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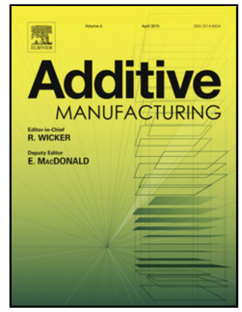

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Authors: Xiayun Zhao, David W. Rosen

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An implementation of real-time feedback control of cured part height in Exposure Controlled Projection Lithography with in-situ interferometric measurement feedback

Xiayun Zhao[a], David W. Rosen[a,*]

[a]*The George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, United States*

Highlights

- Proven real-time measurement capability of an in-house designed interferometry system for in-process measuring cured height (both exposure cured height and dark cured height) in photopolymer-based additive manufacturing (AM)
- Demonstrated real-time closed-loop control of cured height in photopolymerization AM, aided by an empirical dark curing model and the well-developed in-situ optical dimensional measurement system
- Thorough error analysis for future research on improving the process control
- An exemplinary study on a lab-scale parallel computing enabled cyber-physical system for AM process sensing, modeling and control

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A B S T R A C T

Exposure Controlled Projection Lithography (ECPL) is an in-house additive manufacturing process that can cure microscale photopolymer parts on a stationary transparent substrate with a time sequence of patterned ultraviolet beams delivered from underneath. An in-situ interferometric curing monitoring and measurement (ICM&M) system has been developed to measure the ECPL process output of cured height profile. This study develops a real-time feedback control system that utilizes an empirical process model and an online ICM&M feedback to automatically and accurately cure a part with targeted height. Due to the nature of photopolymerization, the total height of an ECPL cured part is divided into exposure cured height and dark cured height. The exposure cured height is controlled by a closed-loop feedback on-off controller. The dark cured height is compensated by an empirical process model obtained from the ICM&M measurements for a series of cured parts. A parallel computing software application is developed to implement the real-time measurement and control simultaneously. The experimental results directly validate the ICM&M system's real-time capability in capturing the process dynamics and in sensing the process output. Meanwhile, it evidently demonstrates the feedback control system's satisfactory performance in achieving the setpoint of total height, despite the presence of ECPL process uncertainties, ICM&M noises and computing interruptions. A comprehensive error analysis is reported, implying a promising submicron control with enhanced hardware. Generally, the study establishes a paradigm of improving additive manufacturing with a real-time closed-loop measurement and control system.

1. Introduction

Additive manufacturing (AM) encompasses a wide range of manufacturing technologies, which are agile and high-valued for fabricating parts directly from a three-dimensional digital model [1]. It has been gaining increasing traction in major industries such as aerospace, electronics, biomedical and health applications. However, the inspirational vision is not fully realized, in large part due to the challenges associated with lacking of real-time systems for AM

* Corresponding author. Tel.: 404.894.9668; fax: 404.894.9342.
E-mail address: david.rosen@me.gatech.edu (D. Rosen), xiayun.zhao@gatech.edu (X. Zhao).