Real-time AI Models for Quality Monitoring & Control in Metal 3D Printing

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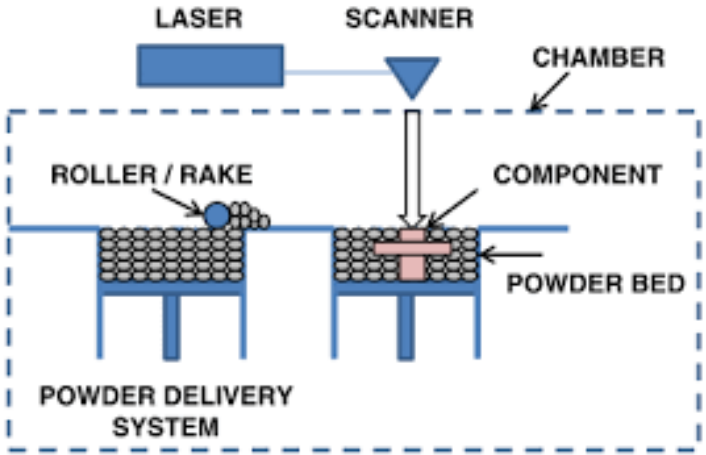
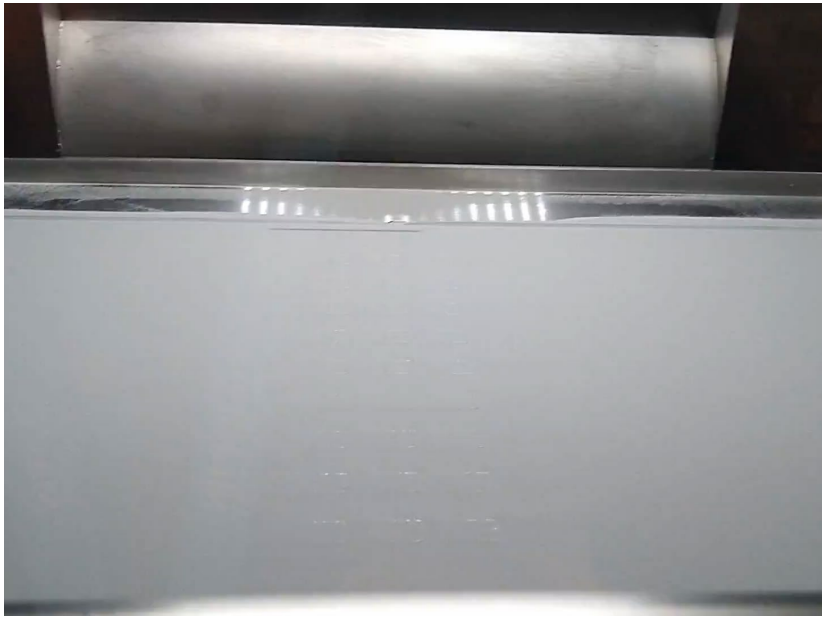
Context: Industrial Scale 3D Metal Printing

Laser powder bed fusion





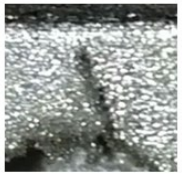
Laser melts metal powder layer-by-layer in the pattern of your choice

The need for Vision-in-the-loop

- Quality control for laser powder bed fusion
  - Medical parts, machine components, functional parts for aeronautics

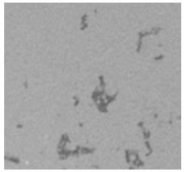
→ Requires products with consistent high-quality

- In practice, often products with reduced quality are obtained



Cracks

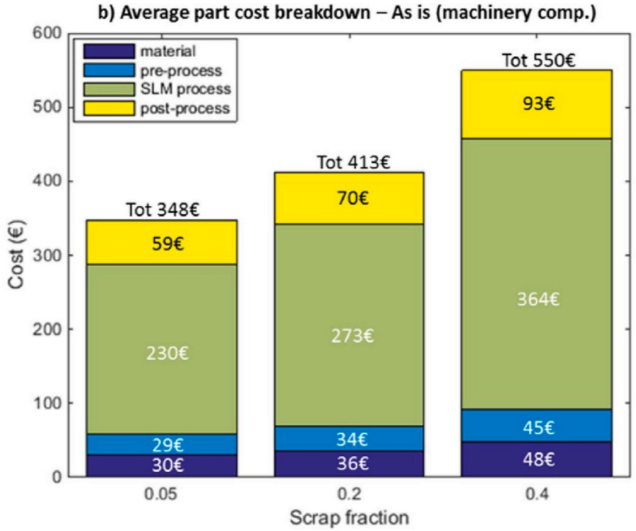
Warping



Porosity

→ Leading to **scrapped parts** and **high costs**

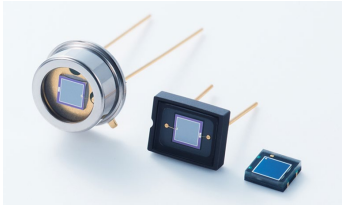
➢ **Goal:** Reduce scrap rates using high-speed monitoring and in-the-loop control

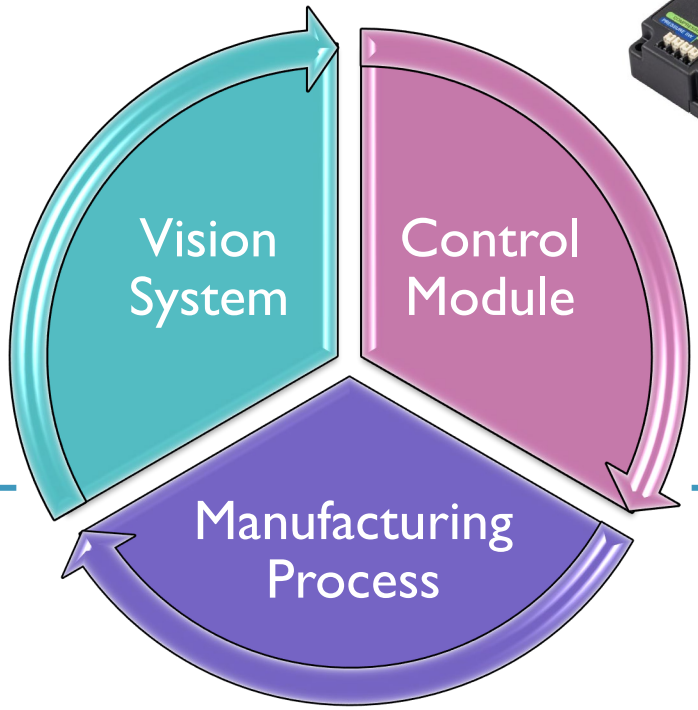


***Reference**: Colosimo, Cavalli, Grasso - A cost model for the economic evaluation of in-situ monitoring tools in metal additive manufacturing - International Journal of Production Economics - Volume 223 (2020)*

Bringing Computer Vision In-the-Loop

Closing the loop between manufacturing and control





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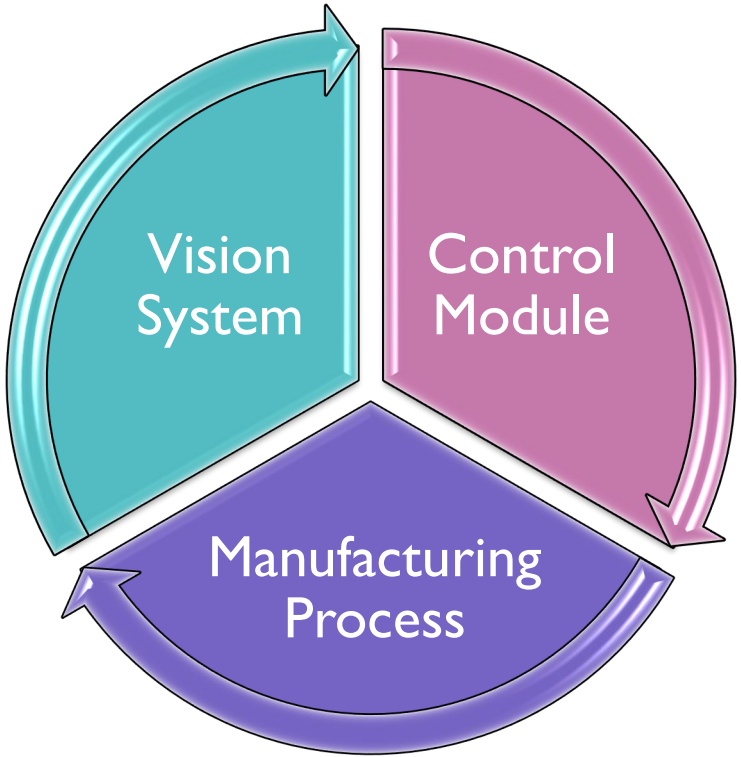
Vision Systems Closing the Control Loop

What are we looking for

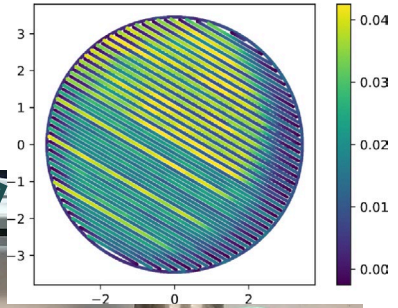
- Vision system requirements:
  - *Real-time performance*
  - *Accuracy*
  - *Robustness & Repeatability*

- The vision system needs to be "intelligent" to process & analyze the visual data quickly and accurately.



High-speed Imaging & Sensing

Optical imaging, short-wave infrared, photodiodes, etc.



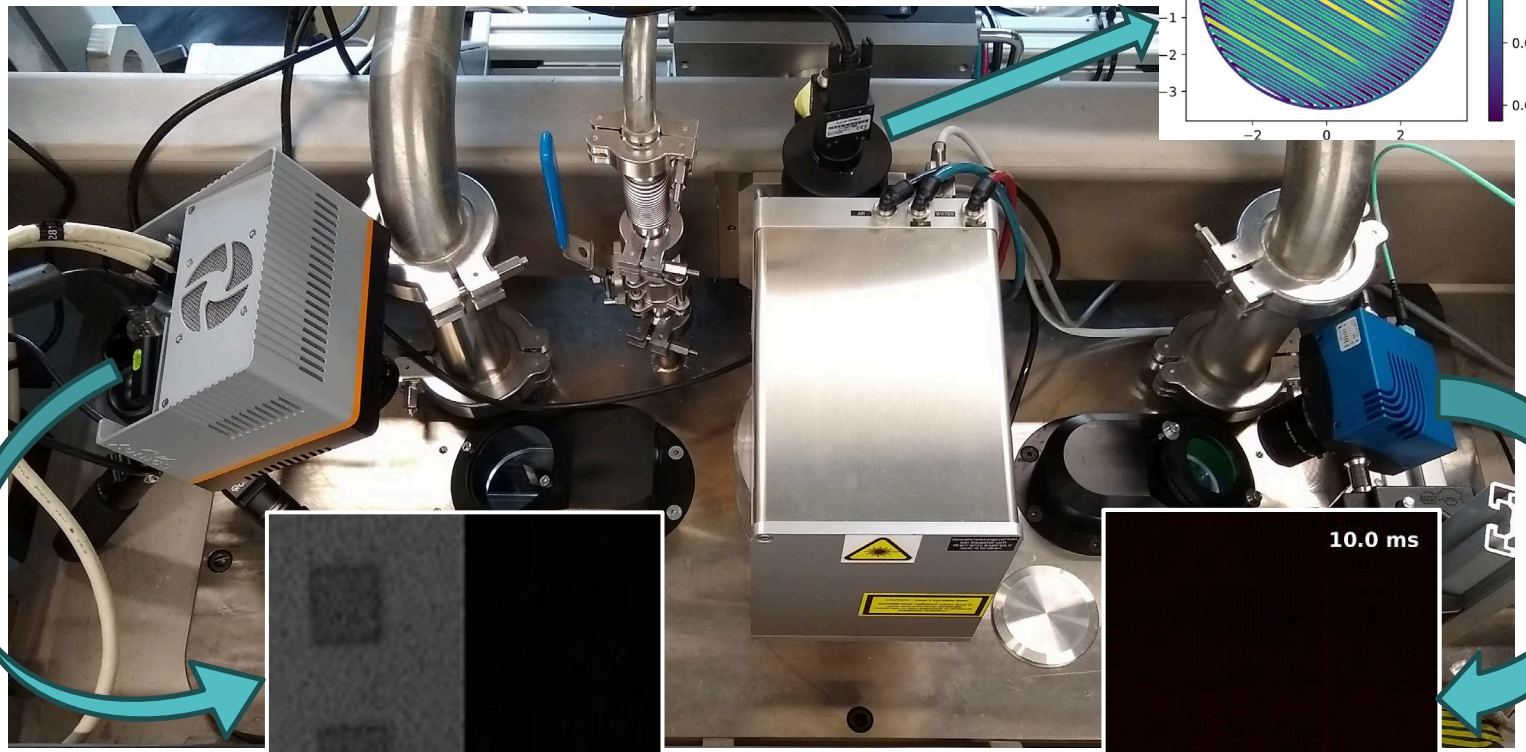


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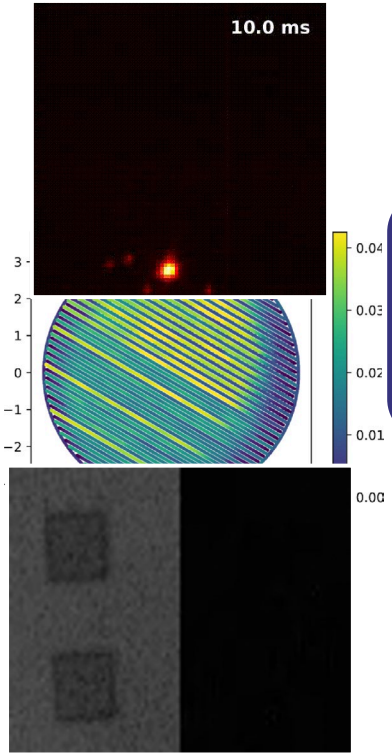
Image Processing & Sensor Fusion

Combining Domain Knowledge with AI

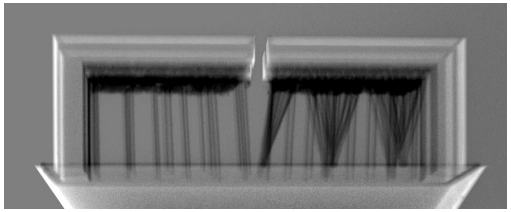


Feature Selection

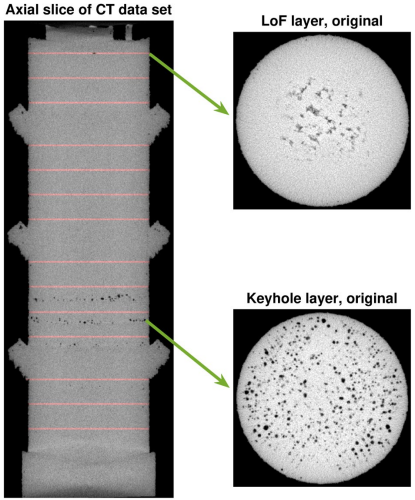
Feature Importance & Fusion

AI Prediction Models

Domain Knowledge



Deformations



Porosity

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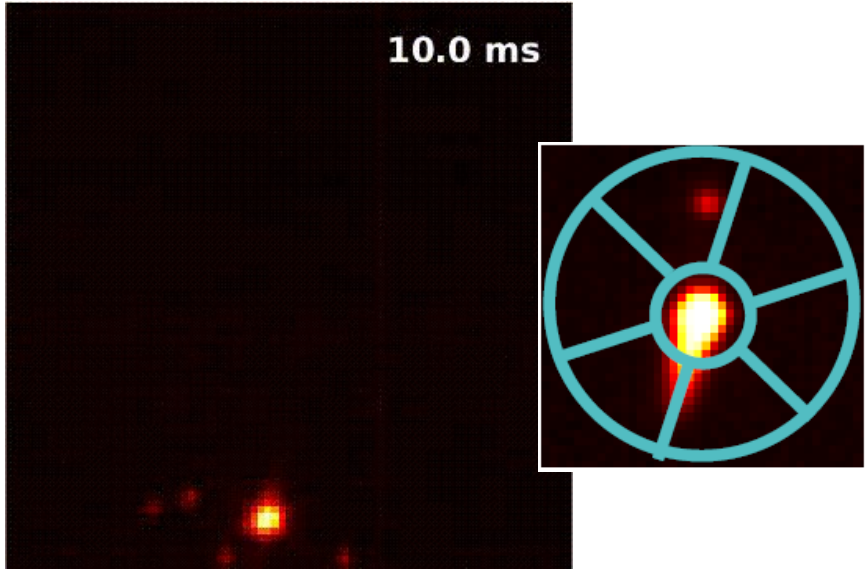
Approach 1: Domain-informed Data Representations

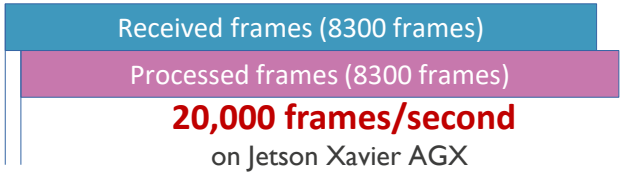
- Leveraging the Physics
  - Hand-crafted image features as input to AI model's defect detection
  - Melt pool features: *size, shape, intensity*
  - Spatter features: *number, direction, size*

- Using hand-crafted features helps keep AI model size small

- Predictions in **45 µs that are 42% more accurate** than competing techniques



Latency: 45 us



20,000 frames/second
on Jetson Xavier AGX

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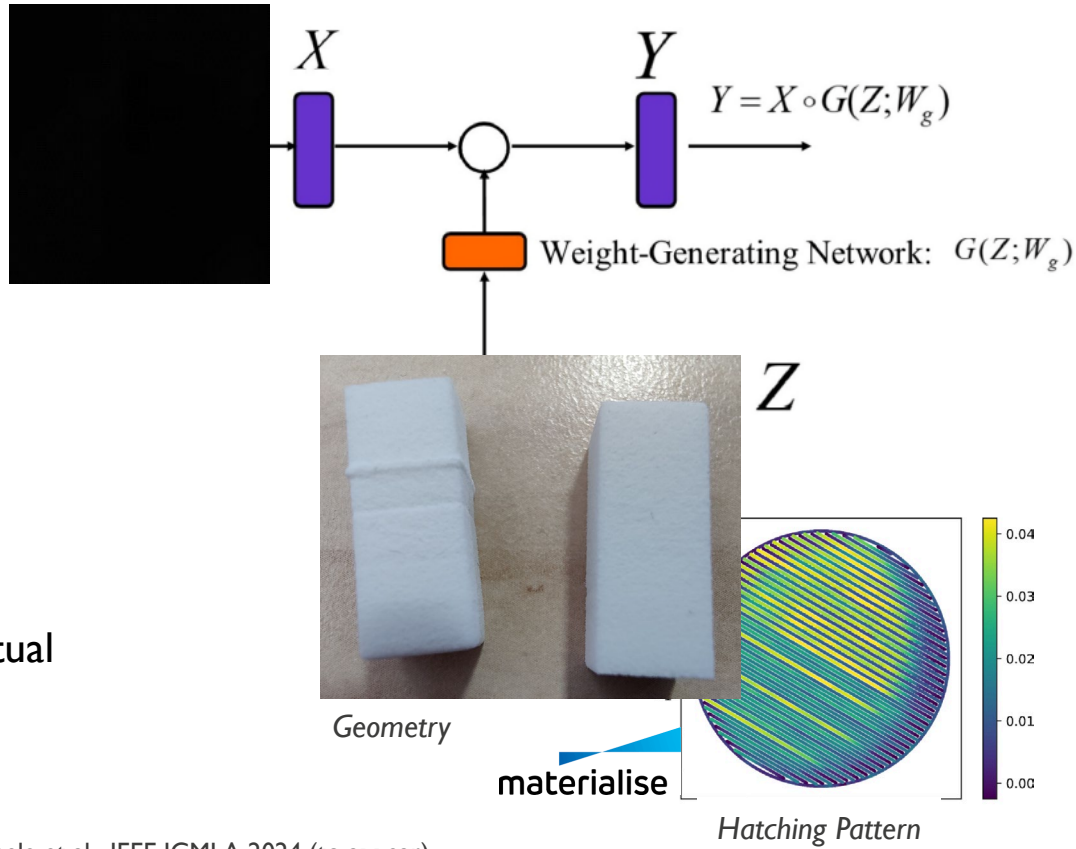
Booth et al., https://doi.org/10.3390/s22103740

Approach 2: Domain Knowledge for Meta-Learning

- E.g.: 3D Polymer Printing
  - High-speed control needed
  - Video doesn't catch enough
- Integrating Contextual Information
  - Features on 3D geometry
  - Print Job Settings (e.g., hatching)
- Use meta-learning mechanisms
  - Learn model weights from contextual data, then apply model to video



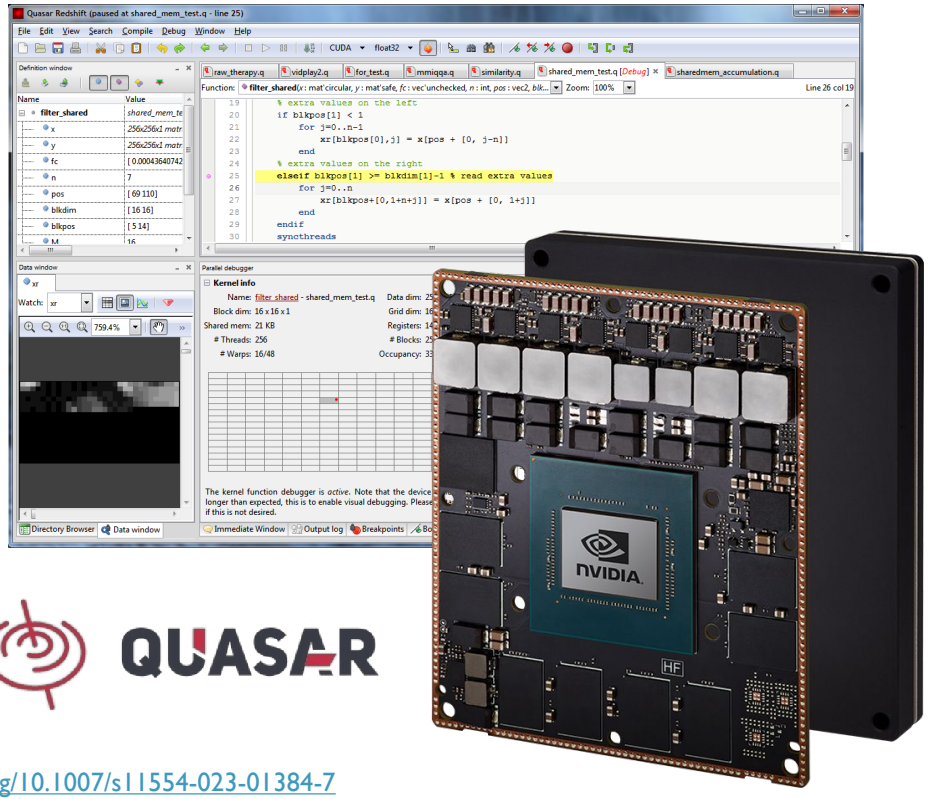
M. Vandecasteele et al., IEEE ICMLA 2024 (to appear)

Deploying Algorithms in the Edge (GPU & FPGA)

Designing & Implementing Algorithms for High Speeds

- Quasar (https://gepura.io)
  - Python-like programming
  - Enables & automates GPU code optimizations → higher speeds

Optimization	Jetson Xavier
Initial implementation [5]	7 ms
+Computation pruning	2.5 ms
+Intra-kernel optimizations	900 us
+Initial kernel fusion	350 µs
+Unconditional kernel launch	280 µs
+Kernel fusion (Fig. 7a)	200 µs
+Kernel fusion (Fig. 7b)	126 µs
+Kernel fusion (Fig. 7c)	95 µs
+Grid-level synchronization	63 µs
+Persistent kernel	45 µs



M. Nourazar et al., https://doi.org/10.1007/s11554-023-01384-7

Where do we go from here?

Looking for Use Cases & Partners

- We offer our expertise in:
  - Computer Vision
  - AI & Expert Systems

- Specific Interest in Practical Constraints:
  - High-speed, in-process monitoring
  - Low-cost industrial inspection
  - Algorithms for embedded systems

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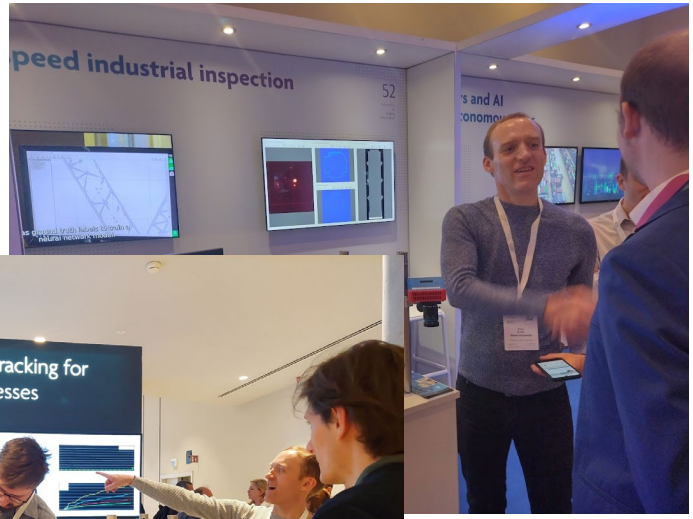

Productive partnerships with:

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