**General Questions**

* What kind of defects are being recognized?
* What are the classes?
* Techniques
* Applications
* Types of additive Manufacturing

Proceedings of SPIE (27 March 2019)

**Smart Additive Manufacturing Empowered by a Closed-Loop Machine Learning Algorithm**

Nariman Razaviarab, Safura Sharifi, Yaser Banadaki

* Abstract
  + Deep CNNs to automatically detect defects in printing layers of 3D metal printers
  + 100% accuracy rate on test set
  + Enhance quality of AM manufacturing, fewer quality hiccups, limiting waste of time and materials
* Deep CNN for Computer Vision
  + DANN architecture and transfer learning technique to retrain Inception-v3 [30] model of Tensorflow platform
  + Batch gradient descent with learning rate 0.001
* Schematics of design software
  + Appears to be non-live printing as full layer is inspected in photos
  + Recognizes defects in the entire layer
* Application
  + Enhances industrial applications in aerospace industry and automotive industry
  + Serves as proof of concept for other AM machines like 3D bio-printers or polymer and liquid-based printers

Advanced Intelligent Systems (Communication) (2019-2020)

**Automated Real-Time Detection and Prediction of Interlayer Imperfections in Additive Manufacturing Processes using Artificial Intelligence**

Zeqing Jin, Zhizhou Zhang, and Grace X Gu

* Abstract
  + Machine-learning model is capable of detecting different levels of delamination (a separation along a plane parallel to a surface) conditions, extent and tendency of warping before it occurs in print job
* Approach
  + Utilizes camera-based images with deep learning algorithms to classify/detect delamination ad novel setup established to gauge strain and warp tendencies
  + Uses GCode and live analysis with CNNs (~97.5 accuracy)
* Yuhan’s Additional Notes
  + This algorithm matches nozzle images to corresponding results of printed layer in order to predict nozzle images that may later cause the result to be delaminated

Artificial Intelligence Review (16 July 2020)

**A Review on Machine Learning in 3D Printing: Applications, Potential, and Challenges**

G.D. Goh, S.L. Sing, W.Y.Yeong

* Abstract
  + Introduces various ML techniques followed by discussion on their use in various aspects of additive manufacturing including design for 3D printing, material tuning, process optimization, in-situ monitoring, cloud service, and cyber security.
* Introduction
  + To overcome the time-consuming physics-based modeling and to detect anomaly during the in-process monitoring for quality control, data-driven models have been used in the AM field.
    - Also used in AM to recognize certain patterns or irregularities in dynamic manufacturing process
* Machine learning techniques
  + Supervised
    - Each training point contains label
    - I.e. linear regression, CNN
  + Unsupervised
    - Data does not contain labels
    - I.e. K-means
  + Semi-supervised
    - Mixture of labeled and unlabeled data, used for large datasets
  + Reinforced
    - Indication of correctness
* Applications
  + Part quality/process optimization
    - 3-layer artificial neural network (ANN) is sufficient (input, hidden, output)
  + In-Situ monitoring
    - Detection of flaws requires in-depth understanding of printing process as well as computer vision knowledge
      * Most common used ML technique in CV is CNN
* Challenges
  + Computational cost
    - Data-driven numerical simulations using ML are more computationally efficient than physics-based numerical simulations
  + Standard for qualification
    - Sharing of data is key for ML algorithms to work

Elsevier: Manufacturing Letters (29 June 2019)

**Autonomous In-Situ Correction of Fused Deposition Modeling Printers using Computer Vision and Deep Learning**

Zeqing Jin, Zhizhou Zhang, Grace X. Gu (second paper in list by these authors)

* Abstract
  + Real-time monitoring and autonomous correction systems are developed, where a deep learning model and a feedback loop is used to modify 3D printing parameters iteratively and adaptively.
* Introduction
  + Fused deposition modeling (FDM) technology slices model into thin layers where polymer filament is deposited to sketch contour and fill internal area layer-by-layer
    - Prone to errors such as under-extrusion and over-extrusion
  + Develops autonomous system incorporating advanced ML algorithms to classify, detect, and correct printing issues (CNN)
* Experimental set-up and methods
  + Machine learning system consists of two parts: post-training procedure and in-situ real-time monitoring and refining
  + Records videos that are labeled with corresponding categories, Good Quality, Over-extrusion and Under-extrusion
  + Camera mounted over nozzle to see image of layer, 20 images captured every 6 seconds and fed into model, 224x224 image
  + CNN has 3 convolutional layers, uses softmax activation
* Monitoring and self-correction
  + Among different printing parameters are print-speed, flow-rate and nozzle height
  + Paper focuses on adjustment of flow rate
    - Flow rate is major factor causing under/over extrusion (other parameters are thought to be minor)
* Conclusion
  + 98% accuracy in predicting printed part status quality
* Yuhan’s Notes
  + Most relevant to current project
  + Paper focuses on adjusting flow rate to correct over/under extrusion, is this synonymous with adjusting the pressure in our system?
  + One of our models sorts errors into 5 classes, an argument for this model can be made because we are thinking about all the variable parameters in the printing process, which some are ignored by this paper
  + This paper thinks nozzle height, one of our considerations for over/under extrusion is minor

Elsevier: Additive Manufacturing (19 July 2020)

**Open Source Computer Vision-Based Layer-Wise 3D Printing Analysis**

Aliaksei L. Petsiuk, Joshua M. Pearce

* Abstract
  + Describes open-source computer-vision-based hardware structure and software algorithm that analyzes layer-wise 3D printing processes, tracks errors, and generates approximate actions to improve reliability
  + Analyzes both shape of printed object and internal structure of its layers
* Introduction
  + Mentioned previous paper (Delli and Chang) that proposed binary 3-D printing error classification
  + Key point of previous works is addressing limited number of specific classes of local defects without taking into account global parameters of printed parts
  + Type of errors
    - Mechanical parameters of printer and environment
    - Temperature parameters of fan/nozzle and bed
    - Algorithm for converting STL to GCode instructions
* Algorithm
  + Proposed algorithm detects printer failure with angled camera that observes both current layer and overall shape
  + Monitors critical errors such as blocked nozzle, major deformations, lack of material, etc and aborts printing
* Conclusion
  + Algorithm development is challenging to (1) uniquely visualize/determine error and (2) establish causal relationship between error and parameter involved and (3) declare in advance what parameter to change to correct error
* Yuhan’s Notes
  + Analyzes pattern of internal layer as well as overall structure of printed object (3D objects/STLs)

Nature Review Materials (January 2021)

**3D-Printed Multifunctional Materials Enabled by Artificial-Intelligence-Assisted Fabrication Technologies**

Zhijie Zhu, Daniel Wai Hou Ng, Hyun Soo Park, and Michael C. McAlpine

* Abstract
  + Electronic and biological links for in-situ 3D printing, AI-powered 3-D printing approaches with open-loop, closed-loop, and predictive control, and recent developments in surgical robotics and AI that could be integrated in future 3D printing approaches
* Open-Loop 3D printing
  + Leverages pre-acquired (offline) sensory data such as reconstructions and laser-scans
* Closed-Loop 3D printing
  + Integrates sensing as part of printing process
  + Real-time adaptation to changes in operation environment, such as motion, deformation of target surface, printing defects, ink-flow control, and nozzle function (CNNs for computer vision to combine machine learning)
* Yuhan’s Notes
  + Briefly mentioned computer graphics and printing to define mechanical structure
  + Focused on biological applications