Tool-path planning for large scale extrusion additive manufacturing guided by thermal modeling and simulation

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In extrusion additive manufacturing (AM), the dimensional accuracy and mechanical properties of the final part depend on heat transfer during the process. In particular, the strength of inter-layer bonds is affected by polymer welding, a thermally-mediated process in which heated polymers experience reptation of their molecules across their adjacent surfaces. Additionally, local temperature gradients can lead to part shrinkage and residual stresses throughout a build. The temperature history resultant from the extruder tool path and the part geometry impact the part's global thermal profile over time, which therefore will have an impact on part quality. This is especially important in large-scale extrusion AM, where large thermal masses impose large temperature gradients, bounding the timescales necessary to achieve good interlaminar strength and prevent cracking due to excessive thermal stress.

The goal of our research is to develop toolpath planning algorithms for large-scale extrusion AM informed by the local and global temperature dynamics. We make use of algorithms based on the Traveling Salesman Problem, which enables the production of tool paths based on both geometric and thermal parameters of interest.

In order to incorporate heat transfer processes into tool path planning, we develop a finite element model of printed tool paths at various dimensions across a print volume. By examining these systems with a similarity analysis of our tool paths, we are able to determine how much heat is retained or lost as more hot material is deposited during a large-scale AM print. This study allows us to establish the time it takes for an entire print to reach a steady state temperature, information we use as a constraint in our tool path planning algorithm. We also develop an analytical model for local temperature at a given region of the print. We further add this information as a constraint, ensuring that the print remains at a temperature high enough to sufficiently bond to previously printed material.

Analyses of both finite element simulations and IR video footage of various tool path geometries quantify the effects of heat transfer and tool path geometry on part mechanics in large-scale printing. The coupling of thermal history, mechanics, and geometry can be used to inform extruder tool path trajectory to prevent cracking and poor mechanical properties in 3D printed components.