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A Novel Uncertainty-Aware Computer Vision Framework for Automated Process Optimization In Additive Manufacturing

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ABSTRACT

The thermomechanical response of materials under high-strain deformation is critical to aerospace, defense, automotive, and additive manufacturing (AM) applications [1–3]. However, capturing this behavior remains challenging due to microsecond timescales of high-velocity impact events and reliance on manual, operator-dependent post-processing [4, 5]. These limitations reduce reproducibility and constrain the generation of high-fidelity datasets for constitutive model development. Current approaches are also limited in accessible strain-rate regimes, restricting applicability to AM processes and introducing uncertainty in predictive modeling [2]. This work presents an autonomous, AI-driven framework that transforms raw high-speed impact videos into structured, model-ready material data. The framework integrates two vision foundation models: Grounding DINO for open-vocabulary object detection and the Segment Anything Model (SAM) for high-resolution segmentation, in a zero-shot configuration, eliminating the need for task-specific labeled datasets [6, 7]. Grounding DINO localizes the deforming specimen, guiding SAM for precise contour extraction over time. These time-resolved contours are processed to extract deformation metrics relevant to constitutive modeling, particularly critical for high-strain experiments where data scarcity limits supervised learning approaches. To ensure robustness, an uncertainty quantification (UQ) strategy is embedded within the pipeline. Leveraging prediction confidence at inference time, the framework autonomously identifies low-reliability regions and triggers iterative refinement, enabling consistent feature extraction across varying experimental conditions. Experimental validation on a lab-scale impact platform demonstrates accurate extraction of deformation dynamics from high-speed image sequences. This work bridges vision foundation models, materials science, and physics-based modeling, delivering datasets for constitutive calibration, digital-twin integration, and AM optimization. Future efforts target real-time implementation, closed-loop calibration, and physics-informed adaptive control for next-generation AM systems.

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