PHOTODIODE BASED MONITORING AND QUALITY ASSURANCE PARADIGMS FOR LASER POWDER-BED FUSION: A SYSTEMATIC APPROACH

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WATERLOO | ENGINEERING

MSAM

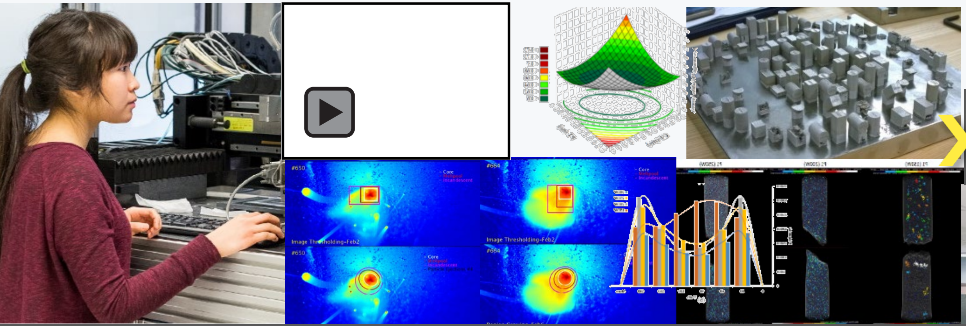
Contents

- Brief overview of Multi-Scale Additive Manufacturing (MSAM) Lab of the University of Waterloo
- A systematic approach to in-situ photodiodes monitoring and analytical/machine learning defect detection algorithms
- Defect healing using an intermittent controller
- Conclusions and Outlook

University of Waterloo

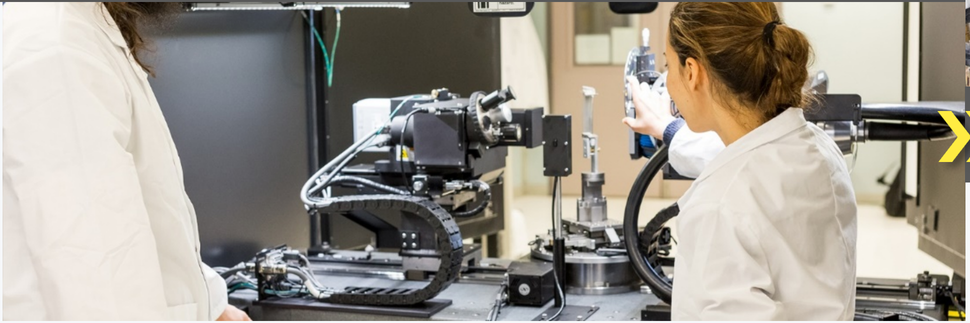
- Most Innovative University in Canada for the last 32 years
- First in Canada and #22 in the World, based on 2021 Pitchbook Top 50 colleges for founders

Multi-Scale Additive Manufacturing (MSAM) Lab



Comprehensive Research Programs

World-class Additive Manufacturing Equipment



Advanced Characterization Equipment

http://msam.uwaterloo.ca

Additive Manufacturing: A Paradigm Shift

- “Today, additive manufacturing is achieving economies of scale in a variety of ways– and doing so without sacrificing economies of scope”.

Richard D'Aveni, “*The Pan-Industrial Revolution: How New Manufacturing Titans will Transform the World*”, Oct. 2018

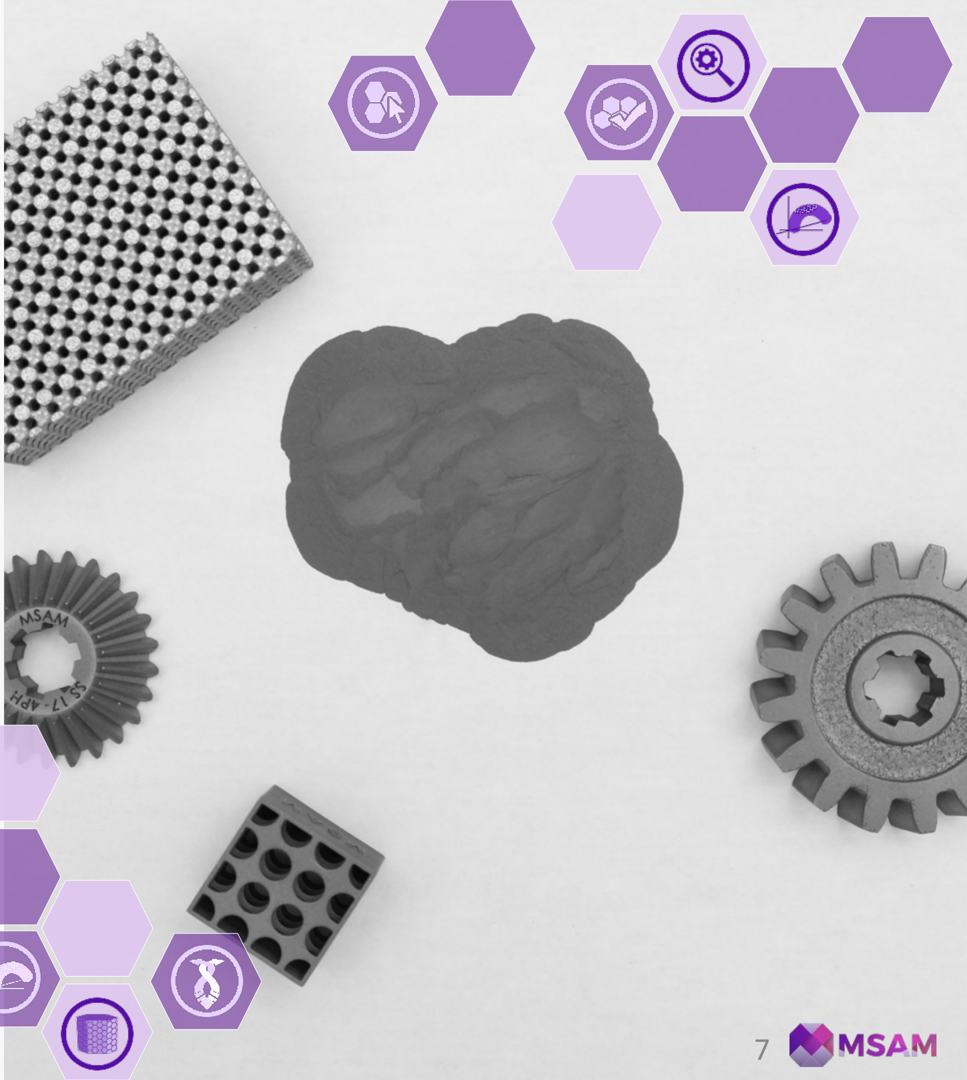
- Like all conventional techniques, in-situ monitoring and quality assurance procedures/tools for AM are of the utmost importance in aiding manufacturers in quality management and certification to confidently step into low- and high-volume manufacturing.

- In-situ monitoring and its impact on the process health monitoring call for the development of standards.

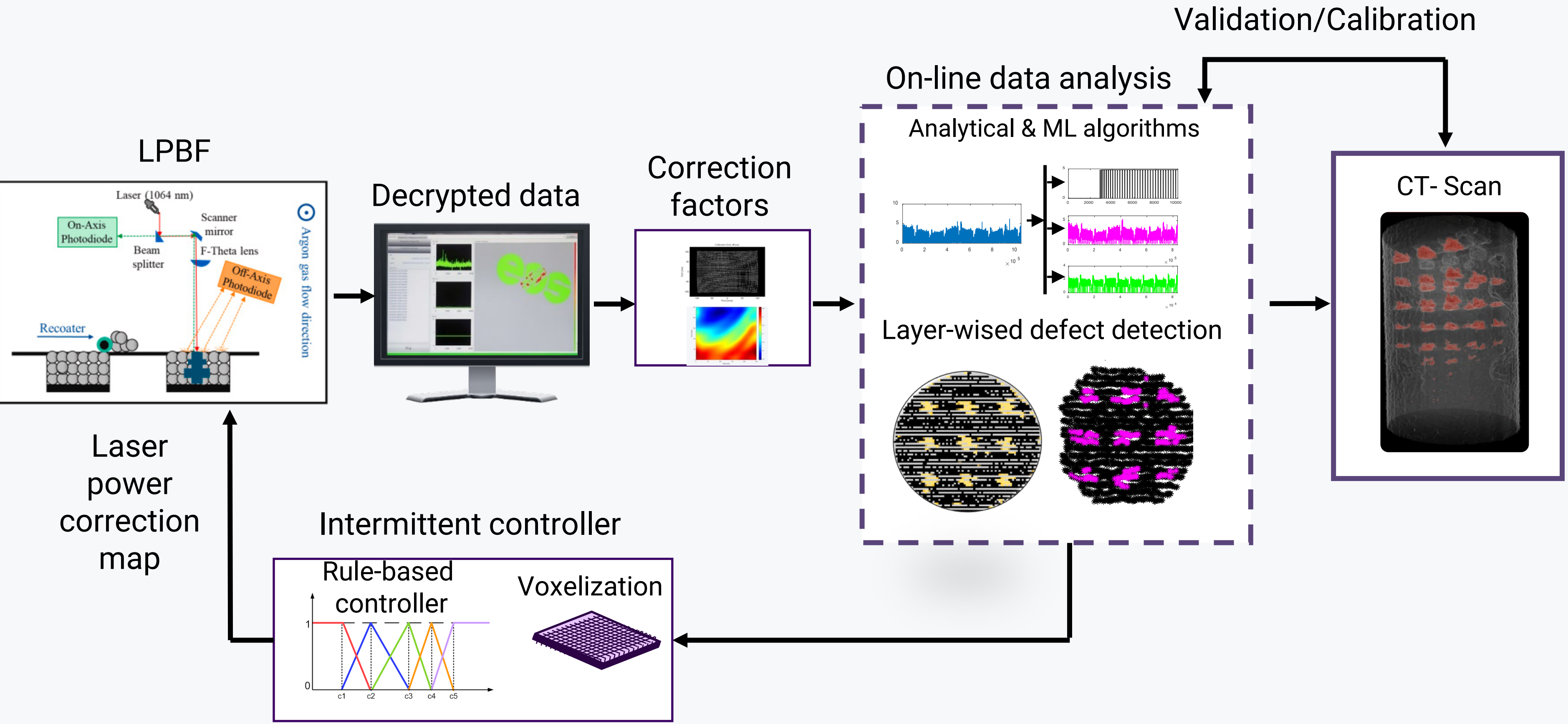
Challenges with In-situ Monitoring and Quality Assurance for LPBF

- Most in-situ monitoring technologies for LBPF are not yet advanced enough to detect process disturbances reliably with high level of confidence.
- Many developments have been carried on in-house developed systems, making it hard to replicate.
- Too many intrinsic and extrinsic parameters involved in LPBF, causing major nonlinear, non-harmonic disturbances during the process.
- Requirement to an adaptive calibration platform due to temperature dependency of intrinsic parameters.
- Not adequate resolution, accuracy and sampling frequency in monitoring devices to count for small size defects (<50 micron).
- Lack of model-based monitoring and quality assurance platforms.

PHOTODIODE BASED MONITORING AND QUALITY ASSURANCE PARADIGMS FOR LASER POWDER-BED FUSION (LPBF): A SYSTEMATIC APPROACH TOWARDS THE DEVELOPMENT OF BEST PRACTICES

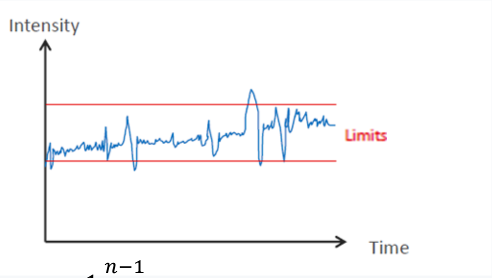


Project Goal



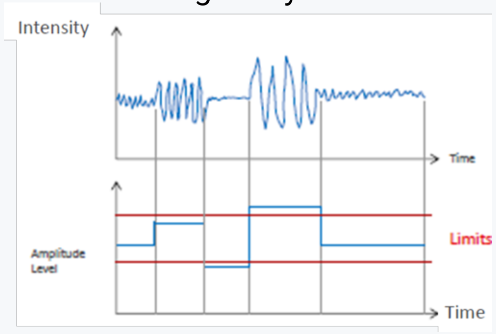
Analytical and ML Methods Applied to Decrypted Datasets

Absolute Limits



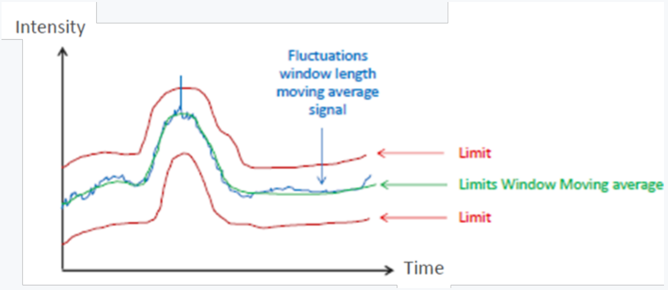
$$\frac{1}{n}\sum_{i=0}^{n-1} intensity\ signal(i)$$

Signal Dynamics



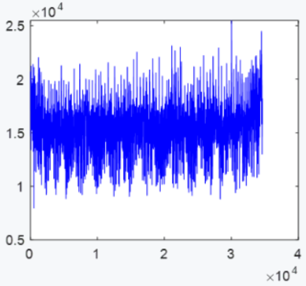
$$moving\ average(intesity) - \ mean\ value(intensity)$$

Short Term Fluctuations

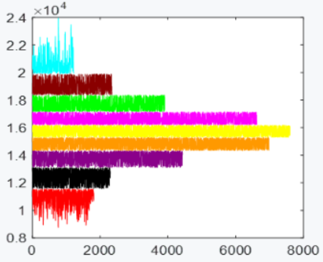


$$(80 - 120)\%\ of\ moving\ average(intensity)$$

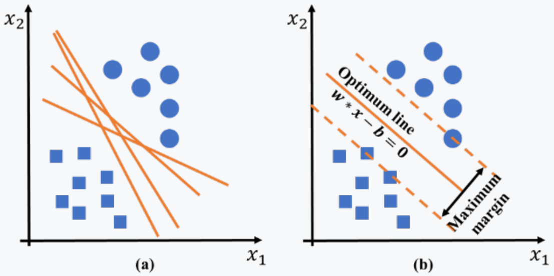
Unsupervised methods



ML

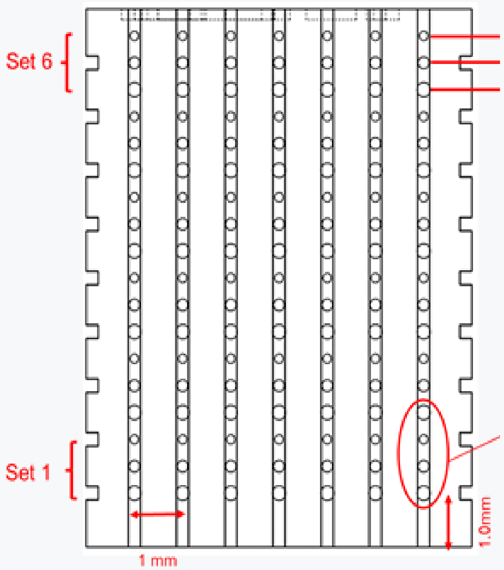


Supervised methods

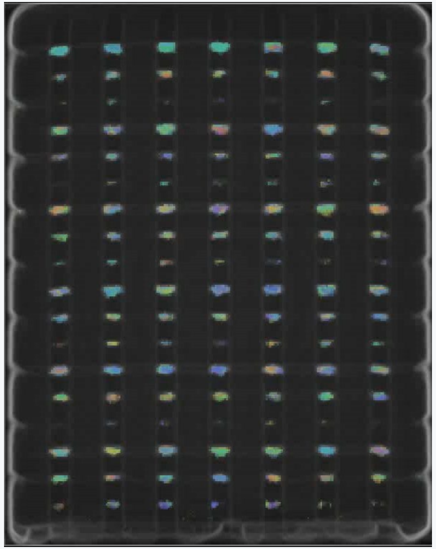


Systematic Approach: Parts with Intentional Defects

Void ranging from 100 to 350 micron

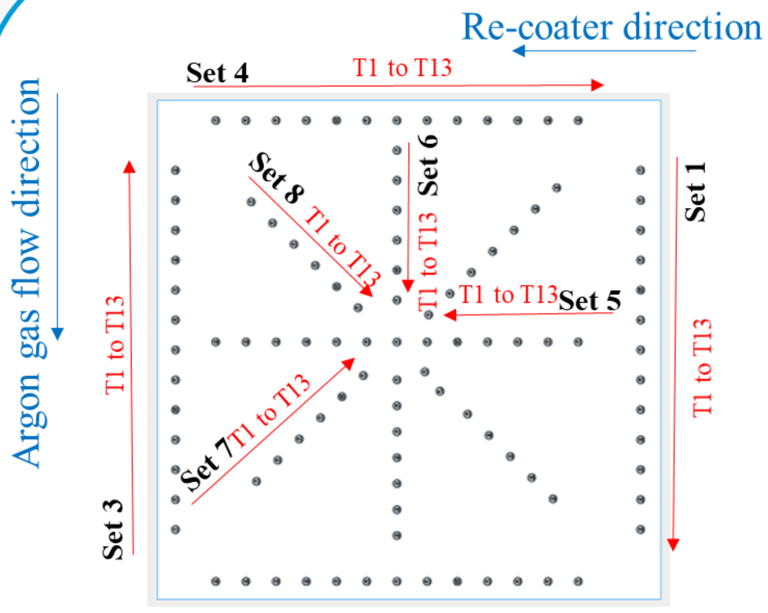


CT- Scan result



- Mimic lack of fusion by creating intentional voids embodied in the design.
- Vertical and horizontal notches were incorporated into design for data registry and matching with CT.
- A periodic change in the height of the intentional cylindrical defects was considered in some samples.
- The inclusion of spheres with different diameters was devised in some samples.

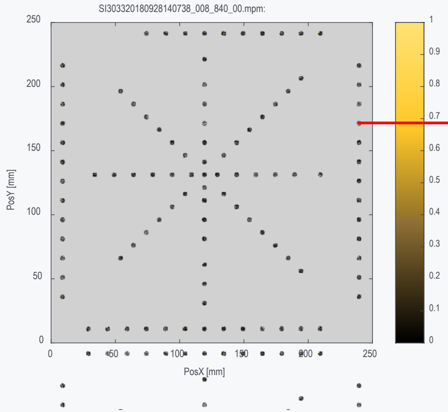
Systematic Approach: Design of Experiments



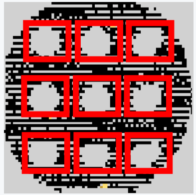
Top view of the arrangement (effect of position/ orientation on the signal)

Note: Parts are printed at different process parameters.
Material tested: HX and Ti64

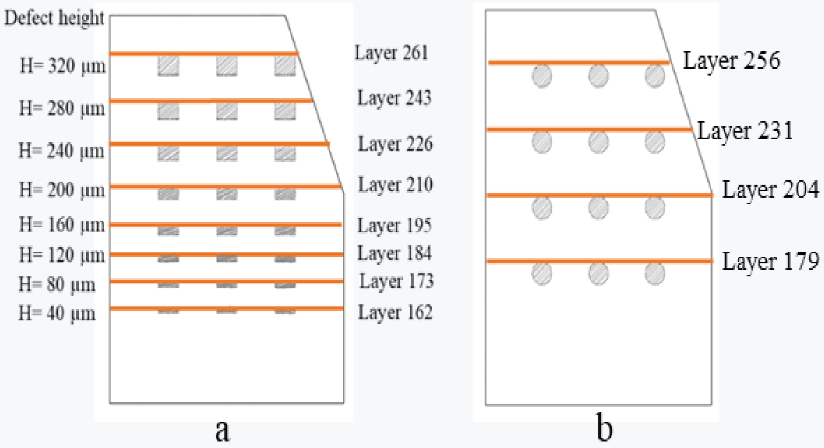
Systematic Approach: Analysis of Data Collected from Capping Layers



One layer of print

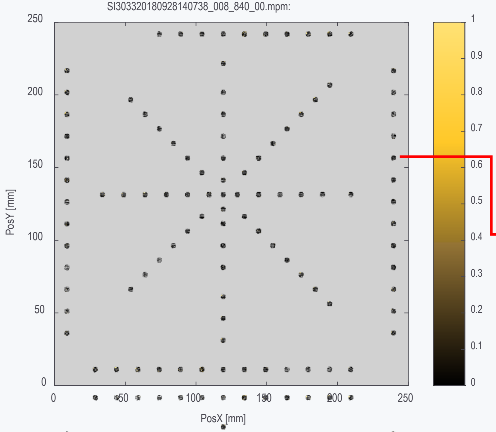


Cross section of one individual part, showing 9 intentional defects

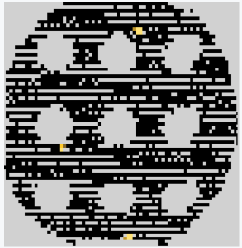


Side view
Analysis is done on capping layer

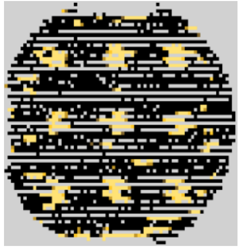
Effect of Intentional Defects on Intensity Signals



Build plate layout



Layer n



Layer n+1

Layer n+2

Layer n+3

capping layer

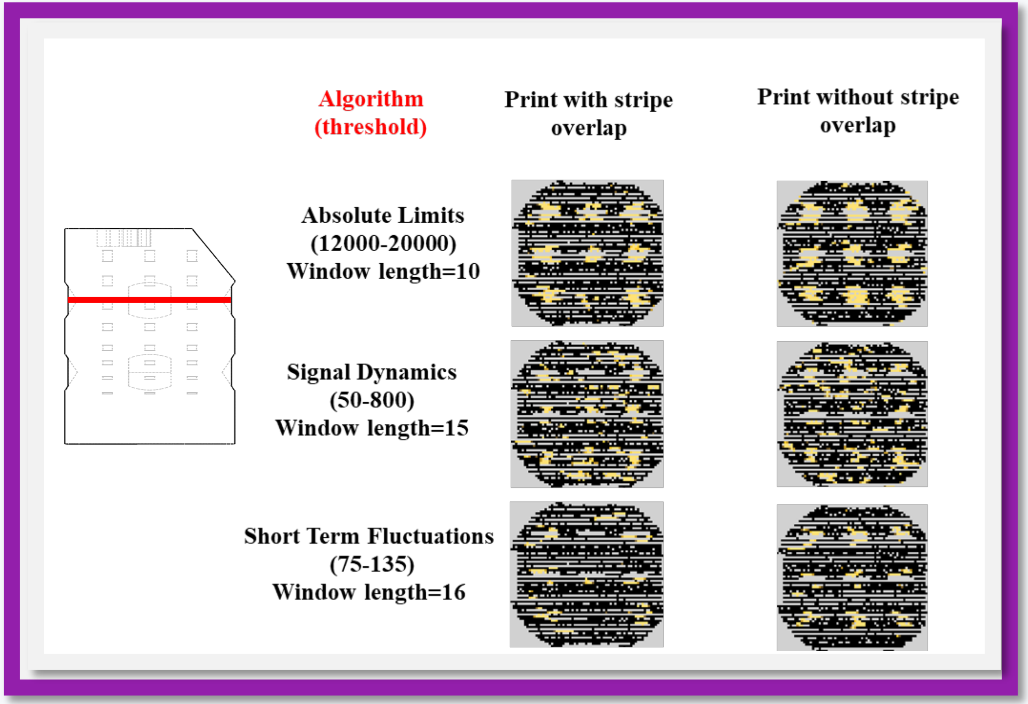
- Footprint of intentional defects is major in the capping layer, while being faded in the successive layers.

Learning Points

1- Absolute Limits (AL) (threshold 10000-22000 and window length 5-30) ✓

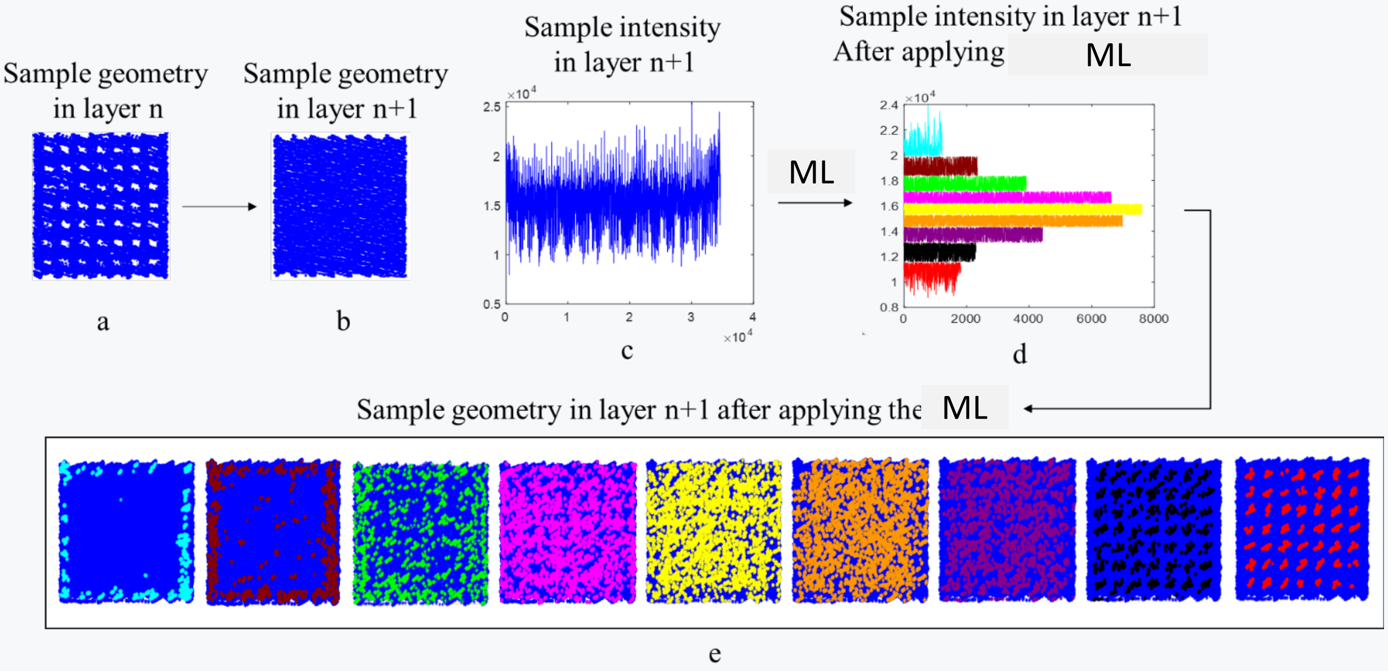
2- Signal Dynamics (SD) (threshold 20-1000, and window lengths 5-30)

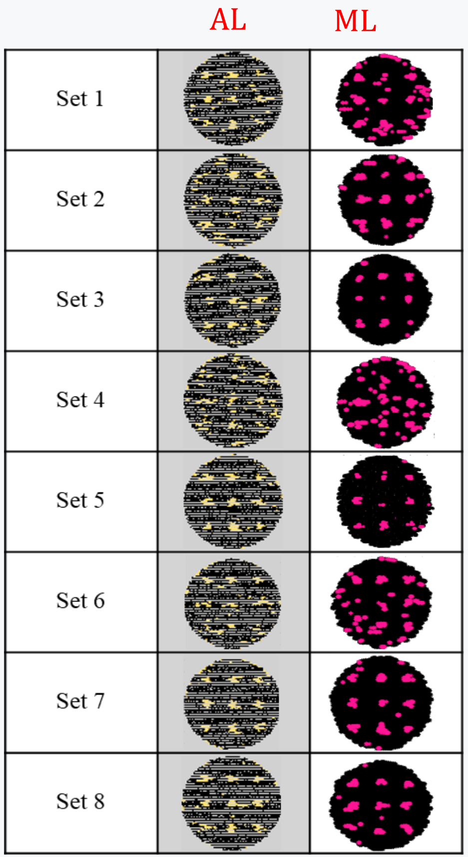
3- Short Term Fluctuations (STF) (threshold 65-140 and window length 5-20)



K. Taherkhani, E. Sheydaeian, M. Otto, C. Eischer, and E. Toyserkani, "Development of a defect-detection platform using photo-diode signals collected from the melt pool of laser powder-bed fusion", *Additive Manufacturing*, 46, 102152, 2021

Unsupervised Machine Learning for Data Classification

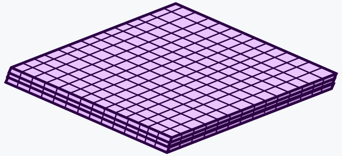


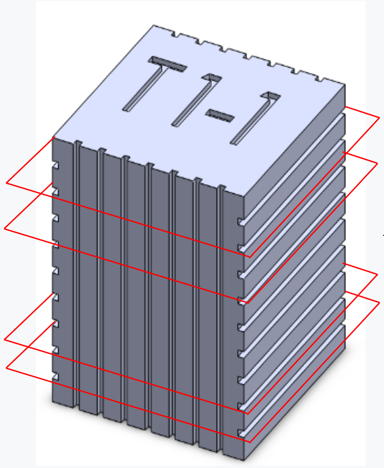


K. Taherkhani, C. Eischer, and E. Toyserkani, “An unsupervised machine learning algorithm for in-situ defect-detection in laser powder-bed fusion”, *Submitted to publication*, November 2021.

Randomized Porosity: Tailored Voxelization

Detection algorithm based on the confusion matrix concept



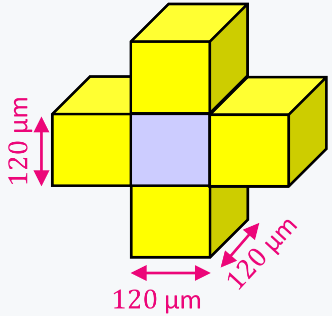


Evaluation of model based on the calculated labels

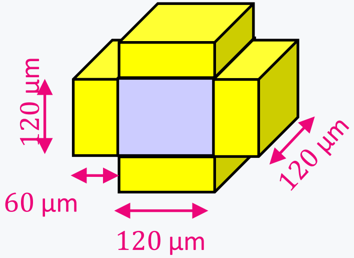
$$\textbf{Accuracy} = \frac{\textbf{TP+TN}}{\textbf{total population}}$$

TP= True positive TN=True negative

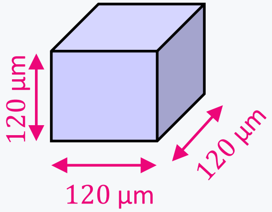
With 120µm overlap



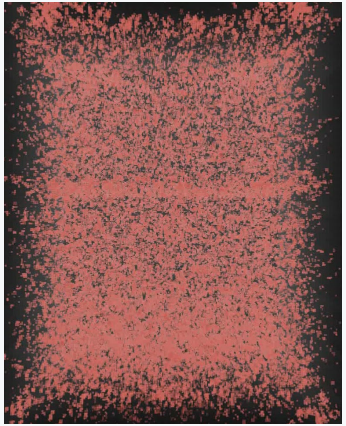
With 60µm overlap

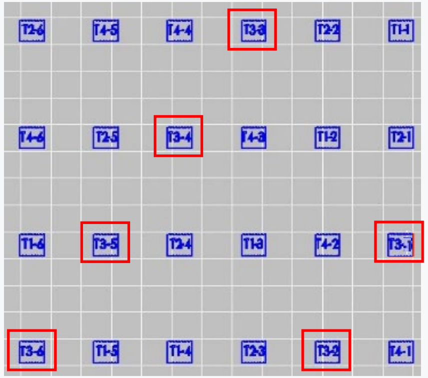


Without overlap

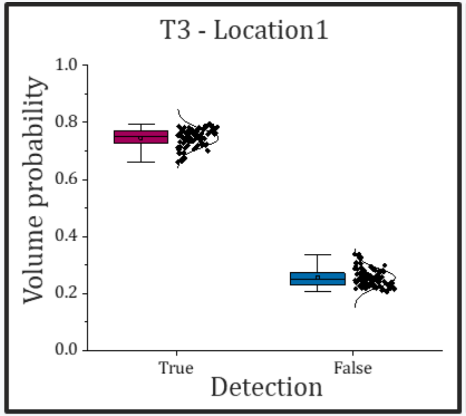


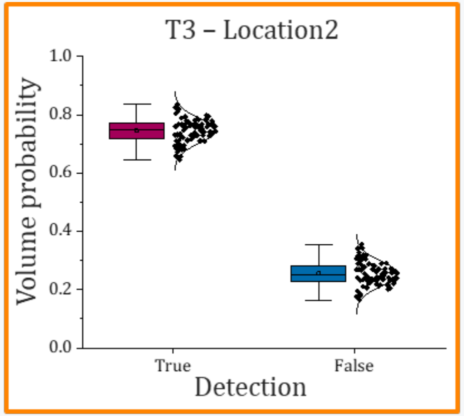
Results: MSAM Detection Algorithm vs. CT-Scan

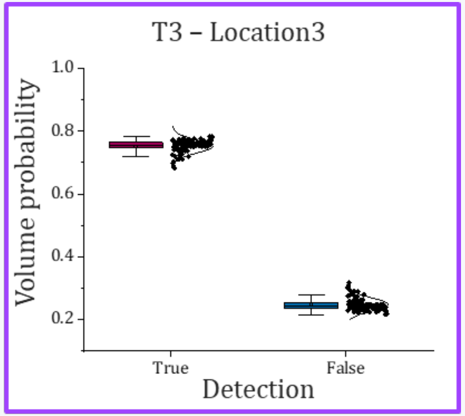


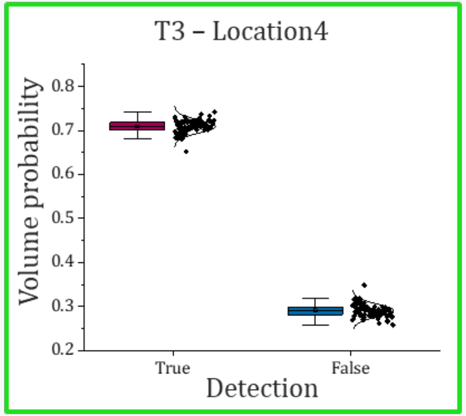


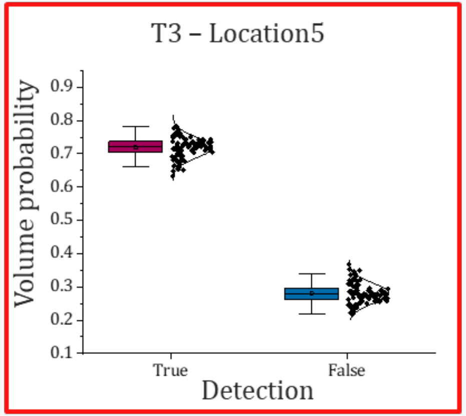
Build top view

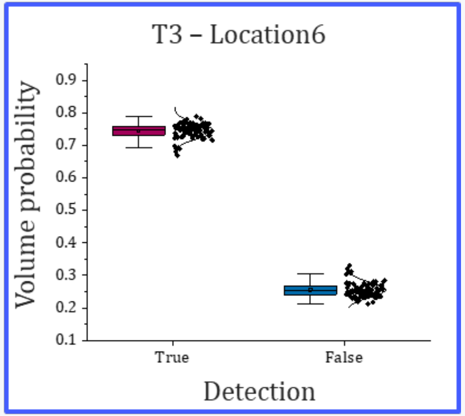










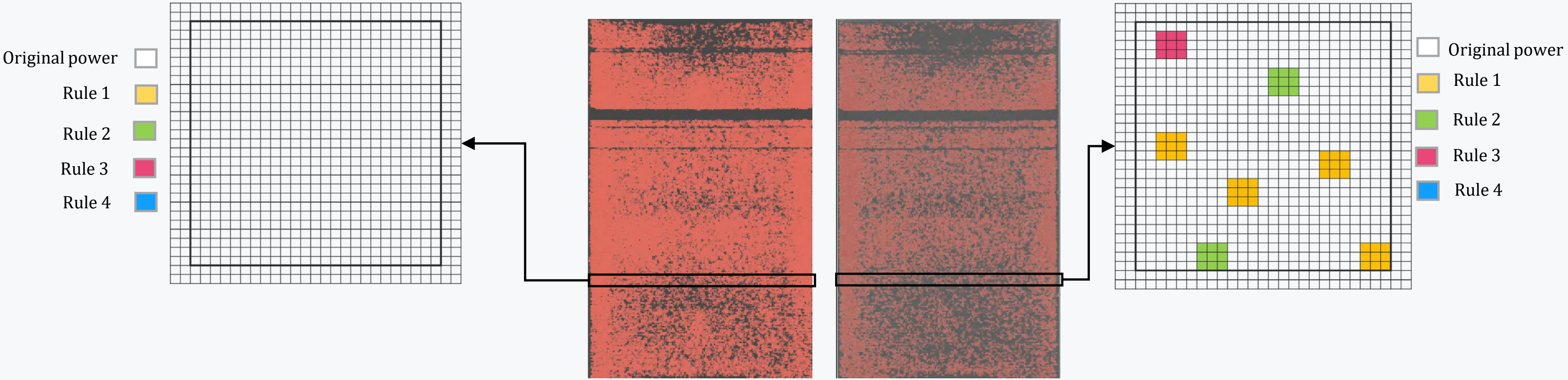


~75% prediction rate for pores larger than 120 micron

Preliminary results of intermittent controller

Pores smaller than 120 μm was filtered out from the CT-Scan results

Without controller | **With controller**



Density= 97.96 | Density= 98.90

Conclusions and Outlook

1. The threshold levels and sampling windows obtained through the systemic approach, applied to printed parts with intentional pores, facilitate a model-based detection platform to identify randomized pores.
2. The successful detection is limited to pores larger than 120 micron.
3. Level of confidence in the detection is more than 75%.
4. With new technical development and improving the hardware resolution and frequency, the detection of finer pores is on horizon.
5. A work item (ASTM WK76983) has recently been registered in ASTM to craft a best practice under “In-situ Defect Detection and Analysis” and collect feedback from peers on the developed approach.

Acknowledgement

Thank you for your attention