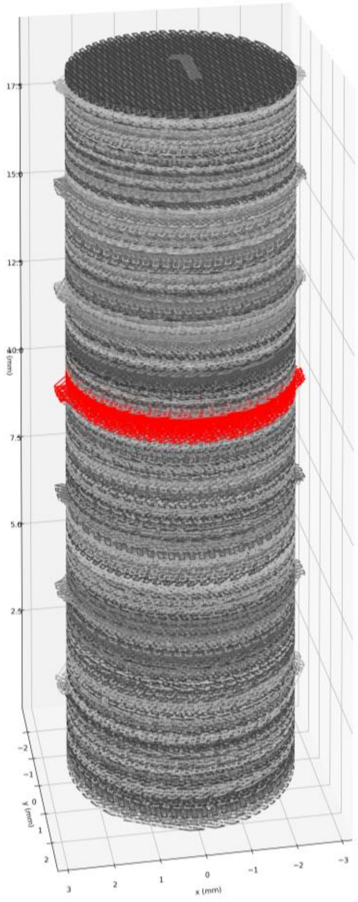
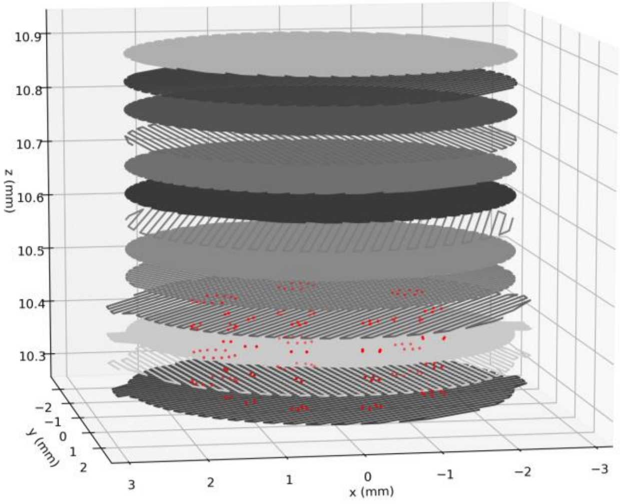
Part 3: Defect mapping

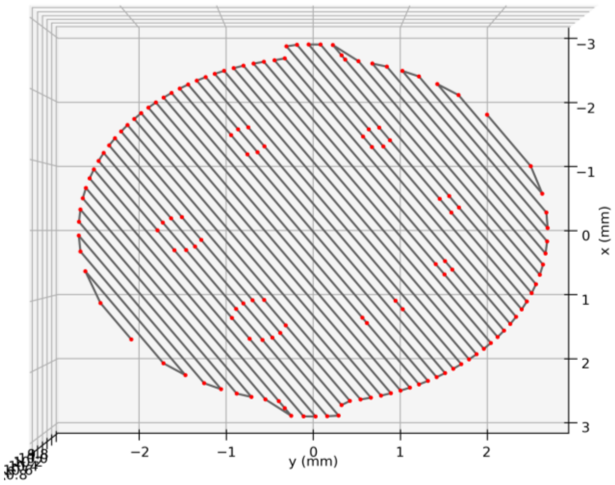
Part of an ongoing study

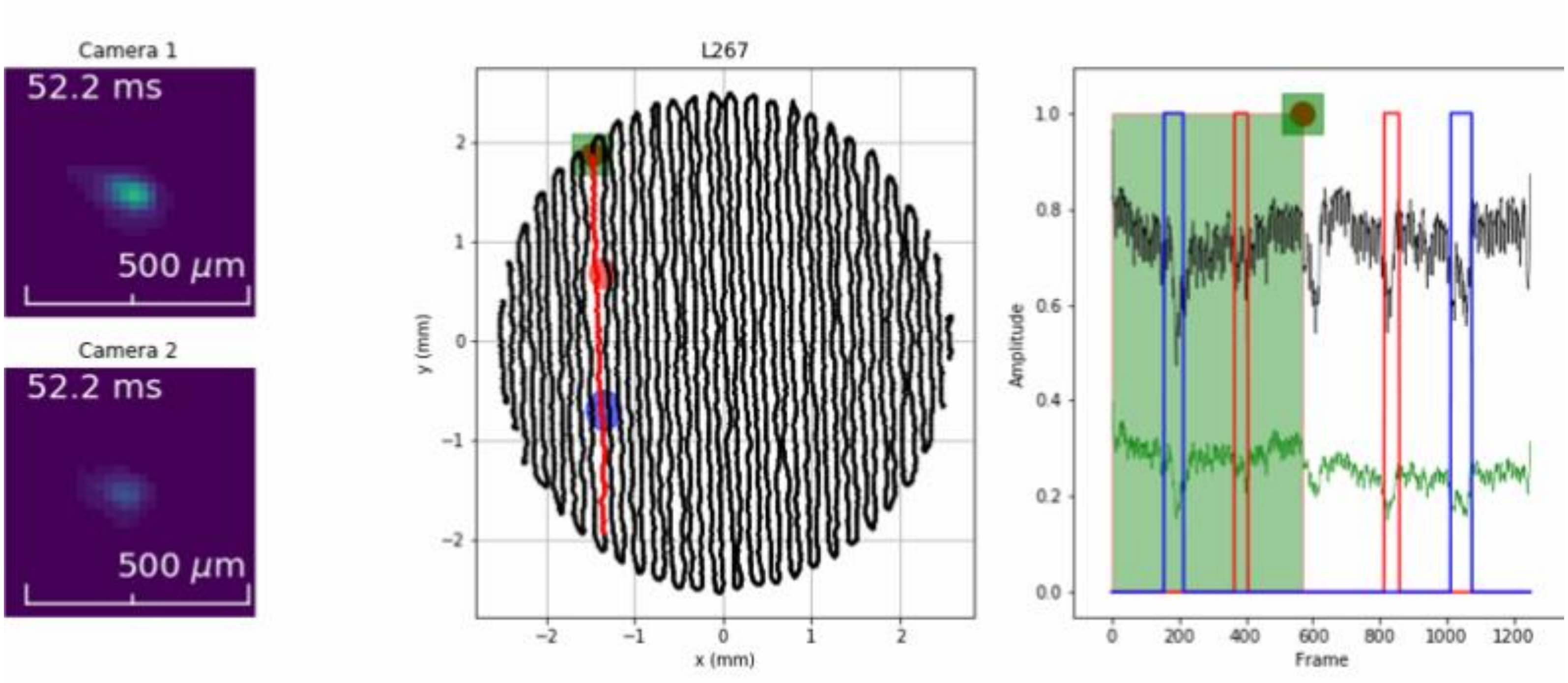


Machine inputs

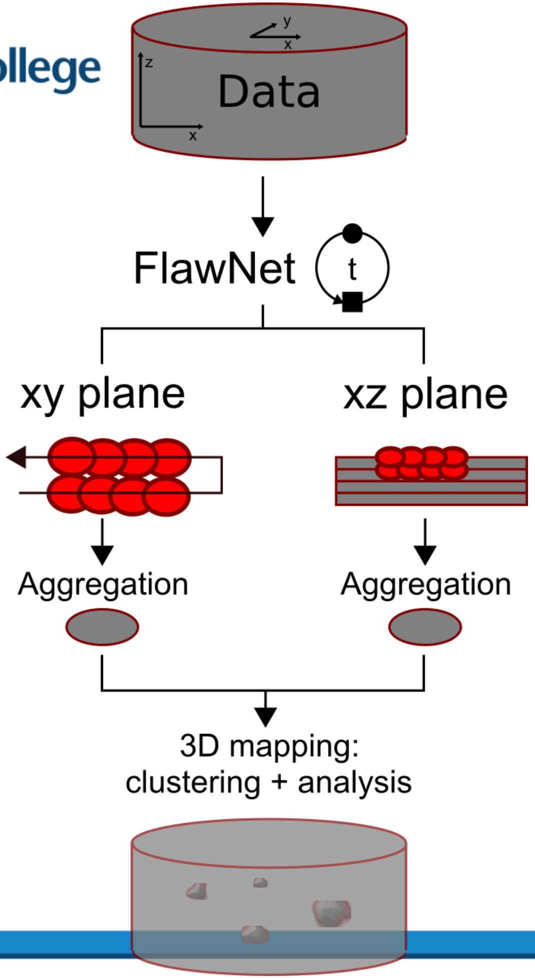


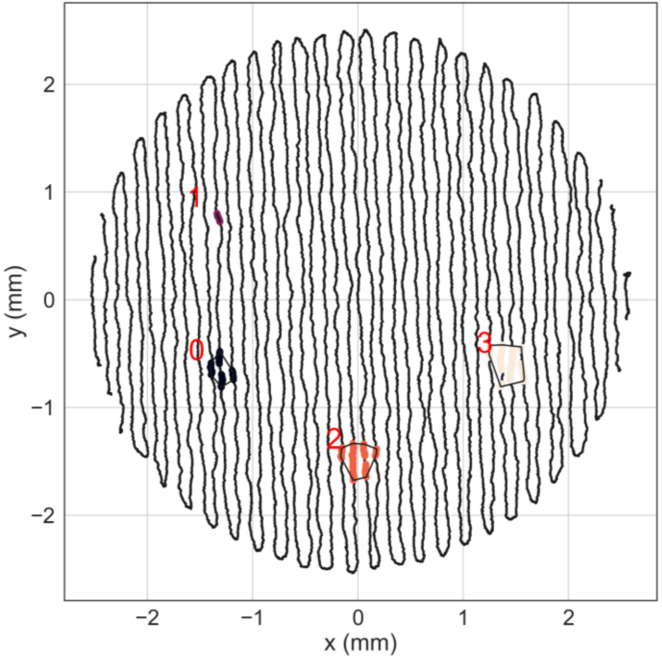




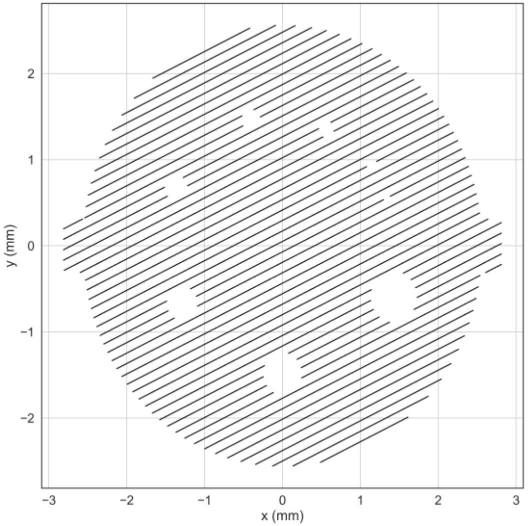

Camera 1
52.2 ms
500 μm
Camera 2
52.2 ms
500 μm
L267
y (mm)
x (mm)
Amplitude
Frame

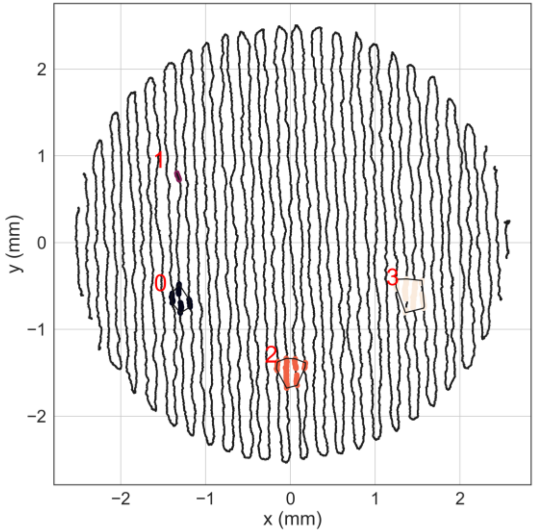
Data representation



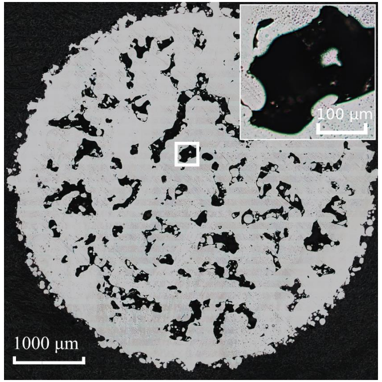


Part 3 summary

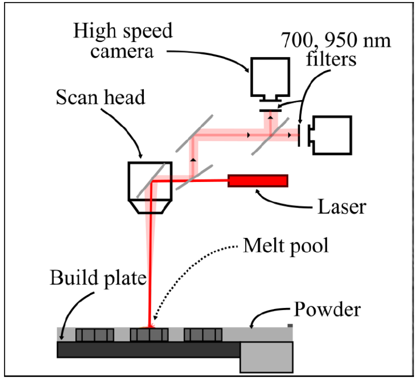




Part 1: Defect sources



Part 2: Defect detection



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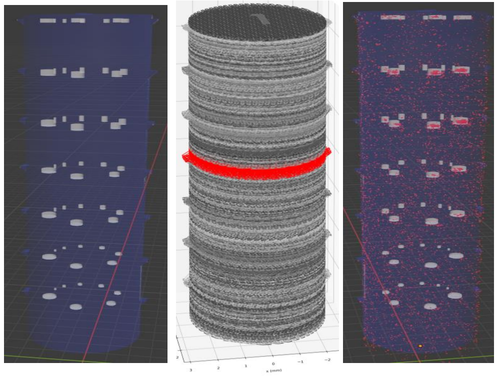

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Thanks to our collaborators

- I would like to thank:
  - Organisers of IBSim-4i conference
  - Research group including Harry de Winton and Dr. Richard Williams
  - Supervisor, Dr. Paul A. Hooper
  - MoM and Department of Mechanical Engineering at Imperial College London

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Questions?

Thanks for your attention!

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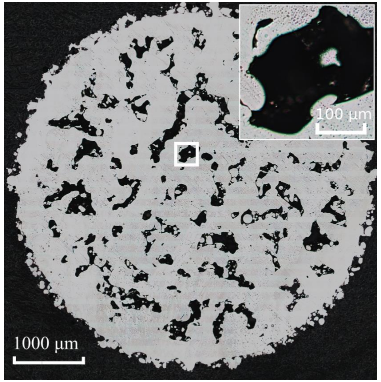

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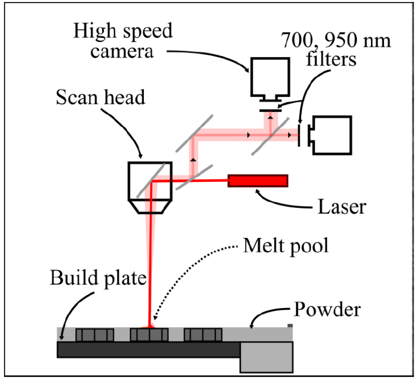

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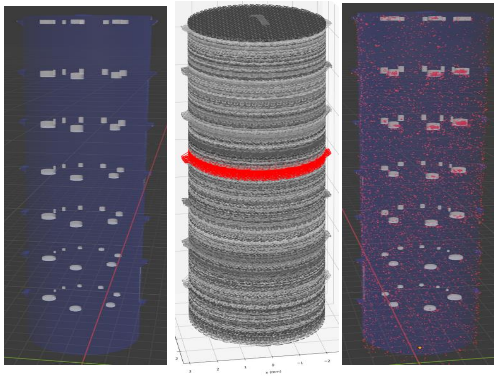

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