POLITECNICO MILANO 1863 | DIPARTIMENTO DI MECCANICA

IC LABS

QDA project 2025

In-situ monitoring of LPBF with dual pyrometry

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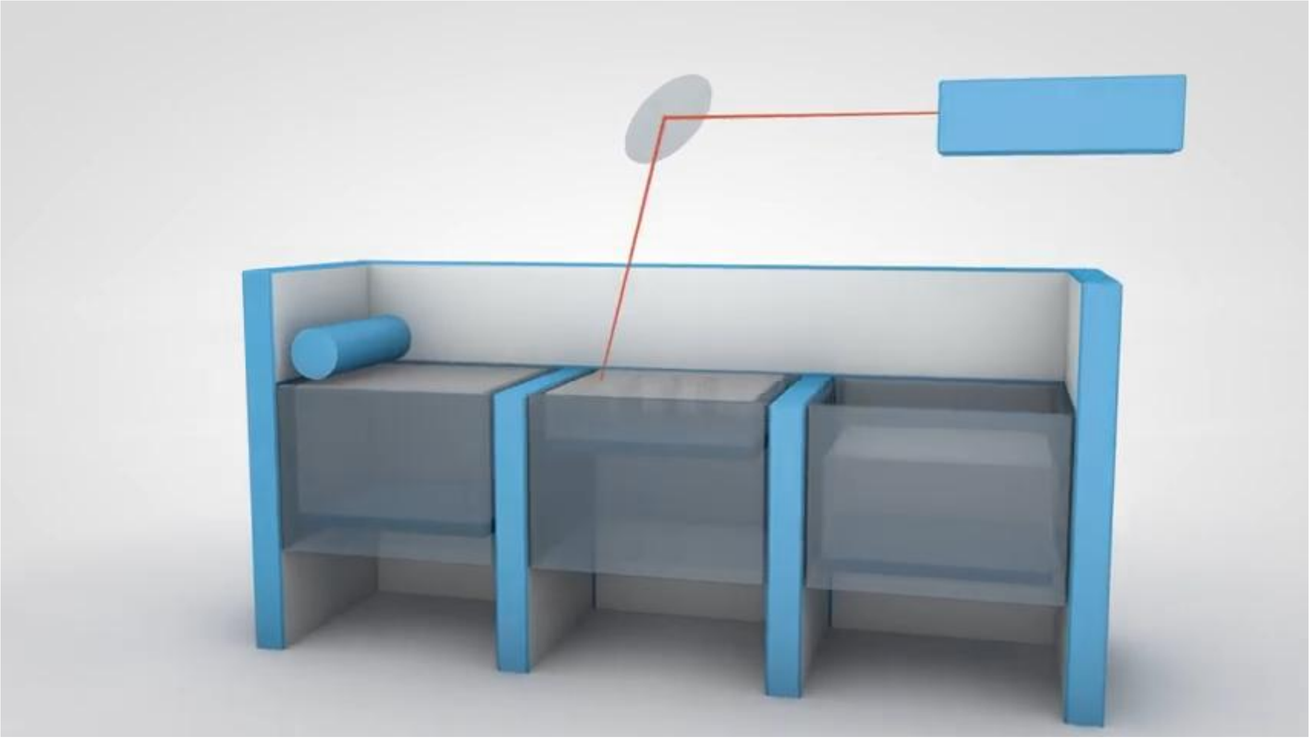
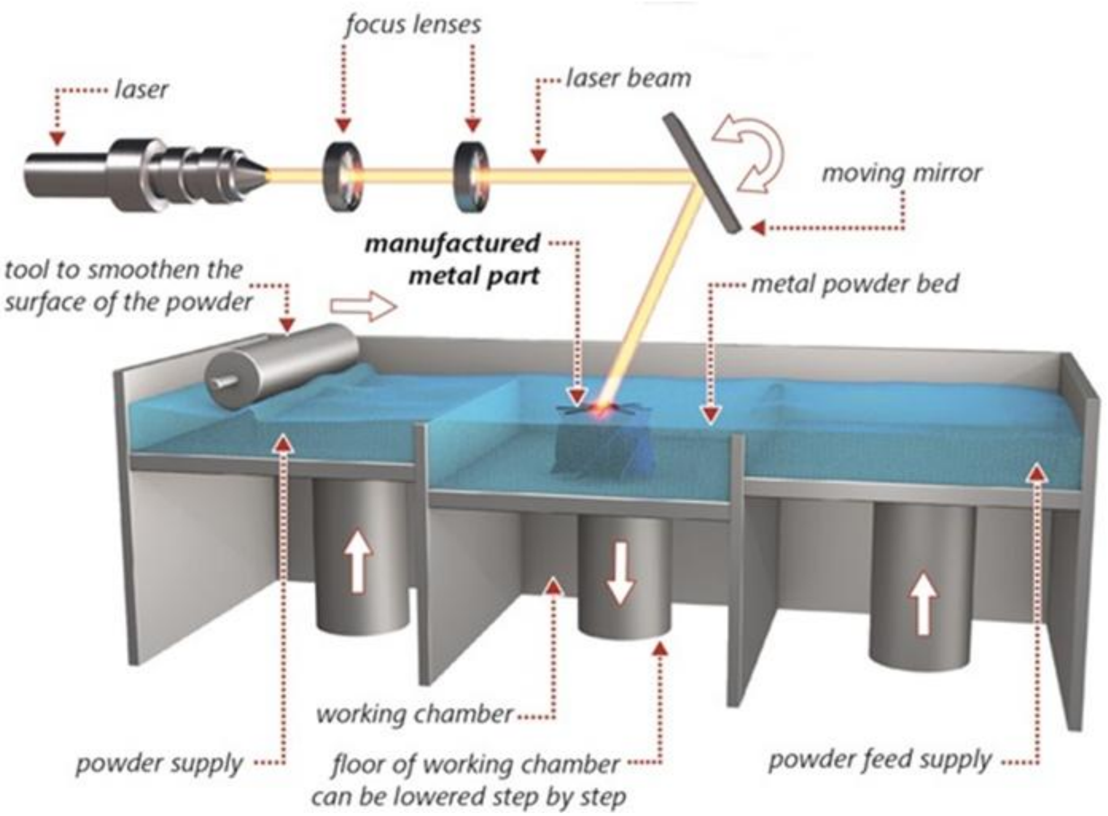
Process monitoring for Laser Powder Bed Fusion

1

Laser Powder Bed Fusion process



https://www.youtube.com/watch?v=ruvRijM7f50



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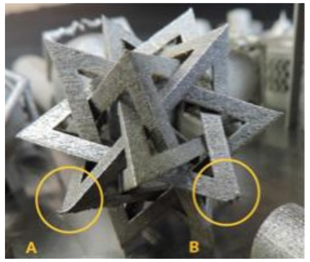
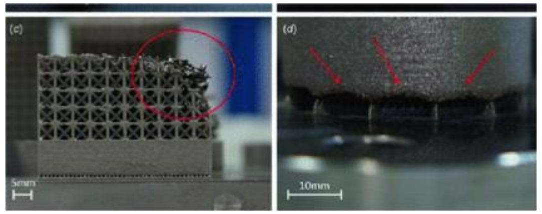
Defects in AM

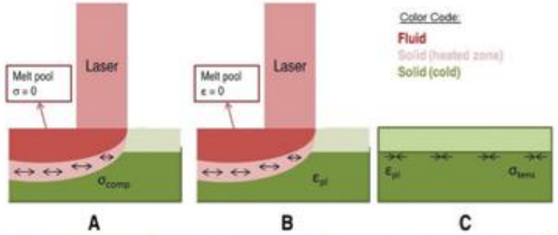


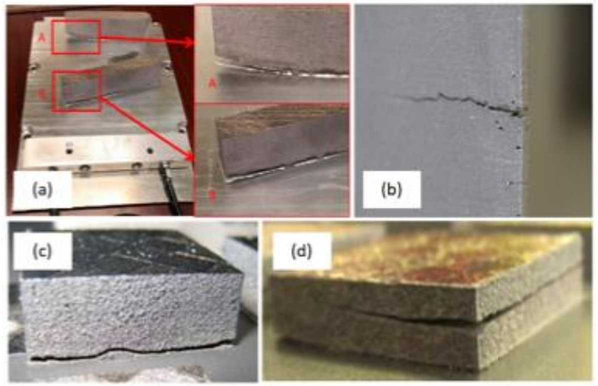


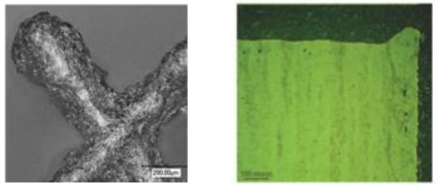
Incomplete jobs or bending

Macro-geometry

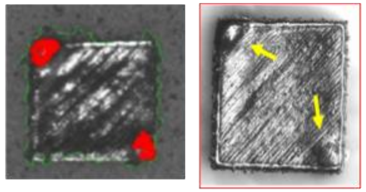
Residual stress, cracking delamination





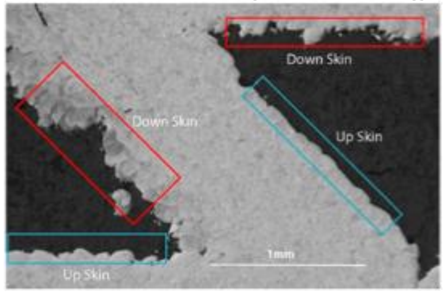


Acute corners

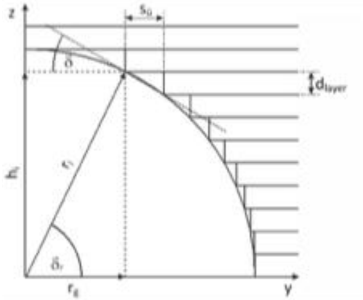


Super-elevated edge

Micro-geometry

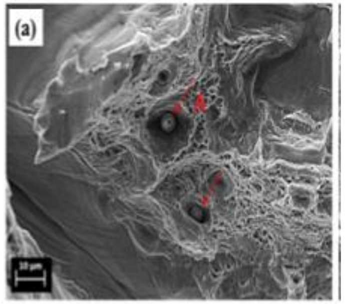


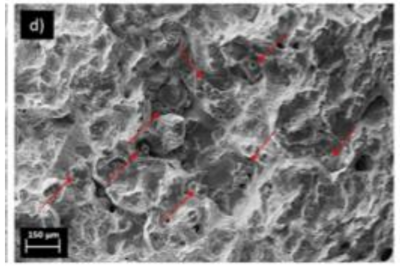
Dross formation



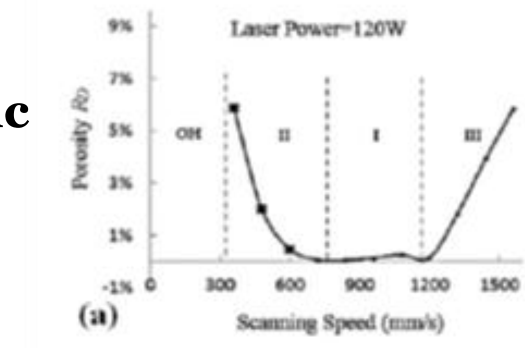
Staircase effect

Microstructural defects and inclusions

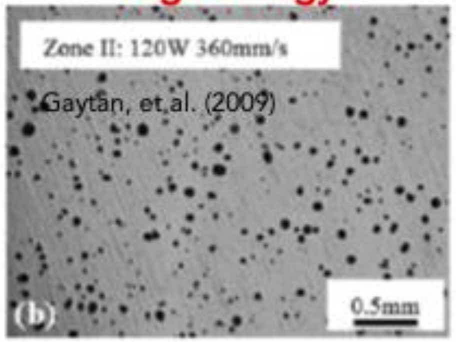




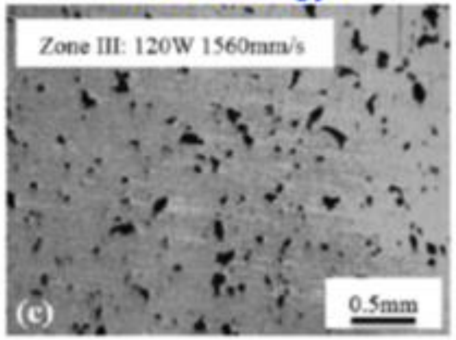
Volumetric errors



High energy



Low energy



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«The limited stability and repeatability of the process still represent a major barrier for the industrial breakthrough of metal AM systems»

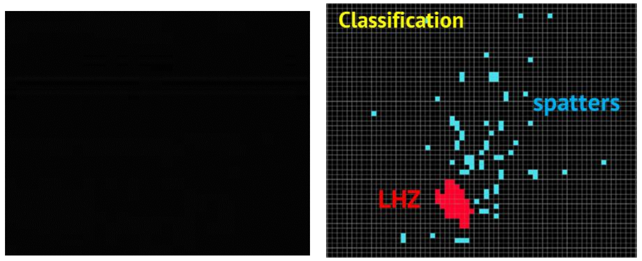
In-situ monitoring in LPBF: the current landscape

Video imaging

Hot- cold-spot
(geometrical and microstructure)

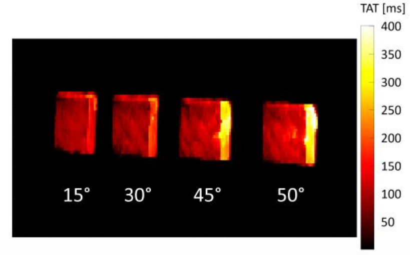
Grasso et al. 2020; Bugatti and Colosimo 2022, Yao et al. 2022

Spattering
(porosity)

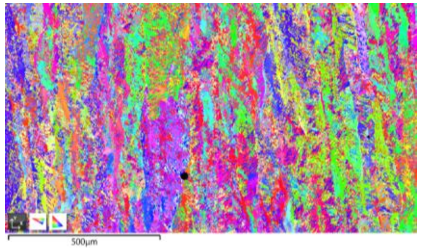


Repossini et al. 2017; Colosimo et al. 2024

Thermal imaging
(for roughness and microstructure)

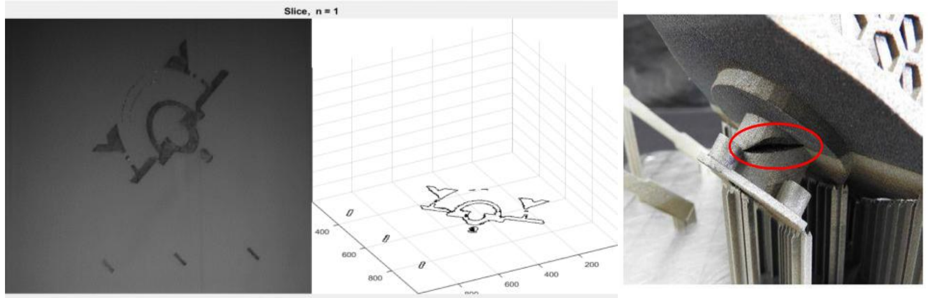


Bugatti and Colosimo 2024

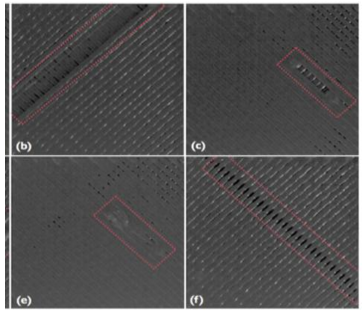


with GA Tech

Imaging



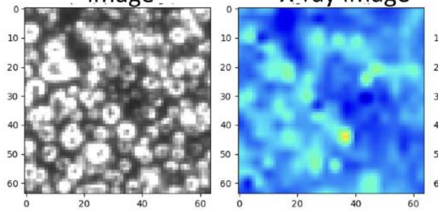
Pagani et al, 2020



Caltanissetta et al. 2023

Input: optical image

Ground truth: X-ray image



Packing density prediction (with MIT)

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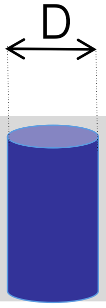
“In a sense, AM has become a manufacturing domain that is **data-rich** but **knowledge-sparse**” https://doi.org/10.1115/DETC2019-98415

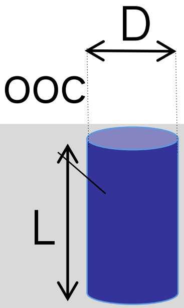
In-situ monitoring in LPBF: the current landscape

PRODUCT DATA



$X = D \in \mathbb{R}$

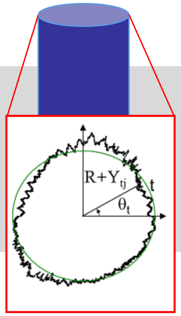
univariate



$\mathbf{X} = [D, L, OOC, \ldots]'$

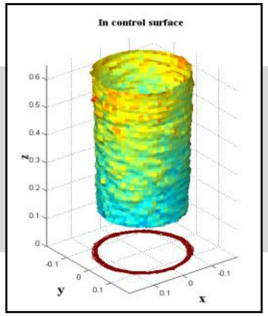
$\mathbf{X} \in \mathbb{R}^p$

multivariate



$X = f(\theta) + \varepsilon$

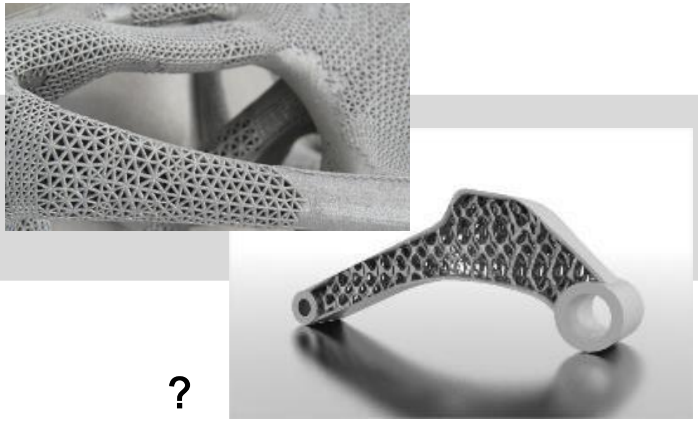
Profiles/
functional data



$X = f(\theta, z) + \varepsilon$

Surfaces

?
Manifold



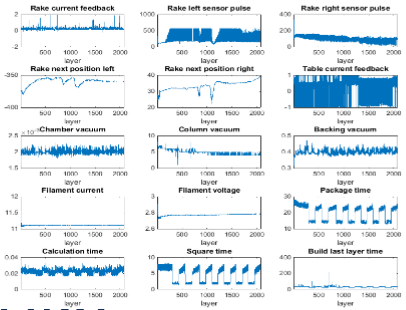
?
Lattice

CHALLENGES

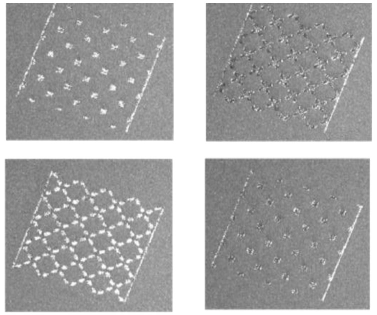
OPPORTUNITY

PROCESS DATA

signals



Image

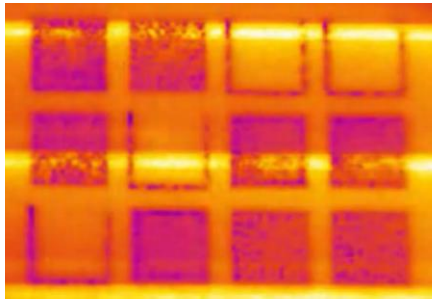


5 - 10 Gbyte

High-speed videos

5 – 10 Tbyte

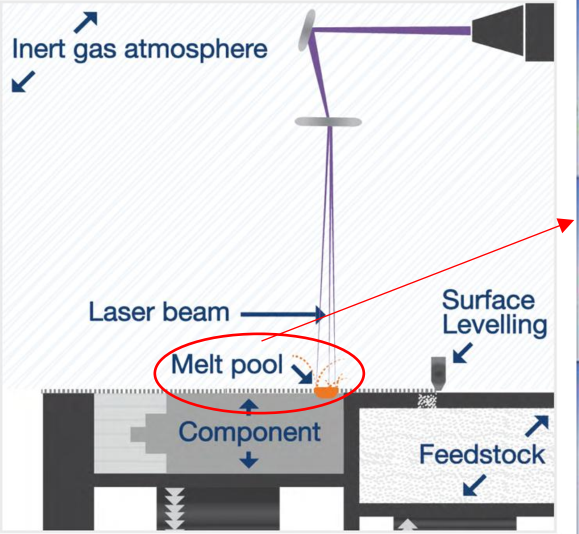
IR videos

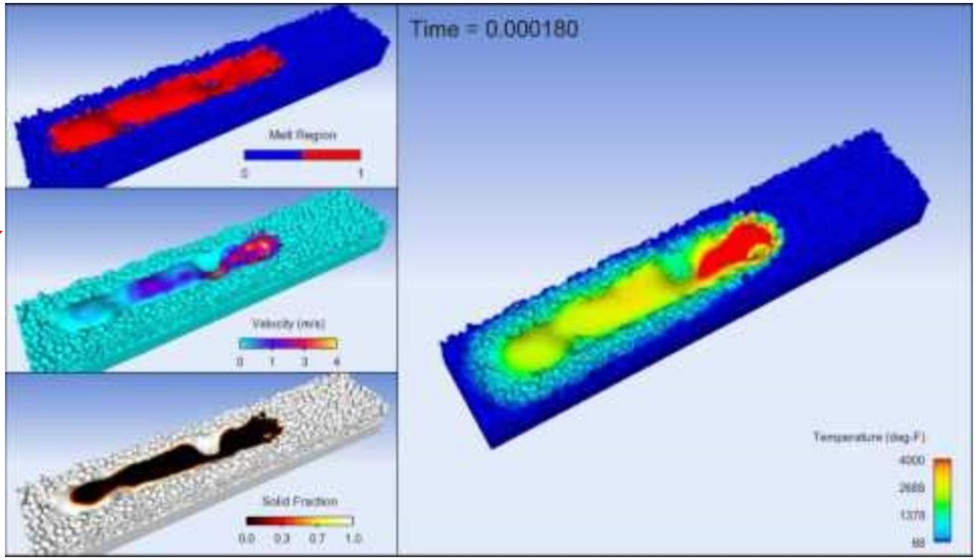


50 – 100 Tbyte

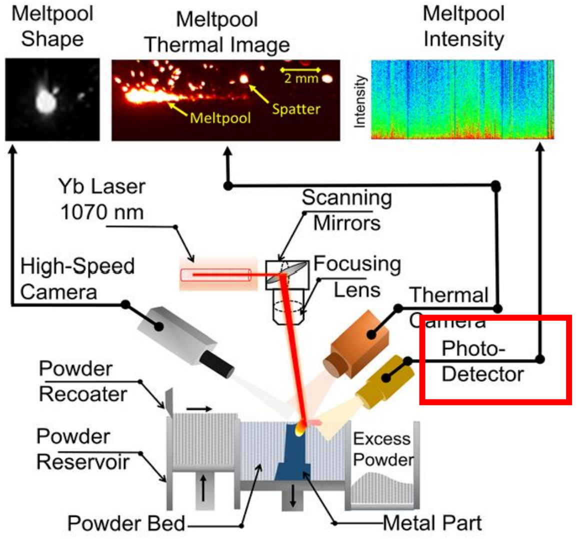
Temperature monitoring in Laser Powder Bed Fusion

The quality of the LPBF printed parts depends on the stability of the melt pool that is generated during melting.





Monitoring the melt pool



https://doi.org/10.1115/1.4040264

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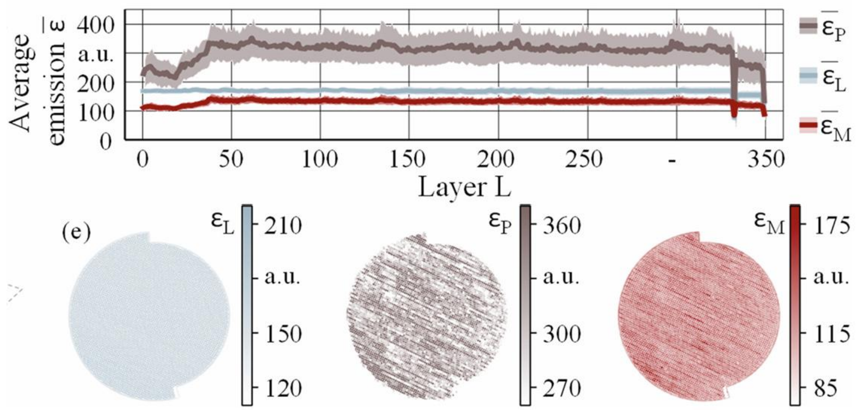
Pyrometer for temperature monitoring in LPBF

Dual-wavelenght pyrometer:

A non-contact temperature sensor that measures emitted radiation at two wavelengths to calculate temperature.

Output of the pyrometer data

By combining the emitted radiation of the two photodiodes, an estimate of the temperature can be calculated (see appendix slides). The output is a real-time temperature signal of the melt pool.



https://doi.org/10.1007/978-3-031-77429-4_ 83

How is it used in LPBF monitoring?

- **Process Quality Control**: Identifies defects like porosity or overheating.
- **Real-Time Process Adjustment**: Enables closed-loop control of laser power and scan speed.

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Project description

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The equipment

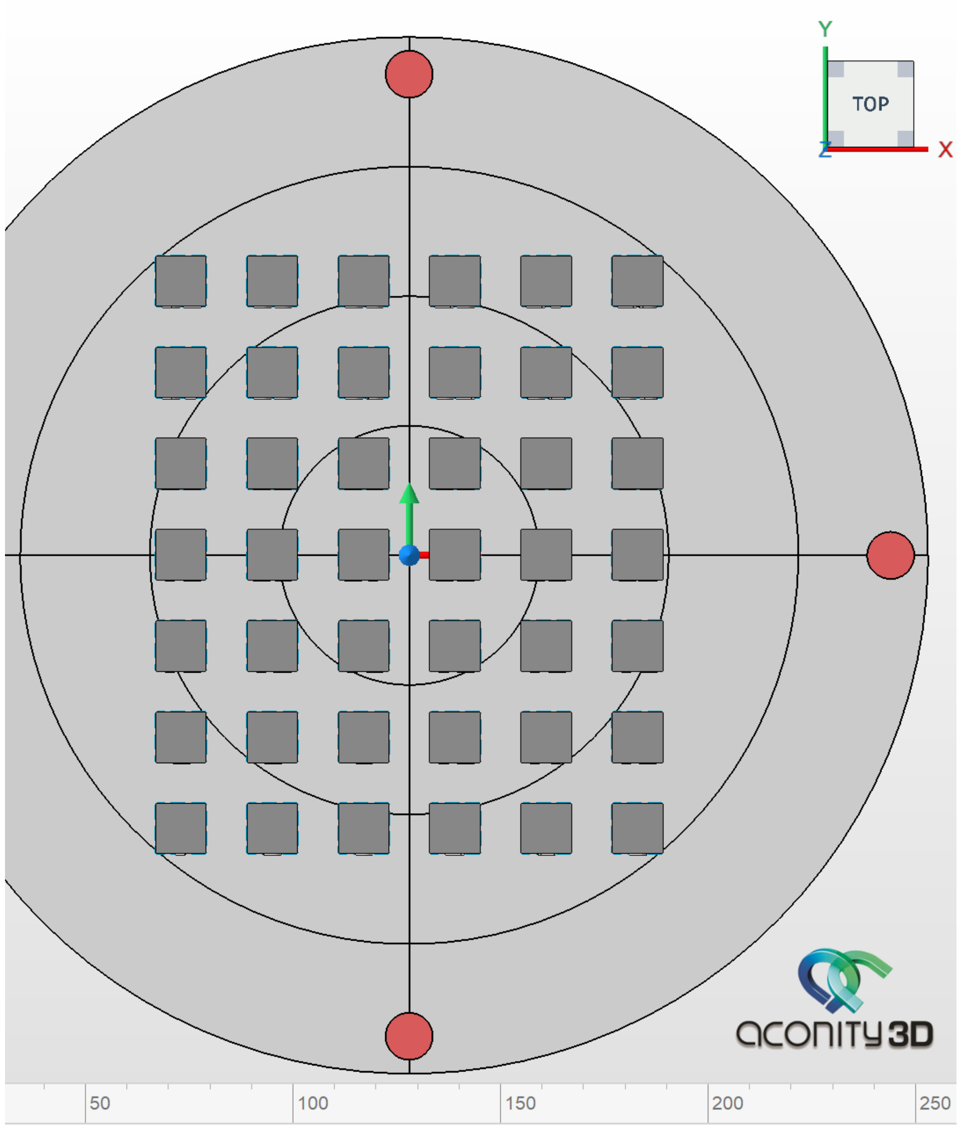
- LPBF system: Aconity MIDI+
- Monitoring: On-axis dual pyrometer

On-Axis Dual Pyrometer specifications	
Optical arrangement	Coaxial monitoring
Sensor type	2 x fiber coupled pyrometers
Spectral range	Pyrometer 1: 1,45 - 1,7 µm Pyrometer 2: 2,00 - 2,2 µm
Measuring range	500 - 2500 °C
Measurement area	ca. Ø 400 µm, lateral adjustable (may vary depending on machine configuration)
Frame rate	100 kHz

Aconity MIDI+ with dual pyrometer

Experimental plan

- 42 cubic samples (12x12x50mm)
- Same power and scan speed
- The pyrometer records the data over 5 consecutive layers every 100 layers.



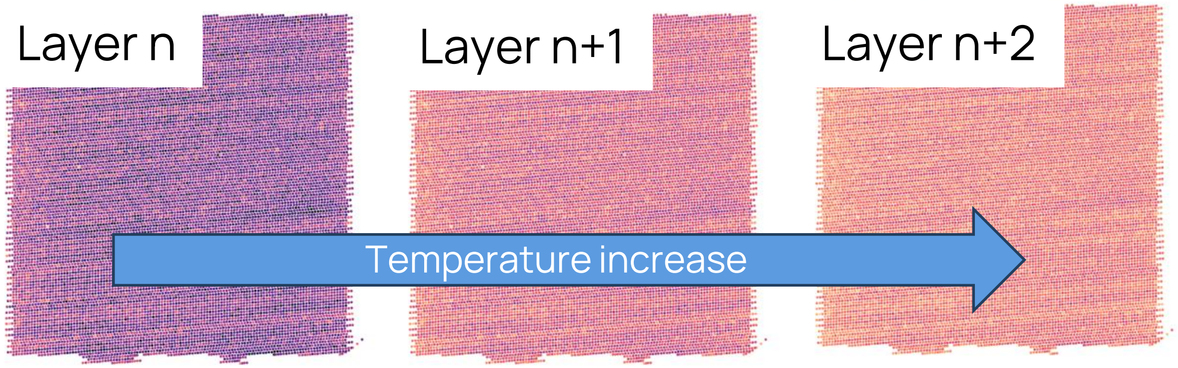
Build platform

Examples of defects

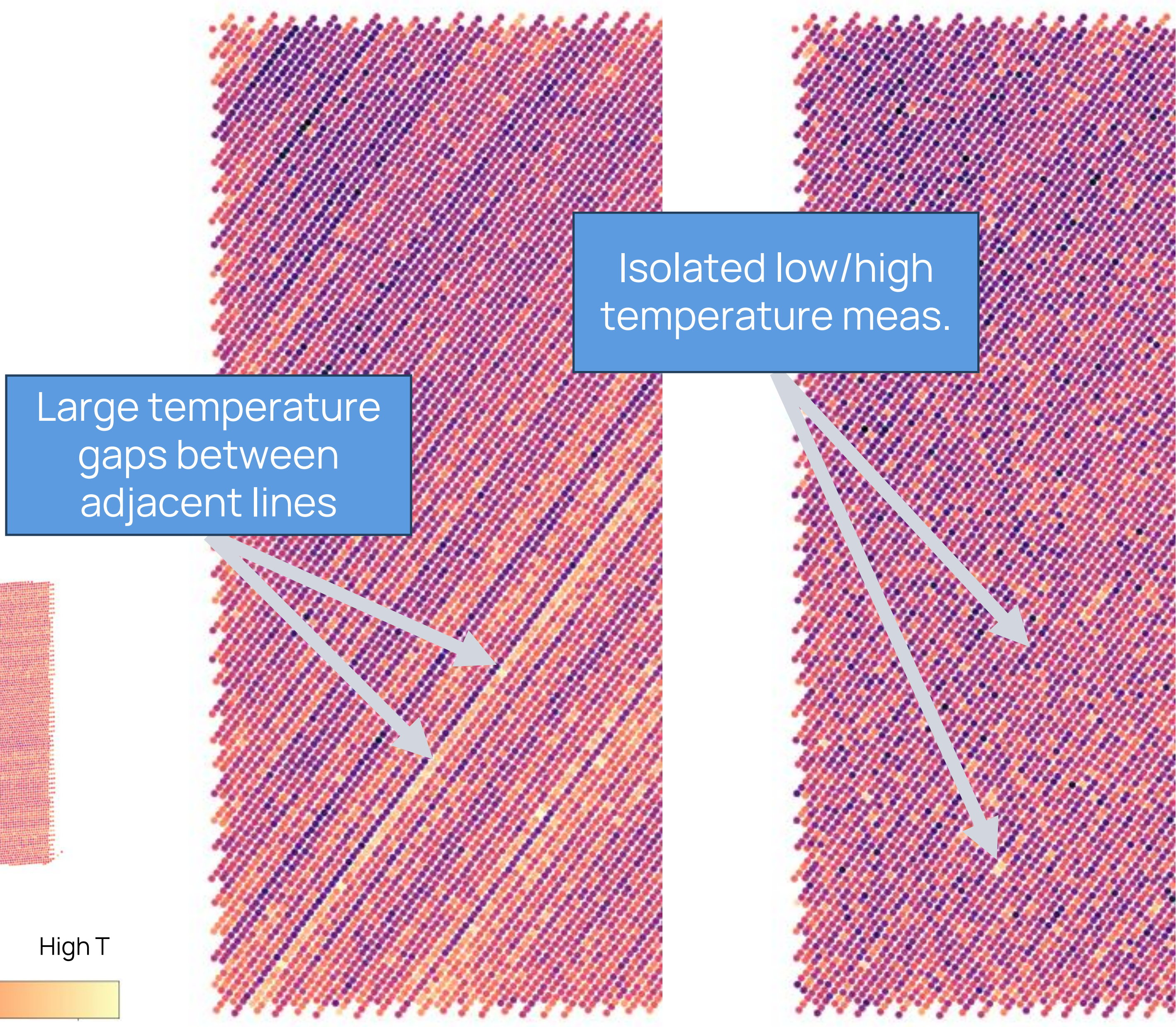
Defects include:

- Under/overheating
- Melt pool instability

Which can occur at layer level or track level.



Layer-level analysis



Track-level analysis

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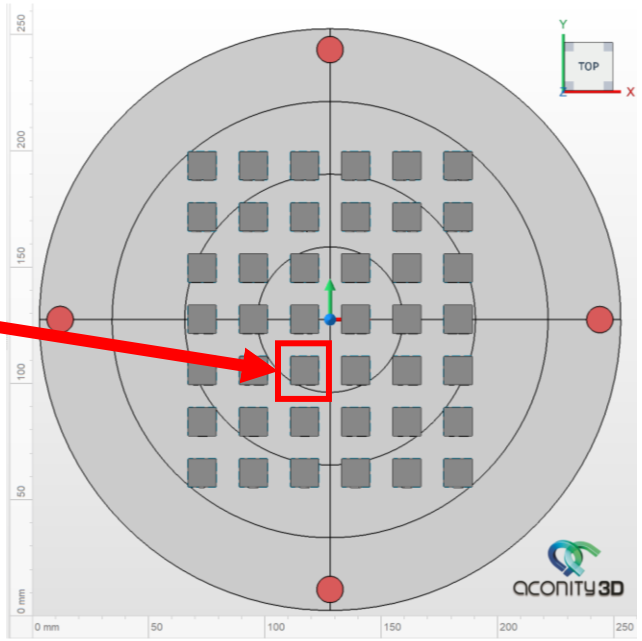
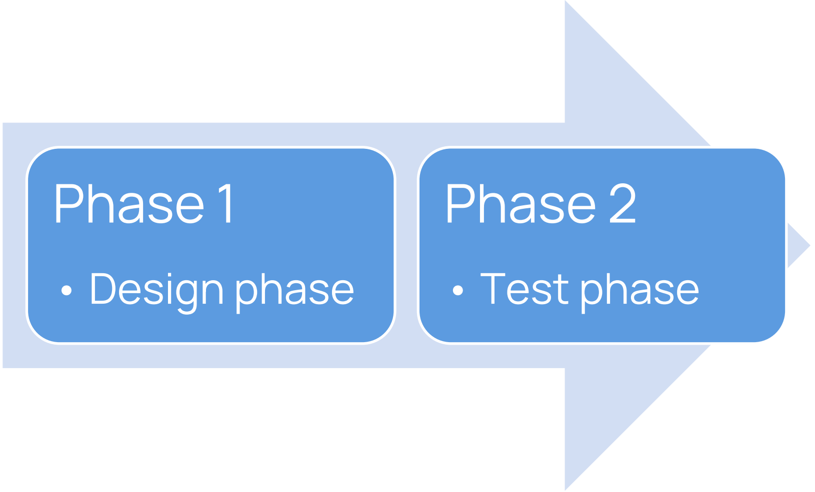
Aim of the work: Design one or more control charts to monitor if the printing process is stable.

The project

You will be given a dataset containing the measurements for one individual sample.

- **PHASE 1 (31st of March – 18th of May)**
    - You will be given a set of files (one for each layer) containing the data collected when printing the first half of the sample.
    - Analyze / model the data.
    - Check assumptions, and design appropriate control chart(s) to monitor the process.
- **PHASE 2 (18th of May – 31st of May)**
    - You will be given a new set of data containing the measurements of the second half of the same sample analyzed in Phase 1.
    - Test the control charts designed in phase 1 on the new dataset.



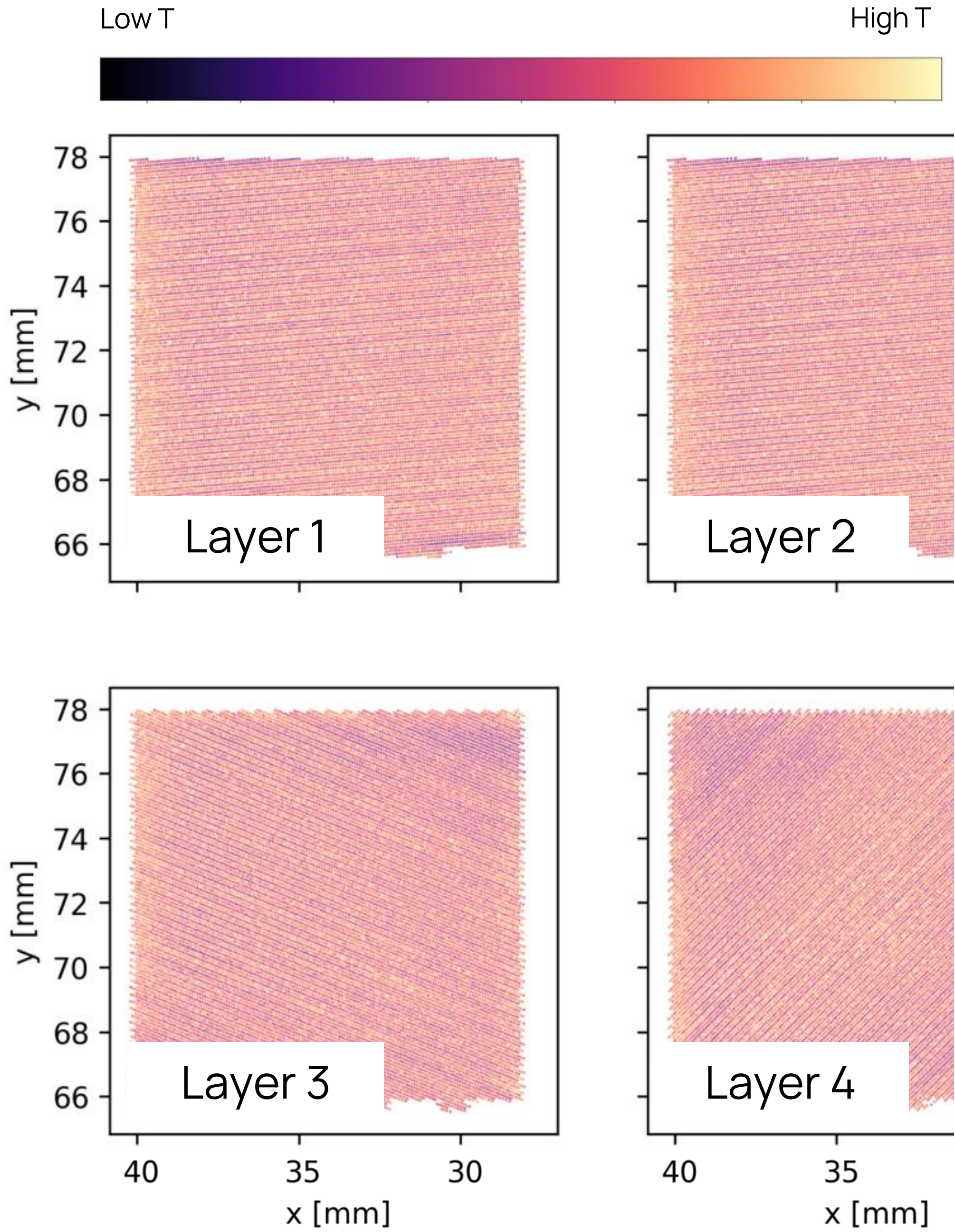


Project phases

The dataset

Each CSV file you will be given contains the following columns.

Column name	Description
t	Absolute time reading (in µs)
x	x coordinate of the measurement (in mm)
y	y coordinate of the measurement (in mm)
z	z coordinate of the measurement (layer height, in mm)
layer_id	Layer number
sensor0	Intensity meas. from pyrometer in the 1450-1700 nm range
sensor1	Intensity meas. from pyrometer in the 2000-2200 nm range
temp	Temperature computed from the intensity meas. (in K)
track_id	ID of each individual track (from 0 to the # of tracks)
track_orient	Orientation of the scan track (0-360°, with respect to the x axis)
pos_rel	Relative position of the meas. with respect to the start of the track (in mm)
t_rel	Relative time of the meas. with respect to the start of the track (in µs)



Example of point cloud data from multiple layers.

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Team registration

Click on this link to open the excel file. Each group must sign up with the names of the members, Polimi person code and email address.

- Create your team with up to 4 people per team (4 people recommended).
- In case your team is incomplete (less than 4 members), you can still register a team. We encourage students who don't have a team yet to contact other incomplete teams to join.
- If you can't find a team, register a 1-member team using the form and we will help you join a team.
- Teams that have less than 4 members, may be assigned additional team members.

QDA project registration

Team ID	Member	Full name	Polimi person code	Email	Note
Example	1	Name Surname	19999991	name1.surname@mail.polimi.it	
Example	2	Name Surname	19999992	name2.surname@mail.polimi.it	
Example	3	Name Surname	19999993	name3.surname@mail.polimi.it	
Example	4	Name Surname	19999994	name4.surname@mail.polimi.it	
1	1				
1	2				
1	3				
1	4				
2	1				
2	2				

Deadline for team registration: 30th March 11:59PM

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Thank you for the attention

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Appendix 1

Dual pyrometer

Each pyrometer captures the **intensity of the radiation from the melt pool** (I_1, I_2)and its surrounding area (approx. Ø 400 µm) at high acquisition rate (100 kHz).

Assuming that the emissivity of the radiator is constant for the two wavelengths ($\varepsilon_1 = \varepsilon_2$), the temperature T can be determined from the ratio of the two intensities measured at different wavelengths.

$$I_1 = \frac{\varepsilon_1 K_1}{\lambda_1{}^5 e^{\frac{h\,c_0}{k\,\lambda_1 T}}} \qquad I_2 = \frac{\varepsilon_2 K_2}{\lambda_2{}^5 e^{\frac{h\,c_0}{k\,\lambda_2 T}}}$$

$$\frac{I_1}{I_2} = \frac{\varepsilon_1 K_1 \lambda_2{}^5\ e^{\frac{h\,c_0}{k\,\lambda_2 T}}}{\varepsilon_2 K_2 \lambda_1{}^5\ e^{\frac{h\,c_0}{k\,\lambda_1 T}}}$$

$$\Rightarrow T = \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) \frac{h\,c_0}{k\ \ln\left(\frac{I_1 \lambda_1{}^5}{I_2 \lambda_2{}^5}\ \frac{K_2}{K_1}\right)}$$

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