Control of Additive Manufacturing Processes and Devices

Open Invited Track, 21st IFAC World Congress

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Abstract: Additive manufacturing (AM) is expected to fundamentally change today's production processes. While basic controllers for temperature or material feed are established in AM, the overall quality and reproducibility of printed parts largely relies on open-loop control. This is surprising, because it has been recognized for a long time that a widespread use of AM processes is currently hampered by the need of case-by-case machine parameter and process parameter tuning, which often can only be carried out by trial-and-error. Consequently, there exist a variety of opportunities for control engineers in the field, ranging from real-time feedback control for single layer and layer-to-layer control, over adaptive and learning methods for the automatic calibration of AM devices, to control methods that address high-level features of printed parts such as residual stresses.

Keywords: Process Control (TC 6.1), Metal Processing (TC 6.2), Manufacturing Plant Control (TC 5.1).

Additive manufacturing (AM) is expected to revolutionize existing production processes and to be an enabling technology for entirely new approaches to manufacturing, with applications ranging from aerospace to personalized medicine (Wohlers et al., 2018). While AM is established for rapid prototyping, it is only recently maturing to a manufacturing tool for operational parts and products. In fact, the lack of repeatability is still considered to be the most important obstacle to a more widespread use. In order for AM to become a mature and profitable production tool, it is crucial to achieve a considerably more consistent quality as well as independence of operator experience, machine setup, and manual process parameter tuning (Tapia and Elwany, 2014; Schmidt et al., 2017; Malekipour and El-Mounayri, 2018).

Surprisingly, feedforward control is still predominant in many AM processes and devices (see, e.g., Everton et al. (2016); Jin et al. (2016)). There exist local feedback controllers for variables such as mass flow in powder based processes or local feedback controllers for extruder temperatures in filament and metal wire based devices. The in-layer generation process, however, is typically not subject to feedback control but relies on a sufficiently precise open-loop material deposition, often implemented with open-loop electrical devices such as stepper motors, even in metal printing devices for industrial use. Similarly, layer-to-layer feedback control is not established in today's devices in spite of being an obvious requirement for a higher repeatability.

The lack of feedback control in AM can partly be attributed to the difficulty to measure relevant output variables (see, e.g., Yan et al. (2018)). Three-dimensional measurements in real-time are obviously instrumental to controlling the quality of three-dimensional parts. Difficult process conditions, such as high-temperatures (in particular in metal AM), partial obstruction of the generated parts (e.g., by material in powder-based processes or machine parts in general), and device-specific difficulties (from, e.g., combining quasi-optical measurements with laser-based energy deposition) make the development of measurement methods and devices a challenge of its own. Consequently, feedback and measurement methods for AM must eventually be considered simultaneously.

Finally, AM processes and devices will always be subject to an intrinsic variability. Raw materials such as metal powders, wire or filaments will be subject to variation, and users will prefer devices that can cope with a range of raw materials such as a range of alloys or plastics. Moreover, printed parts will greatly vary with respect to their geometry and thus heat transport characteristics and sensitivity to residual strains. Consequently, the envisioned feedback control methods need to be adaptive and include parameter estimation or otherwise self-learning components.

The open invited track calls for contributions that address the development of new control methods for increased repeatability of additive manufacturing processes and devices. The track intends to cover all topics including but not limited to intra-layer control, layer-to-layer control, control of residual stresses, combined feedforward and feedback control, and advanced measurement techniques for monitoring and control. The track is not limited with respect to materials and process types.

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