CT-Prüfung für verbessertes Laserauftragsschweißen

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Kurzfassung

Im Zuge des vom BMBF gestützten ProSLAM Förderprojekts bemüht sich diondo, zusammen mit den Projektpartnern Fraunhofer ILT, Precitec, BCT, Resolto und Point 8, um die umfangreiche Weiterentwicklung des Laserauftragsschweißens (LMD). Eine deutlich höhere Prozesseffizienz und Zuverlässigkeit soll so gewährleistet werden, was auch den Endanwendern (assoziierte Partner Airbus, Isar Aerospace, Toolcraft & Mercedes-Benz) im Projekt zugutekommen soll. Einerseits wird die Anlagentechnik mit zusätzlicher Sensorik erweitert, anderseits werden die Prozessdaten, die während des LMD-Prozesses gesammelt werden, mit Edge- und Offline-KI (künstlicher Intelligenz), analysiert, um so die Prozesssteuerung zu optimieren. Der Fokus von diondo liegt dabei auf der Ertüchtigung der Röntgen Computer Tomographie (CT) Prüfung, die als unterstützendes Sensorsystem agiert. Die Aufgabe besteht darin, einen optimierten und reibungslosen Abgleich zu den Prozessdaten zu ermöglichen, zum einen durch das Sammeln optimierter Scandaten, zum anderen durch die optimierte Aufbereitung der gesammelten Daten. Die Arbeiten in beide Richtungen lassen sich auch dem Bereich „NDE 4.0“ zuordnen, da u.a. der digitale Zwilling der CT-Prüfung genutzt wird.

Der Beitrag wird eine Übersicht zu den Fortschritten im Projekt präsentieren.

diondo
x-ray systems and services

CT-Prüfung für verbessertes Laserauftragsschweißen

Dr Nick Brierley, Karin Chrzan, Dr Olaf Günnewig

diondo dx

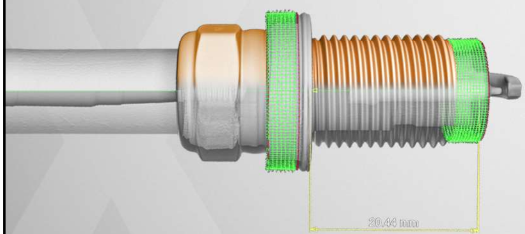
Industrial Computed Tomography and X-Ray Systems

	diondo dsub µ Highest Resolution Sub-Micron CT System	diondo d1 High Performance Micro CT System	diondo d2 Powerful Micro CT System	diondo d4 Compact CT System for High-Density Parts	diondo d5 Universal CT System with a Large Variety of Applications	diondo d7 High Energy Linac CT	diondo d! Special Solutions for Custom Applications
Sample Size	●○○○○	●●○○○	●●●○○	●●●○○	●●●●○	●●●●●	○○○○○
Sample Density	●○○○○	●●●○○	●●●○○	●●●●○	●●●●○	●●●●●	○○○○○
Accuracy	-	●●●●●	●●●●○	●●●○○	●●●●○	●●○○○	○○○○○
Resolution	●●●●●	●●●●○	●●●●○	●●●○○	●●●●○	●○○○○	○○○○○
Footprint	●○○○○	●●○○○	●●●○○	●●●○○	●●●●○	●●●●●	○○○○○

diondo evo$_{03}$

Lowering the Barriers to Entry for the Industrial Computed Tomography World

- Very compact
- Very user-friendly
- Very affordable
- And yet – very capable!



ProSLAM Overview

Advancing Laser Metal Deposition (LMD) Additive Manufacturing (AM)

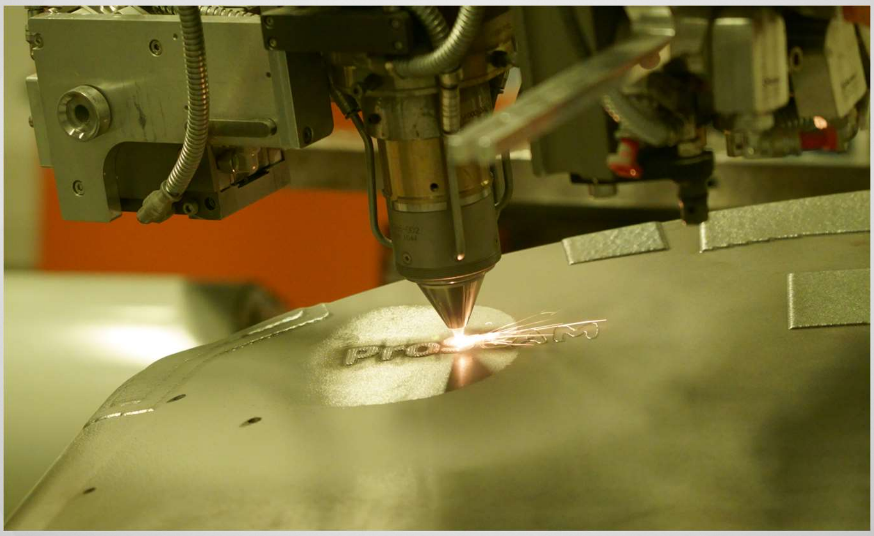


Image courtesy of BCT & Fraunhofer ILT

ProSLAM Overview

Advancing Laser Metal Deposition (LMD) Additive Manufacturing (AM)

The ProSLAM collaborative R&D project seeks to enable a step-change in the performance of Laser Metal Deposition (LMD) Additive Manufacturing (AM) through:

- Novel process monitoring technology to collect more (relevant) data during the build
- Edge artificial intelligence (AI) to detect and correct process deviations in real-time
- Offline AI to establish correlations between process monitoring and post-build part quality as determined by CT
- Advances in CT technology for post-build final inspection

Project embodies numerous aspects of NDE 4.0!

The Federal Ministry of Education and Research (BMBF) is funding the ProSLAM project within the "Innovationen für die Produktion, Dienstleistung und Arbeit von morgen" funding measure.

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AI-driven LMD AM

NDE for Industry 4.0

- The post-build CT inspection is correlated with the in-process monitoring to enable data feed during build to be used to keep LMD in a high part quality operating regime and facilitate "right first time".
- Major challenges:
  - Data volumes / rates
    - 10s of GBs for even the smallest builds
  - Data registration
    - Multi-modal
    - Temporal-spatial mapping
    - Temporal-spatial offset
- Solution approach:
  - Generation of binary masks of defect indications as basis for correlation with in-process monitoring data using machine-learning-based segmentation
    - Data reduction by >1 order of magnitude
  - Move towards returning all sensor data in coordinate system of the nominal geometry (CAD)
    - Registration workflow can be automated

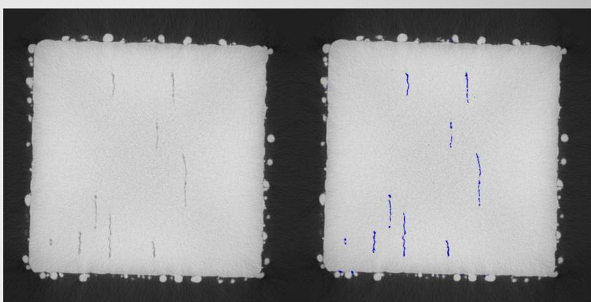
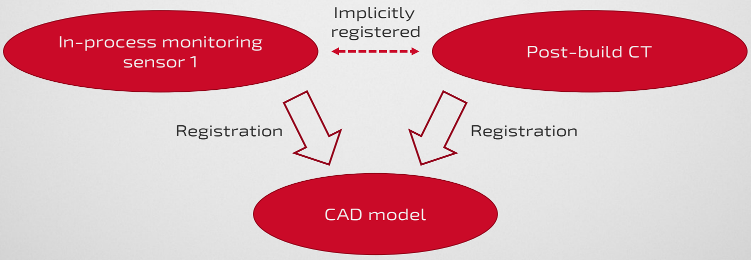


Illustration of the binary mask (shown as overlay on right) for a slice through the CT volume of an LMD test cube intentionally built with defect-inducing parameters.

AI-driven LMD AM (2)

Registration via CAD coordinate system

- Providing inspection & monitoring data in the CAD coordinate system allows data channels to be implicitly registered to each other.
- Basing registration on CAD coordinate system has numerous advantages, including:
  - Exploitation of prior knowledge
  - Scalability by containment of multi-modality
  - Enabling digital twin of part instance
  - Automation



AI-driven LMD AM (3)

Obtaining CT data in CAD coordinate system

- Approaches to obtaining CT data in CAD coordinate system:
  1. Alignment in post-processing via best fit to surface
     - No prior knowledge necessary
     - Highly dependent on scan quality
     - Unusable for planning
  2. Use of a preliminary, fast scan
     - As for (1), with additional time cost and some potential for planning
  3. Use of an additional sensor system
     - Additional costs and complexity of multi-modal registration
  4. **Use of a fixture of known geometry**
     - Suitable for planning
     - Requires a digitally specified known fixture
     - Accuracy imperfect
  5. **Use of initial projection(s)**
     - Suitable for planning
     - Requires part to closely match CAD
     - Computationally demanding

Enhancing Inspection Through Use of a Digital Twin

Industry 4.0 for NDE

- Synchronisation is a defining aspect of a digital twin
- Knowing where a part is placed inside the machine is key element of physical -> virtual synchronisation

Virtual informs physical

Physical informs virtual

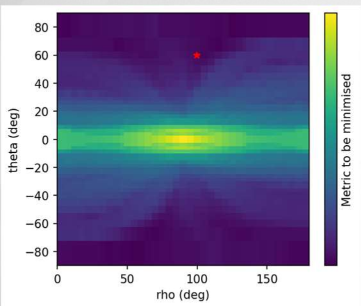
Virtual representation

Physical manifestation

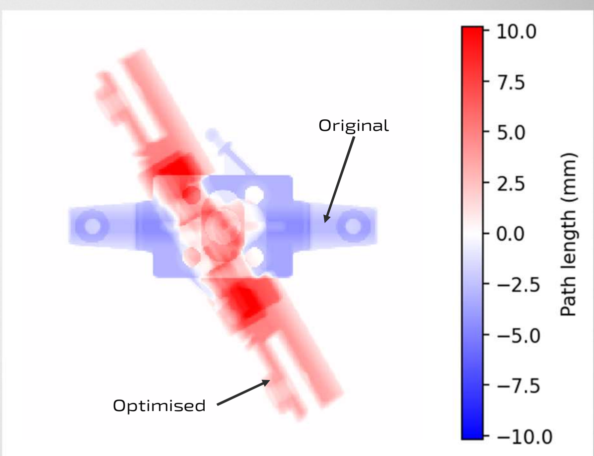
Enhancing Inspection Through Use of a Digital Twin (2)

Industry 4.0 for NDE: digitally optimised pose

- Prior knowledge of component geometry allows CT inspection configuration to be digitally optimised, see e.g. *A. Amirkhanov et al., "Visual Optimality and Stability Analysis of 3DCT Scan Positions," in IEEE Transactions on Visualization and Computer Graphics, vol. 16, no. 6, 2010.*
- Computation relies on fast simulation of many potential sample poses etc. to numerically maximise an objective function that represents the expected image quality



The two-dimensional objective function space describing the sample pose, with the ultimately selected pose highlighted

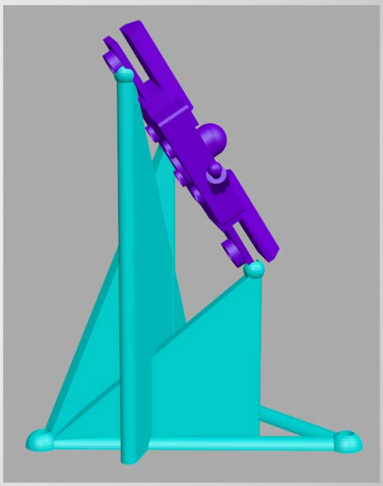


Comparison of the first projection of the scan before and after pose optimisation as difference of path lengths

Enhancing Inspection Through Use of a Digital Twin (3)

Registration by use of a fixture of known geometry / Implementing digitally optimised pose

- Physically implementing the determined sample position and pose is an example of virtual -> physical synchronisation
- Achieving this in practice is not straightforward, given that most of the time samples are fixtured in a highly manual process
- Using polymer 3D printing to rapidly manufacture a bespoke fixture provides a route
- An auto-fixture generator has been developed to provide a fixture geometry that delivers the desired sample pose respecting the constraints of the manufacturing system

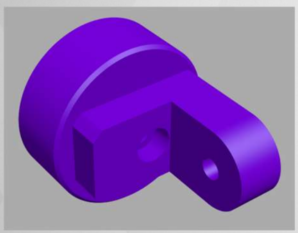


Example of an auto-generated, polymer-3D-printable fixture for holding sample in a known, pre-computed position and pose

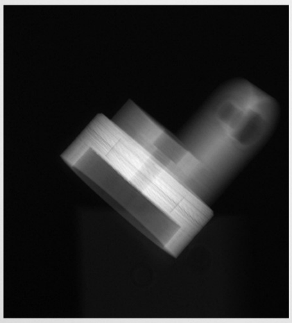
Enhancing Inspection Through Use of a Digital Twin (4)

Registration by use of initial projection(s)

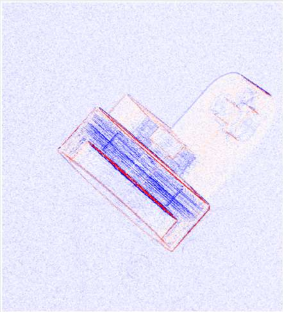
- If no bespoke fixture is possible, achieving registration from the initial projection(s) is an attractive option
- This also relies on a fast simulation of many potential sample poses to maximise an objective function that represents the similarity to the provided experimental image
- The fact this is an optimisation with 6 degrees of freedom to solve for means this is a non-trivial computational challenge



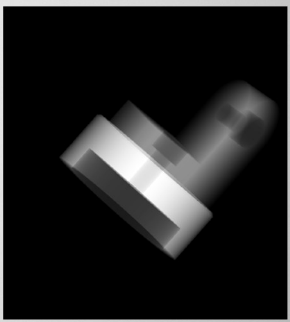
Rendering of test geometry, physically manufactured by polymer 3D printing



Input experimental projection



Difference of gradients image, for visually assessing quality of fit



Computed corresponding simulation projection (position and pose correctly computed)

Conclusions

- The ProSLAM project is driving forward Laser Metal Deposition AM
  - Enabling the greater uptake for new manufacture, repair and modification applications
- The project advances both
  - NDE for Industry 4.0
  - Industry 4.0 for NDE

  aspects of NDE 4.0
- diondo is at the forefront of these developments through pioneering the use of a digital twin of the CT inspection.