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Identifying material data in generalized continua

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Abstract

Generalized continuum theories are essential for describing material behavior that is strongly influenced by microstructural effects. This line of research originated from the seminal work of the Cosserat brothers, who first introduced continua enriched with independent microrotations. After remaining largely dormant for decades, it was revived during the 1960s and generalized into micromorphic continuum theories, endowed with fully tensorial microdeformations. Traditionally, these theories have been pursued mostly through constitutive modeling, i.e., by postulating constitutive relations for the additional (non-classical) stress measures and identifying their parameters, ideally from observations. More recently, model-free data-driven approaches have been proposed as an alternative, in which the generalized kinematic relations and balance equations are closed directly with empirical material data, thereby avoiding an explicit closure relation. In either case, a central bottleneck remains: the availability of data comprising representative generalized stress–strain states. In particular, as in Cauchy continua, stress quantities are not directly measurable and can only be inferred. This challenge is further compounded by the presence of non-classical stresses whose consistent link to observations is far from straightforward. This renders material identification a fundamental challenge and helps explain why, despite their descriptive power, generalized continuum theories have not always found widespread practical application. This work presents a model-free, data-driven identification (DDI) framework that yields generalized material data directly from full-field kinematics and force measurements in boundary value problems. In contrast to homogenization methods, which typically rely on problem-dependent boundary conditions, the proposed approach infers generalized stress fields by enforcing non-classical compatibility relations and balance laws, relying solely on displacement–microdeformation field data and prescribed forces. The method outputs the corresponding generalized stresses (including non-symmetric and higher-order components) and a representative dataset obtained by clustering generalized stress–strain states in a metrized, non-classical phase space. The resulting dataset can be used either for constitutive model calibration or to inform model-free data-driven simulations of generalized continua. The generalized DDI framework is validated on synthetic studies in which the ground truth follows a full first-order micromorphic model, including both symmetric and skew-symmetric microdeformations, and is shown to reliably recover the underlying generalized stress states. An application to mechanical metamaterials is then presented, where microdeformations arise from lattice-scale rotations; in this case, a homogenized micropolar continuum provides a reference response for benchmarking. The identified datasets enable accurate predictions for unseen boundary value problems, in strong agreement with full-field responses from direct numerical simulations.

Keywords:

Data-driven methods Material identification Generalized continua Micromorphic continua