Deep reinforcement learning (DRL)-based closed-loop control of PinVPP: an initial case study of pillar printing

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Abstract

This work proposes a deep reinforcement learning (DRL)-based closed-loop control framework for photoinhibition-enabled digital light processing (DLP) printing, aimed at achieving precise geometric control of printed structures. The printing platform employs a dual-wavelength DLP system, where blue light initiates photopolymerization while ultraviolet (UV) light induces photoinhibition. The targeted structures are circular pillars, printed layer by layer using a uniform circular exposure mask.

Real-time feedback on the sample's curing progress is obtained using an in-situ Interferometric Curing Monitoring (ICM) system. The raw signals collected by ICM are processed through a machine learning model to predict two key geometric parameters: the thickness and diameter of the cured layer. These predicted values form the state vector input to a DRL policy network, which learns to output a pair of scalar grayscale values G_{blue} and G_{uv}, corresponding to the required exposure intensities for blue (curing) and UV (inhibition) light in the next layer. These actions are implemented through two FPGAs, which perform region-based grayscale modulation over a circular area. Specifically, the PC converts each of the DRL-generated values G_{blue} and G_{uv} into a sequence of eight binary images per wavelength per layer, which are then transmitted to the FPGA for projection with appropriately weighted exposure durations.

By iteratively adjusting the exposure settings based on the ICM-predicted curing state, this DRL framework enables adaptive, layer-wise control of the DLP process. The goal is to ensure that the final structure closely conforms to the desired thickness and diameter profiles while maintaining high morphological fidelity. This study illustrates the potential of integrating real-time interferometric monitoring, physics-informed machine learning, and deep reinforcement learning into a unified framework for intelligent, adaptive control in additive manufacturing.