Effective super-resolution X-ray tomography using deep learning applied to architectured materials

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Résumé

Context

Lattice structures are architectured materials combining material and space, configured in such a way as to have unique attributes used for structural lightening, mechanical energy absorption, gradient properties or heat exchanges. Their development has recently benefited from the availability of industrial metal additive manufacturing, notably Laser Powder Bed Fusion (LPBF). The specificity of lattices is their intrinsic multiscale aspect: they can form relatively large structures composed of repeated patterns, themselves including smaller structures such as elongated struts, which can include defects at the scale of the fused powder. Common defects in these materials are pores, cracks, high surface roughness and drift from dimensional tolerance. Those have great impact on the structure's mechanical properties and can be characterised in 3D by non destructive techniques such as X-ray microtomography. However, an exhaustive imaging of the lattice at the defect's resolution is not compatible with its multiscale aspect since it would require a prohibitive amount of scan time and data, which is not compatible with the perspective of high throughput acquisition and *in situ* testing. Imaging the structure at lower resolution is faster nevertheless it implies a detrimental loss of information at the defect's scale that can prevent its quantitative analysis.

Objective

This work aims at assessing the effective super-resolution achievable on a specific lattice structure, which is quantified on morphological descriptor of the features of interest. A strategy is proposed to improve the quality of fast low-resolution scans using only one local high-resolution scan of the same structure by the means of a multiscale registration of the images followed by deep learning super-resolution. Applied to experimental data, the performances of the method in terms of reduction of acquisition time and resolution of morphological descriptors of typical defects are discussed.

Methods

A steel lattice (10*10*10mm) was printed by LPBF with suboptimal parameters with the aim to maximise the appearance of defects and especially the presence of pores. Then, regions of interest (ROI) of the sample were scanned with a laboratory microtomograph at three different pixel sizes (18μm, 9μm and 3μm), with the 3μm scan being defined as the

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ground truth (GT) of the study. The ROI of the GT was taken inside the ROI of the lower resolution scans. Based on the volumetric correlation software SPAM (Stamati *et al.* 2020), a multiscale registration of the scans was then performed at the intersection of the ROIs, and pairs of 3D registered and rescaled images were obtained. These images were divided into training, validation and test datasets with a ratio of respectively 8% and 2% of whole data for training and validation. A Mixed-Scale Dense Network (MSDNet) (Pelt *et al.* 2018) was trained for 48 hours to convert lower resolution images to their corresponding high-resolution GT. The trained network was then applied to the test datasets to obtain the super-resolution images. The quantification of the image quality was performed at several levels, comparing the improvement of the image quality on: (i) the greyscale data, (ii) the segmentation of the pores at a global and local scale, (iv) local and global surface measurements. Image quality was therefore measured not only using signal analysis tools, but also according to the metrics of interest to the materials scientist.

Results

The cases of x3 and x6 magnification factor between low-resolution scan (9/18μm pixel size) and GT (3μm pixel size) are reported. The super-resolution image shows a clear quality improvement compared to the low-resolution image with a higher SSIM and PSNR value. Furthermore, it allows recovering most of the metrics of interest such as the pores morphological descriptors and the roughness profile with little change on their values, which was not at all possible directly from the low-resolution image. Hence, this super-resolution strategy can accelerate the scan time by several orders of magnitude with a marginal impact on the quantification of defects. The relevance and the limit of the methodology will be discussed by comparing increasing magnification factors between low and high-resolution images, while focusing on the evolution of the metrics of interest. Also, emphasis will also be placed on the effect of the accuracy of the prior multiscale registration.