Generative AI and transfer learning methods for zero-defect additive manufacturing and bioprinting

Marco Grasso, Matteo Bugatti, Bianca Maria Colosimo

Department of Mechanical Engineering

Politecnico di Milano

marcoluigi.grasso@polimi.it, biancamaria.colosimo@polimi.it

POLITECNICO
MILANO 1863

Politecnico di Milano (since 1863)
Largest technical university in Italy (47000 students)

QS Manufacturing and Mech Eng (2024)
- 1st in Italy
- 4th in Europe
- **9th worldwide**

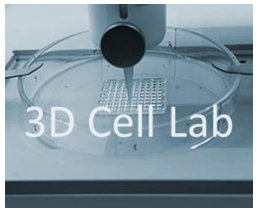
QS Engineering & Technology (2024)
- 1st in Italy
- 8th in Europe
- **23rd worldwide**

Bianca Maria Colosimo's research group
2 Associate Prof., 4 Assistant Prof., 10 PhD candidates, 20 MSc students

Our Team

IC LABS
www.ic.polimi.it

AddMe.Lab



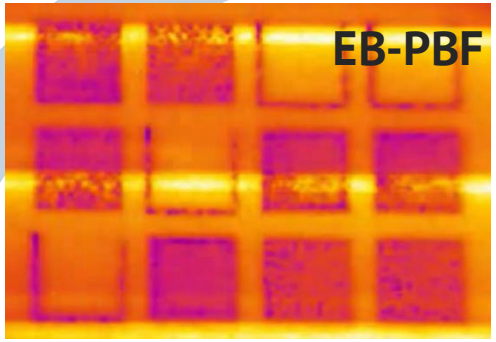
Our Mission

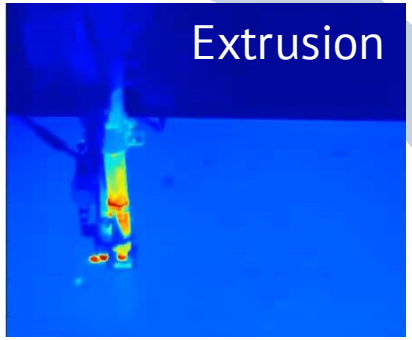
Big data mining & machine learning for advanced manufacturing process monitoring, modelling and control towards zero-defect and sustainable production

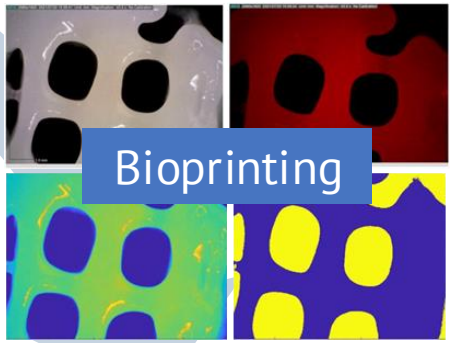
AIM-NET

Our research

IN-SITU MONITORING

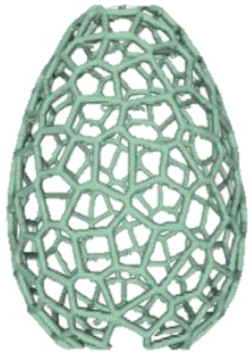


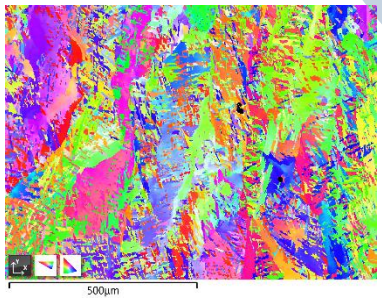


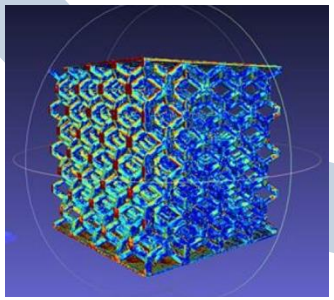


Towards zero-defect in AM

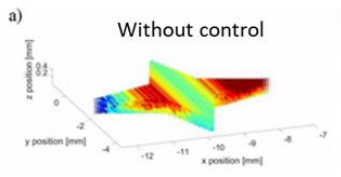
QUALITY MODELLING

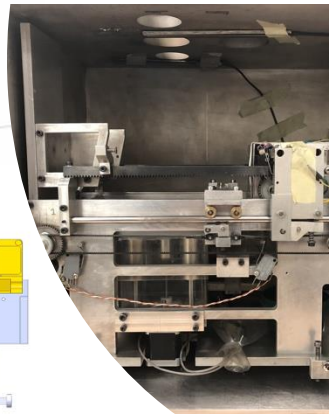






CONTROL AND DEFECT CORRECTION





The intelligent AM machine

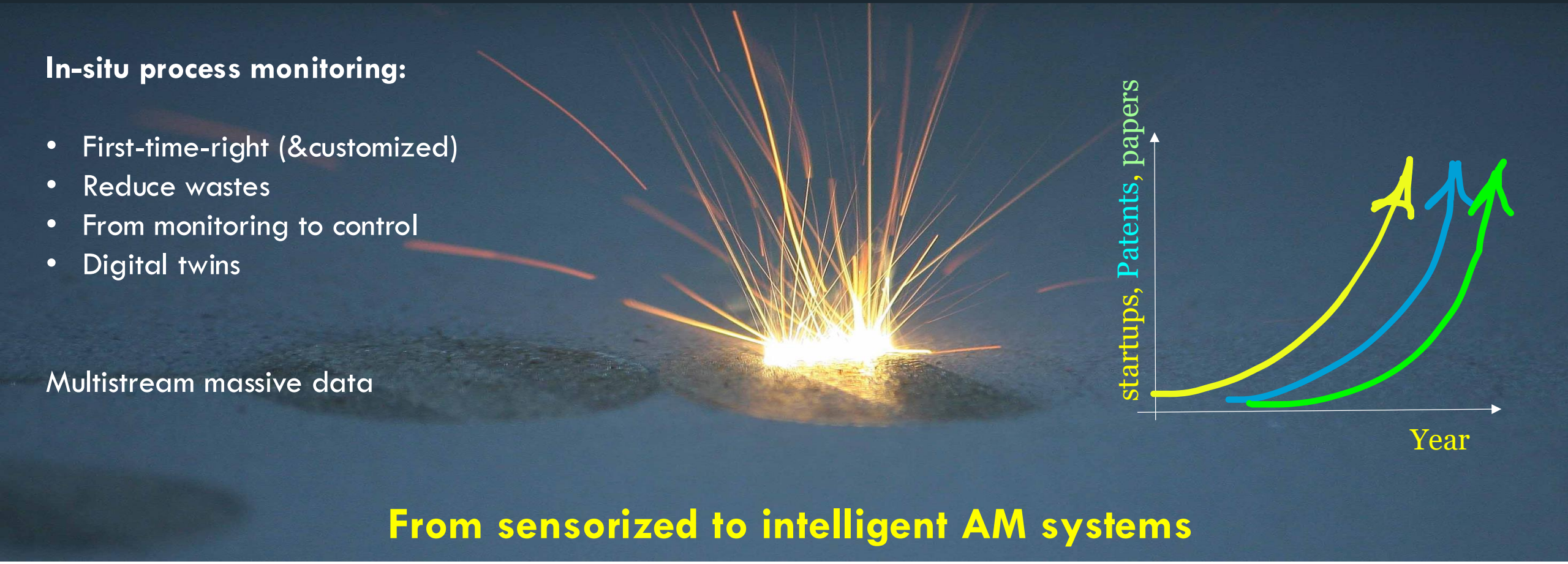
“More 3D printers will have eyes (sensing) and brains (machine learning)”

(Additive Manufacturing trends in 2022)*

In-situ process monitoring:

- First-time-right (&customized)
- Reduce wastes
- From monitoring to control
- Digital twins

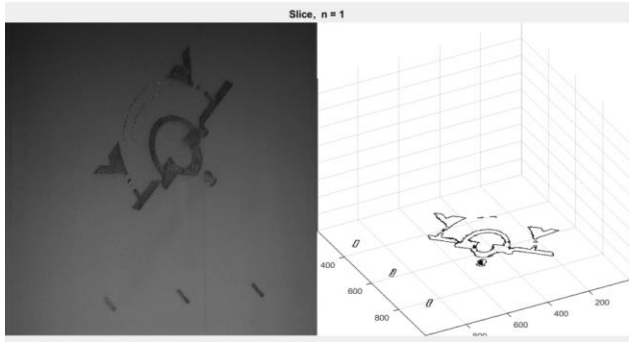
Multistream massive data



From sensorized to intelligent AM systems

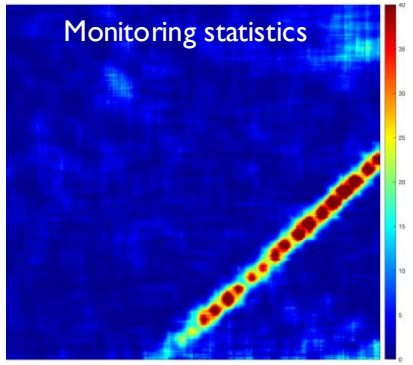
AI for the Intelligent AM machine

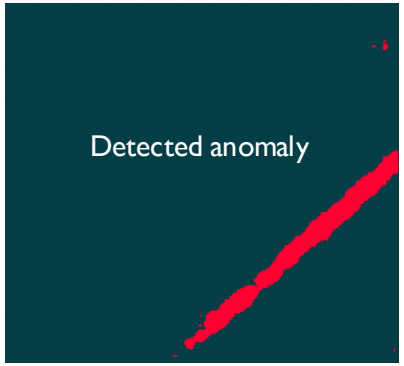
In-line geometry reconstruction (layerwise imaging)



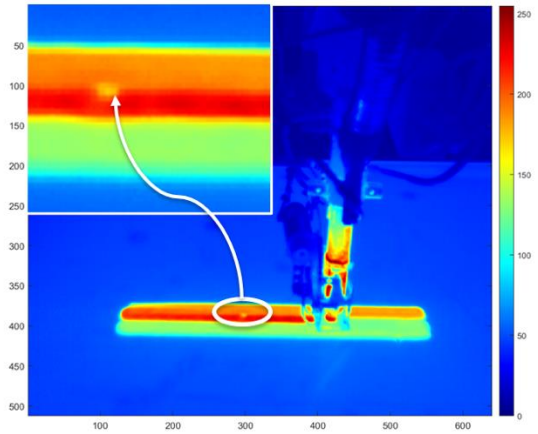
Pagani et al. 2020

Deviation between in-situ and nominal geometry

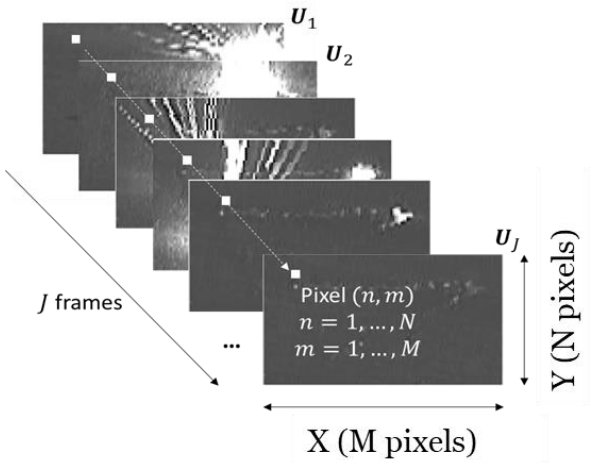


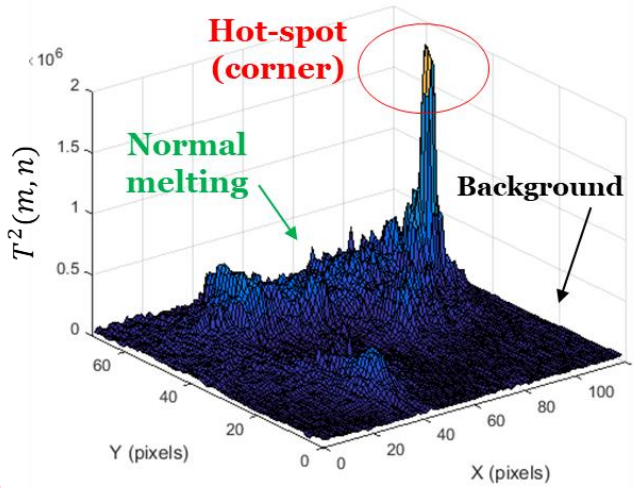


Caltanissetta et al. 2024

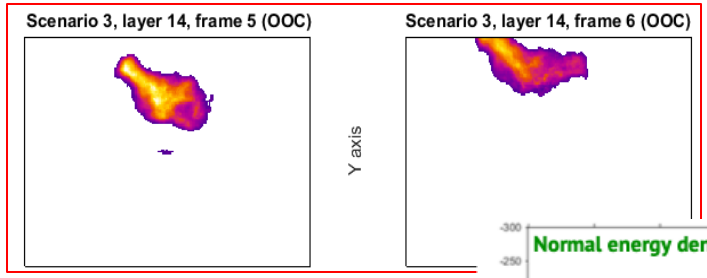


Colosimo et al. 2023

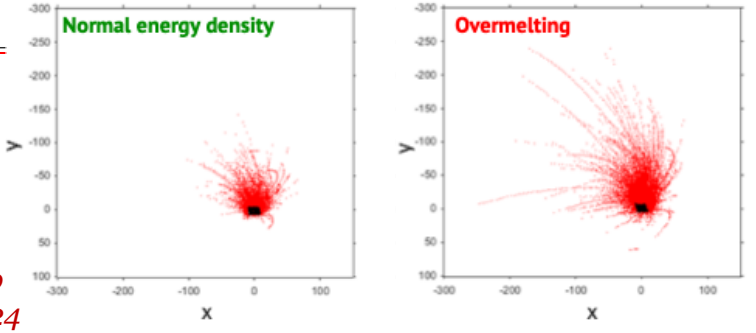




Colosimo & Grasso, 2018, Bugatti and Colosimo, 2022

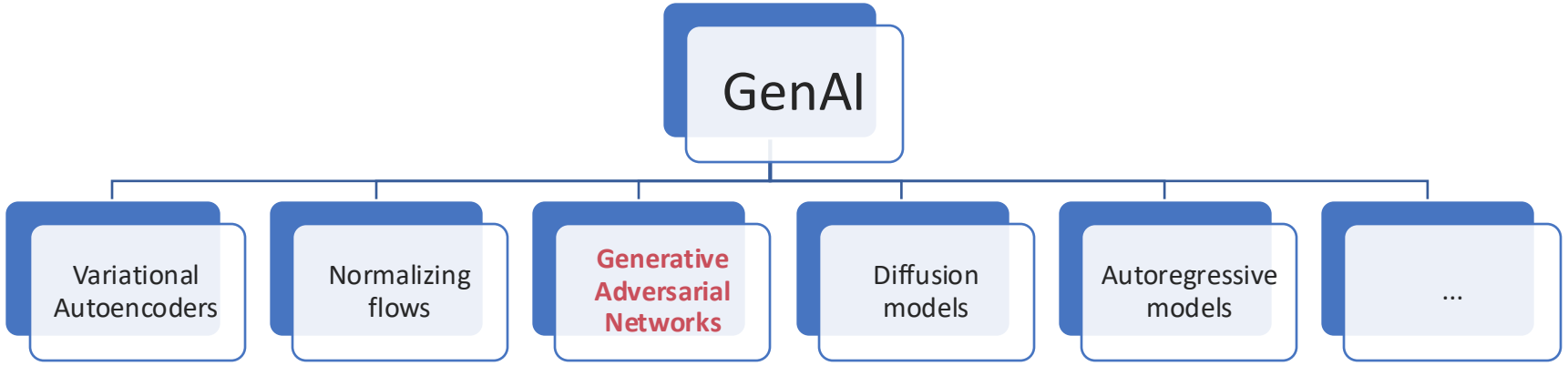


Grasso and Colosimo, 2019



Colosimo et al. 2024

Generative AI for zero-defect AM



Applications

- **Data generation / augmentation**
- Process outcome prediction
- Anomaly detection from generatively predicted patterns
- …

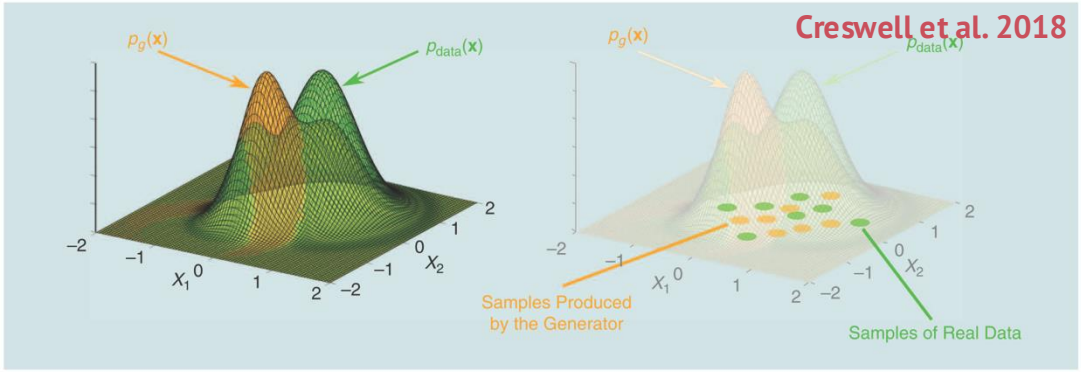
Type of data

- Time series, signals
- Images
- Videos
- Multi-sensor data,
- …

- In the big data era, **real data are commonly highly unbalanced** (e.g., more difficult to gather data in defective states than in normal states)
- Sometimes defects and faults are observed only at severe levels – **lack of data in intermediate states**
- **Process monitoring and classification** performances suffer from these limitations
- Simulation is sometimes used to fill this gap, **but complex data / complex process dynamics are difficult to simulate** in realistic way

Generative AI for data augmentation

GANs – Generative Adversarial Networks



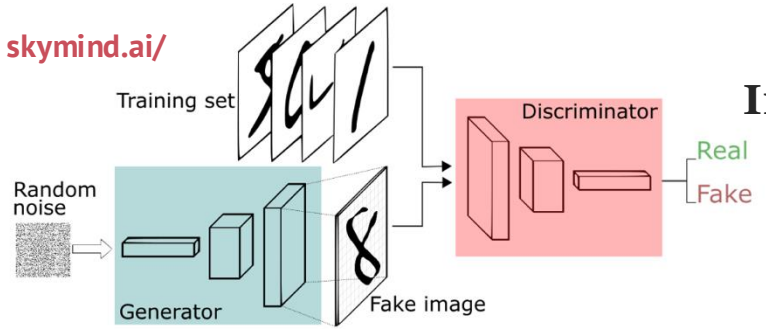
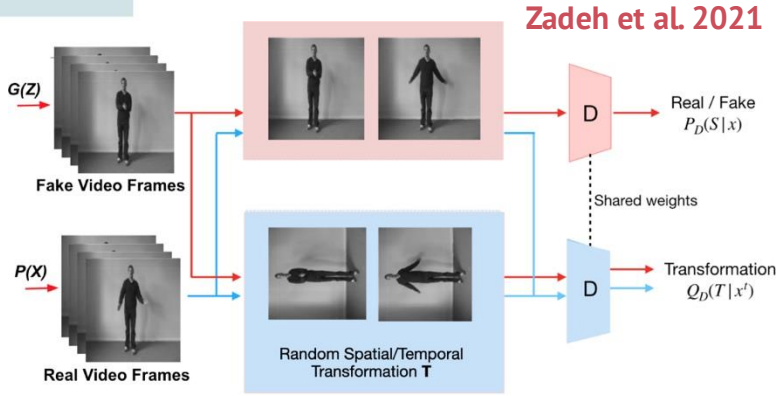


Image data

- Powder bed images (before and after melting)
- Surface texture images
- CT data
- …

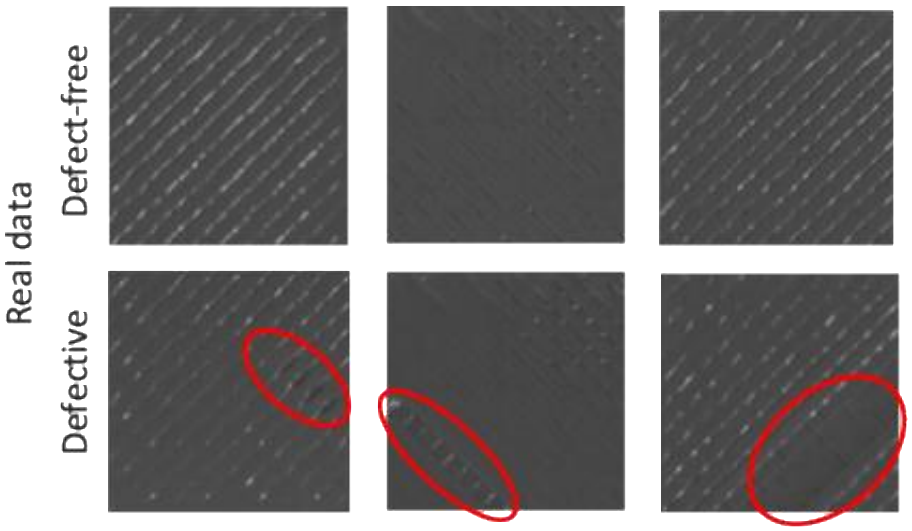
Video-image data



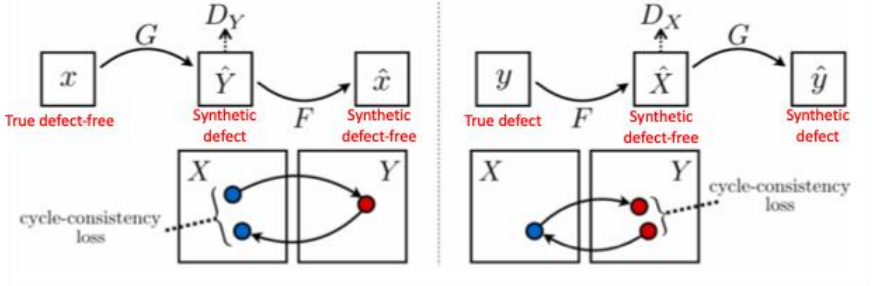
- Thermal videos
- High-speed videos (visible, NIR, stereo)
- …

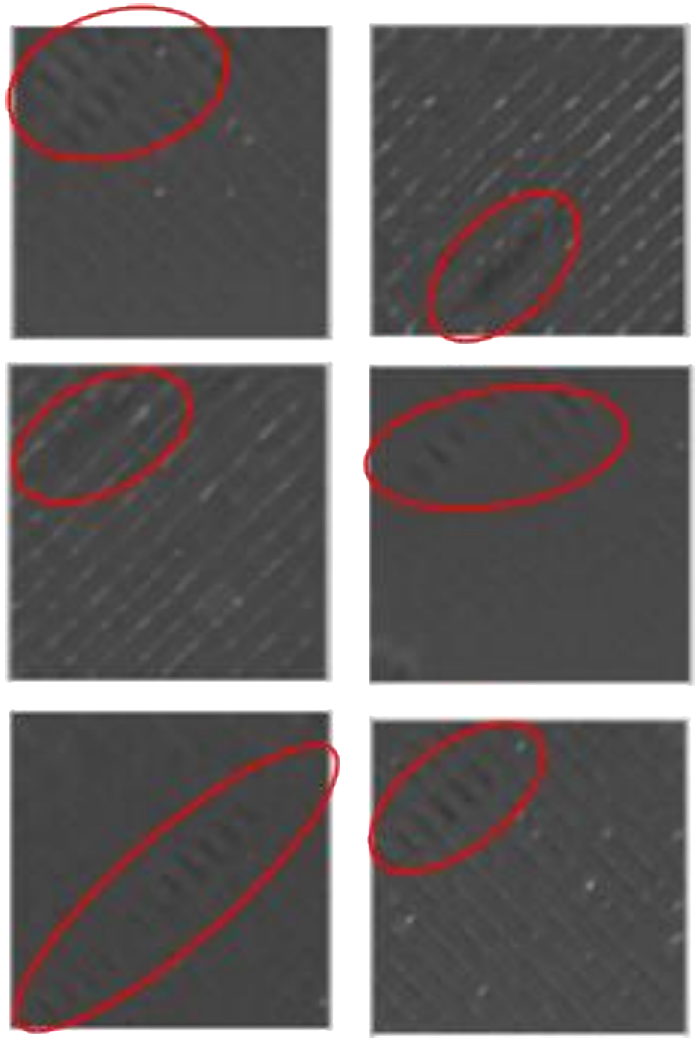
Case study in AM

Surface defects in extrusion-based Additive Manufacturing (*Colosimo et al. 2023*)



CycleGAN





- Good and realistic output, despite the limited size of the input data.
- Agnostic with respect to defect type, size, shape and location.
- Limited extrapolation, overfitting traits.

Limitations, Challenges and Outlook

AI and machine learning tools can be game changers to move from sensorized AM machines to intelligent AM systems

Efficient AI, transfer learning and GenAI can enable a transformation of industrial practices and methods

Proliferations of GenAI architectures, but limited guidelines to overcome major issues…

- Lack of effective automated validation methods
- Unstable training
- Extrapolation capability limited by over-fitting issue
- Complex and highly computationally expensive training process
- Lack of consolidated methods for network selection/optimization

Open issues and outlook

- Transfer to enable efficient transfer of knowledge and AI models from one machine/material/geometry to another
- Use of domain knowledge to enhance loss function definition and output evaluation metrics
- Implementation of resource-efficient AI methodologies and tools for real-time implementation

mecc

DIPARTIMENTO DI ECCELLENZA
MIUR 2018-2022

CONTACTS

Prof. Bianca Maria Colosimo
biancamaria.colosimo@polimi.it
phone: +39 02 2399 8490

Marco Grasso
Marcoluigi.grasso@polimi.it

www.ic.polimi.it
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