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# Dynamic thermomechanical modeling and simulation of the design of rapid free-form 3D printing processes with evolutionary machine learning

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## Abstract

Rapid free-form printing of heated polymeric materials, whereby an extruder is attached to a robotic arm, is a growing field. In order to properly plan a complex tool path, one needs to determine the dynamic thermomechanical response of the extruded filament material as the robot arm is moving in free-space. Accordingly, the analysis in this work involves:

- Kinematics of the robot arm and the extrusion-printer head,
- Dynamics of the extruded polymer filament,
- Thermal conduction along the length of the heated filament,
- Convective and radiative cooling of the filament through the surroundings and
- Curing and solidification of the filament.

Numerical simulations are undertaken to illustrate the basic model and a Machine Learning Algorithm is developed to optimize the robotic system to deliver a prespecified structure. Detailed extensions are also discussed.

## 1 Introduction

Within the last decade, several industrialized countries have stressed the importance of advanced manufacturing to their economies. Many of these plans have highlighted the development of additive manufacturing techniques, such as 3D printing which, as of 2017, are still evolving. The objective is to develop superior products, produced at lower overall operational costs. For these goals to be realized, a deep understanding of the essential ingredients comprising the materials involved in additive manufacturing is needed. The combination of rigorous material modeling theories, coupled with the dramatic increase of computational power can potentially play a significant role in the analysis, control, and design of many emerging additive manufacturing processes. Specialized materials and the precise design of their properties are key factors in the processes. One such process is extrusion-based deposition. The goal of these processes is primarily to build freeform structures that are extremely difficult to construct using classical manufacturing methods.

Specifically, Additive Manufacturing (AM) is usually defined as the process of free-form deposition of materials to build up structures from 3D model data, as opposed to subtractive manufacturing methodologies, which remove material

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