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Digital Twin Modeling for Defect Detection in LPBF Parts: A Case Study

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Abstract

Computer-aided design (CAD) and additive manufacturing (AM) open new possibilities for optimizing parts design and manufacturing in various industries. Conducting a reliable nondestructive testing (NDT), to comply with standards and ensure homologation of complex geometry components, represents one of the main challenges for a broader use of AM technologies. X-ray computed tomography (CT) is the most widely used NDT technique to this end. However, a CT scan is a multiparameter imaging system with numerous nonlinear variable interactions. Furthermore, it is subject to acquisition artifacts that negatively impact image quality and, therefore, defect detection capability. The latter is commonly quantified using the defect probability of detection (POD) of the segmentation algorithm applied on a given CT volume.

Although CT segmentation algorithms have been significantly advanced by the growth in artificial intelligence, segmenting defects in CT volumes remains challenging. Furthermore, generalization of these models using different scan parameters and parts represents a significant research endeavor. Considering all these factors, making an optimized CT scan and reliable inspection for an expected POD is not trivial.

This study focuses on defect detection in laser powder bed fusion (LPBF) AM parts and presents a pipeline for the development of a CT LPBF digital twin (DT). This DT should allow direct comparison with experimental data and a priori assessment of defect POD in a specified CT volume. To this end, a database of 67k experimentally observed defects (including voids and lack-of-fusion) was built. Next, an automated DT generation pipeline was implemented combining the CAD and material of the part, the random defects sampling, and the expected CT parameters. Then, physics-based CT simulations were carried out, generating the CT volume and ground truth annotations. An automated algorithm developed to calibrate the CT simulations was used to obtain realistic grey values. Next, a part-specific DL defect segmentation model was trained using the DT and used to calculate POD of these defects. Finally, the digital twin was validated, and the defect POD predictions were compared on different CT volumes using a series of Ti6Al4V LPBF parts with different distributions of process-induced flaws. Preliminary results indicate comparable image quality between the real case study CT volume and the DT, with respect to signal-to-noise ratio and contrast-to-noise ratio, within a margin of error of 1%. This approach constitutes a promising step towards the satisfaction of an industrial imperative to shorten the inspection time, while ensuring the detection of critical defects.