Predict Shape Distortion of 3D Printed Products Through Engineering-Informed Machine Learning

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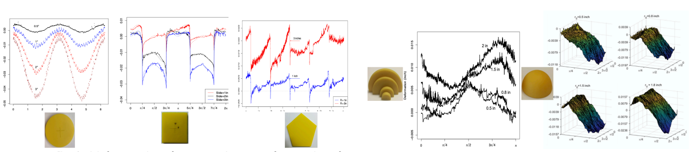
- To enable high-confidence and interoperable cyber-physical additive manufacturing systems (CPAMS), it is critical to establish smart and dynamic system calibration methods under a highly heterogenous learning environment.
- Engineering-informed machine learning approaches are more suitable to predict and control the shape distortion of 3D printed products, and to provide process insights.

Challenges in Shape and Process Complexities

- Shapes of AM built products: infinite variety
  [Kendall et al., 2009, Sharon and Mumford, 2006, Dryden and Mardia, 2016]
- Sample size for each shape: one-of-a-kind Mfg ($N \approx 1$) vs. mass production ($N \approx \infty$): AM often faces limited training samples for individual shapes.
- Process complexity: Varying materials, process conditions, and machines
  The same shape of different sizes can have different deformation patterns due to the layer-by-layer fabrication process. [Jin et al., 2019, Huang et al., 2019]



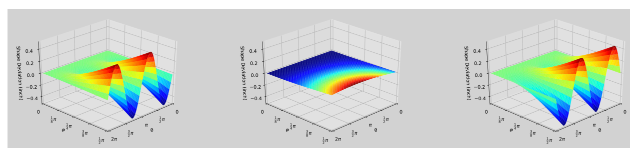
Deviation profiles of 4 disks [Huang et al., 2015], 3 squares, and 2 pentagons [Huang et al., 2014] Deviation profiles of 4 disks (vertical) [Jin et al., 2016a] and 4 domes [Huang et al., 2019]

Strategy and Solution

- Establish an engineering-informed Convolution Learning for AM
- Understand the layer interaction and deformation accumulation
- Integrate 2D and 3D shape deformation learning

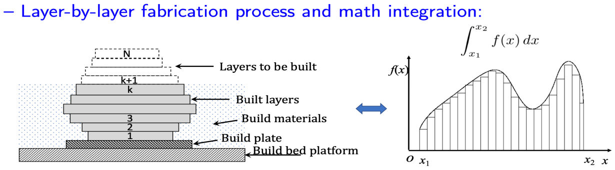
Scientific Impacts on CPS

- Establish an engineering-informed ML method to learn heterogeneous data in CPAMS
- Provide a path for model and knowledge transfer from shape to shape and process to process.
- Obtain engineering insights

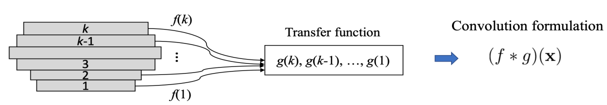


$$y\big(r_0(\theta,\varphi),\theta,\varphi,\big) = (f*g)\big(r_0(\theta,\varphi),\theta,\varphi\big) + \mathcal{GP}(0,k(\cdot,\cdot)) + \epsilon'$$

– Layer-by-layer fabrication process and math integration:



– System inputs, transfer function, and convolution formulation:



Smart Calibrators for CPAMS

Enable a cloud-based calibration and shape distortion control service for 3D printing users and manufacturers

Software demo on Youtube

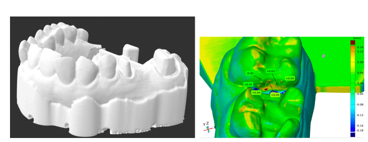
Education and Outreach

- Promote interdisciplinary training and education
- Promote international collaboration among faculty and PhD students

FACAM workshop at ENS Paris-Saclay, 2019 (https://facam-online.blogspot.com/)

Broader Impact

- Improve 3D printing shape accuracy by 50% or more through machine learning with small training samples
- Extend to medical and aerospace industries



2019 NSF Cyber-Physical Systems Principal Investigators' Meeting
November 21-22, 2019 | Crystal City, Virginia
Award ID#: CMMI-1544917