New measurement strategies for data-driven mechanics

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There has been explosive growth in numerical, data-driven approaches to various problems in the mechanics of materials. These data-driven methods are data-hungry, but traditional measurement protocols are inherently data-poor. Consequently, most studies using these data-driven methods have relied on synthetic data. This dearth of measurement techniques presents opportunities to transform laboratory-based methods, making them better suited to emerging data-driven methodologies in mechanics. We first give a brief overview of emerging laboratory techniques that enable observations that were hitherto considered nearly impossible, at least in a laboratory setting. These methods include (i) dynamic tomography to enable 3D visualisation of high-speed deformations [1], (ii) digital volume correlation in nominally homogeneous materials [2], and (iii) democratising synchrotron technologies to allow the measurements of local stresses within statically indeterminate specimens via energy-dispersive diffraction measurements.

These and other new laboratory measurement methods provide new observations and large datasets. But how can they be used in the data-driven mechanics discovery of constitutive behaviour? Broadly, the constitutive model discovery approaches fall into two categories: (i) supervised models that require data in the form of stress-strain pairs and (ii) unsupervised models that require no stress data but only full-field displacement and global force data. Energy-dispersive measurements provide fully labelled stress-strain pairs for supervised constitutive model discovery. Using these measurements, we shall demonstrate the learning of the plasticity models for Ti64 from a single tensile test on a simple notched specimen. Remarkably, the model indicates that simple J2 plasticity is not sufficient to accurately model the plastic response of Ti64- while this is, of course, known in the literature, those inferences were obtained using multiple different complex specimens designed with significant a priori knowledge of the material response. These new measurement techniques offer the potential to quickly learn complex constitutive responses and may lead to the discovery of new physics.

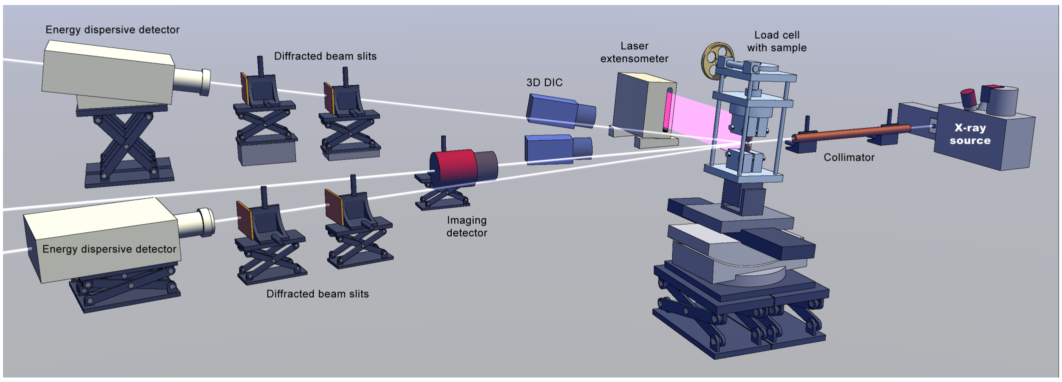

Figure 1. Democratisation of synchrotron-based X-ray diffraction for laboratory-scale property measurements

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[1] I. Grega, W. Whitney and V.S. Deshpande (2025), *High-speed X-ray tomography for 4D imaging*, **Proceedings of the National Academy of Sciences,** 122, e2521089122.

[2] Z. Wang, S. Das. A. Joshi, A.J.D. Shaikeea and V.S. Deshpande (2024), 3D observations provide striking findings in rubber elasticity, **Proceedings of the National Academy of Sciences,** 121 (24), e2404205121.