Melt Pool Depth Prediction in Directed Energy Deposition Single-track Prints Using Point Cloud Analysis

Youmna Mahmoud, Jiaqi Lyu, Chaitanya Krishna Prasad Vallabh, Souran Manoochehri
Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ

OBJECTIVES

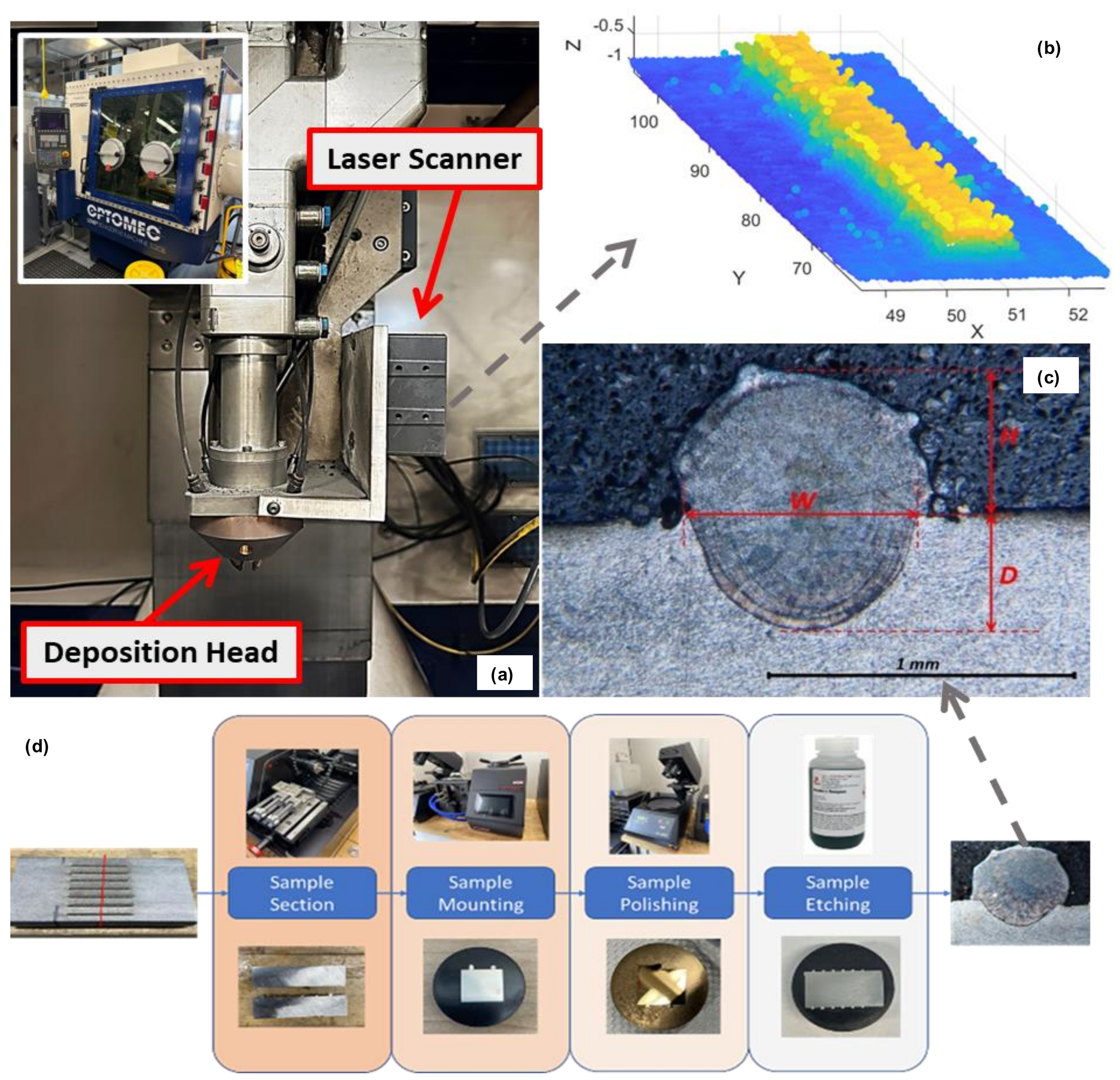
Problem Statement: Study melt pool features for improved dimensional accuracy and mechanical performance in Directed Energy Deposition (DED) process, elevating its reliability and precision compared to conventional methods.

Motivation: Traditional assessment of melt pool size in metal additive manufacturing (AM) is time-consuming and expensive, involving tasks like cutting, polishing, and detailed microscopy.

Research Aims:

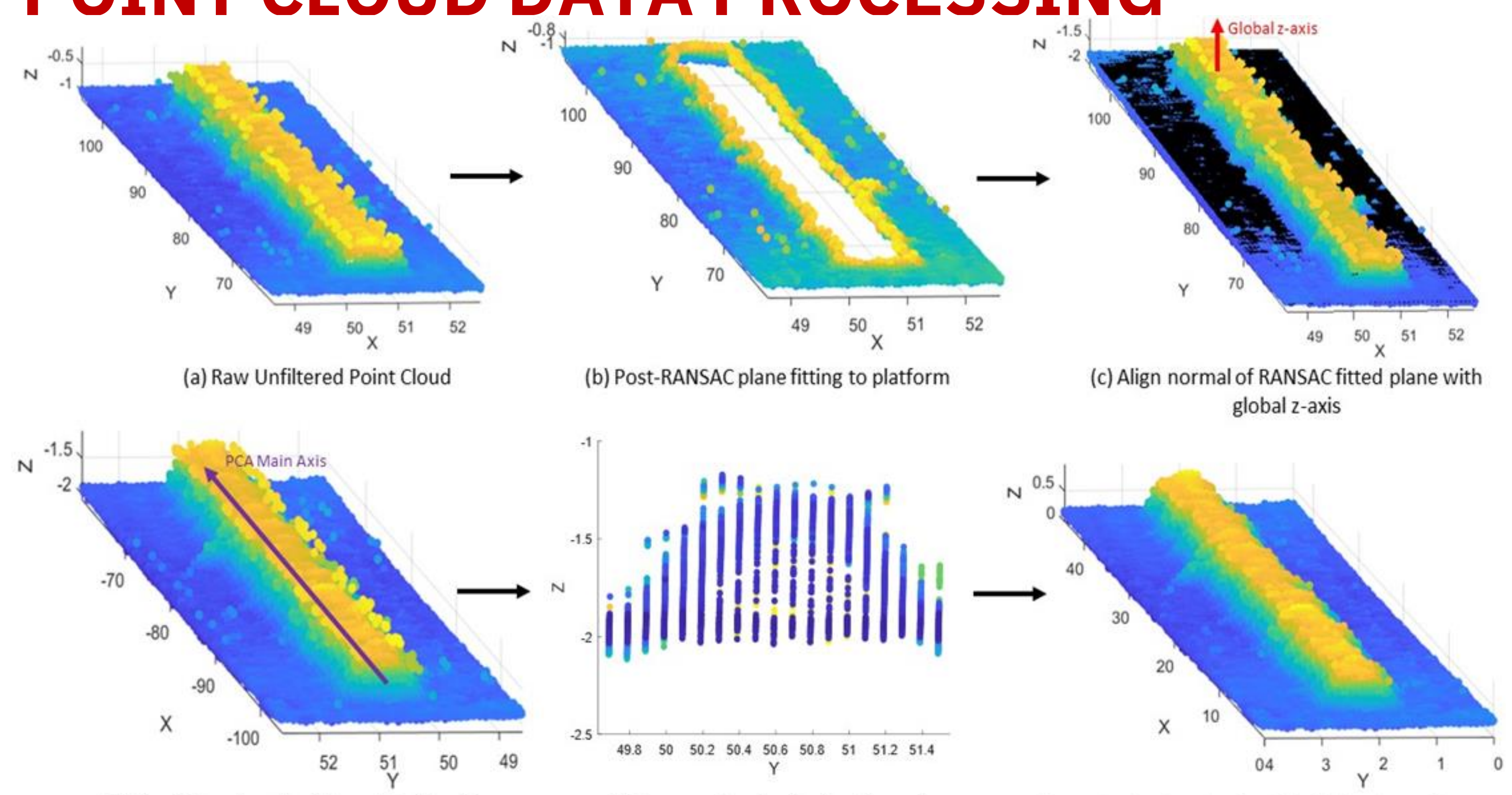
- Utilize point cloud data from a laser scanner combined with Machine Learning (ML) models to predict melt pool depth in deposited single-track prints, a parameter typically unobservable during print inspection, particularly when using a laser scanner.
- Automating the analysis of captured point cloud data, eliminating the need for manual parameter selection in filtering algorithms.

EXPERIMENTAL SETUP

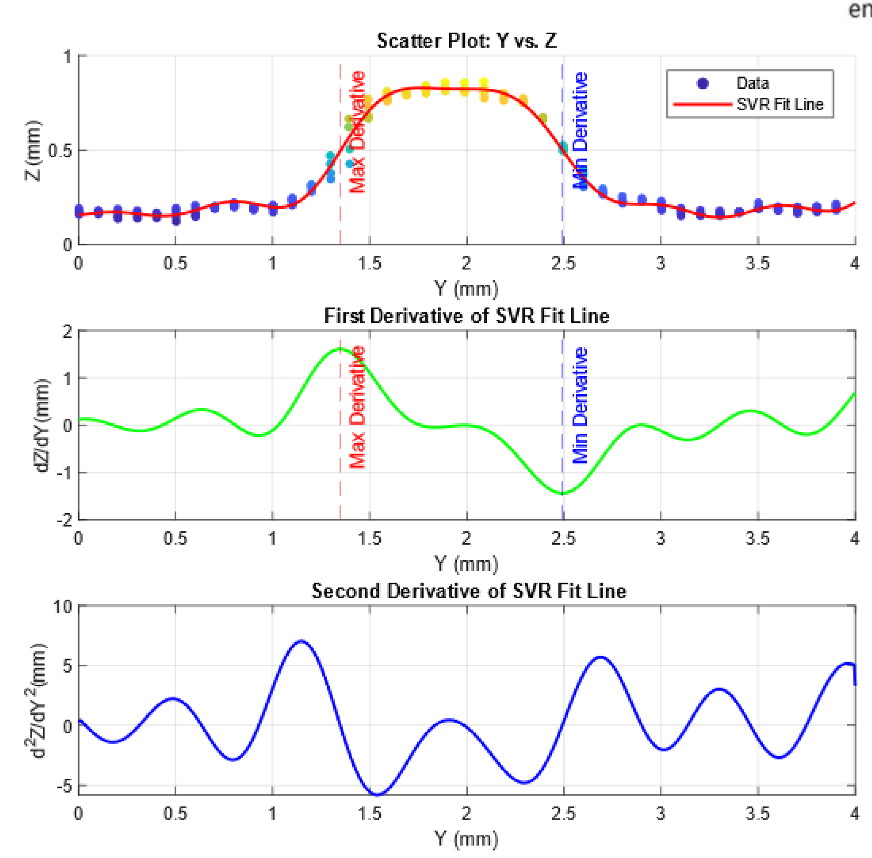


(a) Laser scanner setup on printer head (b) Captured point cloud scan of single-track print (c) Optical Microscopy cross section image (d) Sample processing steps

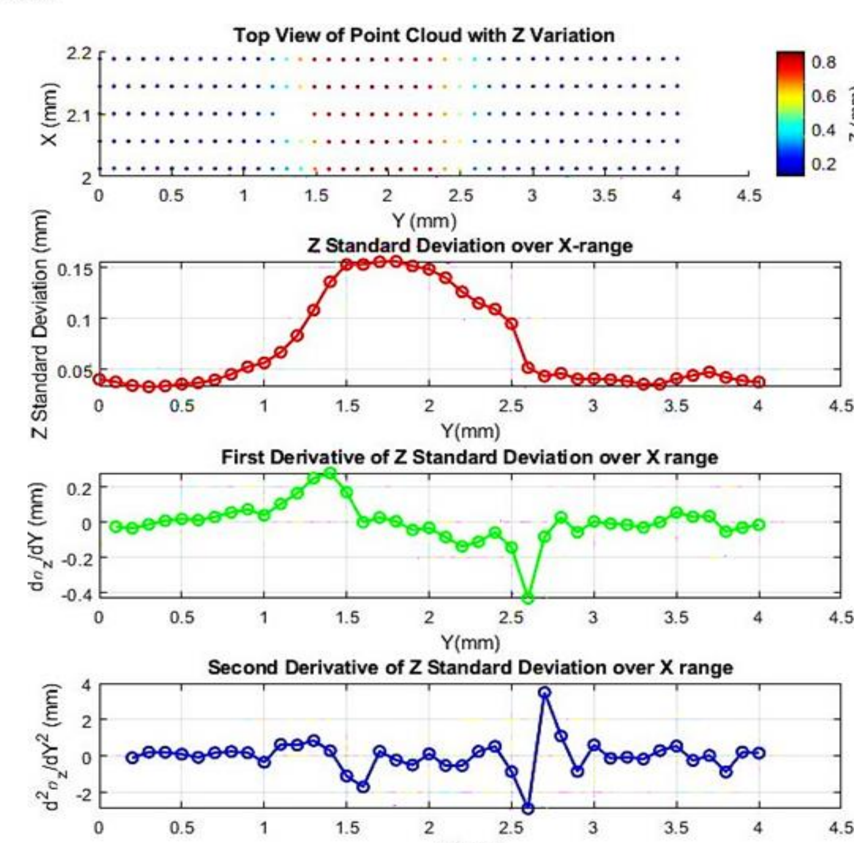
POINT CLOUD DATA PROCESSING



(a) Raw Unfiltered Point Cloud
(b) Post-RANSAC plane fitting to platform
(c) Align normal of RANSAC fitted plane with global z-axis
(d) The PCA main axis of the printed track is adjusted to align with the global X-axis
(e) Rotate point cloud using tilt angle to align YZ-data points from start to end of track
(f) Denoised point cloud with initialized coordinates



Evaluating the front view of the cross-sectioned point cloud data for measuring the track width

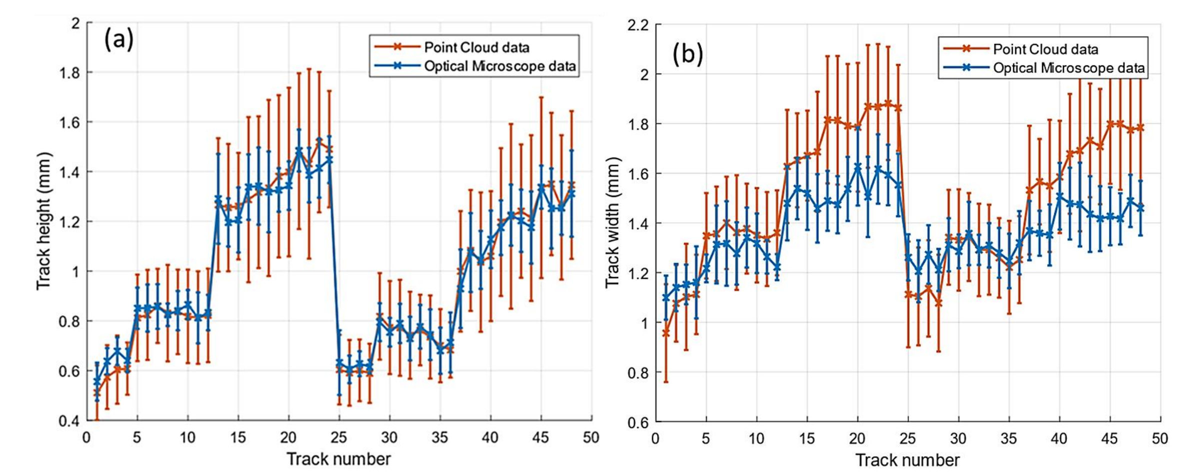


Evaluating the cross-sectioned point cloud data from the top view to use the z-standard deviation to measure the track's height

The process parameters along with the track's width and height extracted via a multi-step point cloud data processing algorithm were utilized to train ML models to predict the melt pool depth.

ML models employed in this study: Linear Regression, Decision Tree (DT), Support Vector Regression (SVR), Gaussian Process Regression (GPR), and Neural Networks (NN).

RESULTS



The track's width and height, as measured by laser scanner point cloud data and optical microscopy, show good agreement.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|C_{mi} - C_{pi}|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(C_{mi} - C_{pi})^2}$$

ML models' performance: Out of all the regression models used, the Gaussian Process Regression (GPR) shows the best performance with the smallest MAE and RMSE values.
By incorporating the extracted track width and height collected by the laser scanner in addition to the process parameters, a significant enhancement in the prediction accuracy of the melt pool depth is achieved, specifically, an improvement of 63.78% in MAE and 19.9% in RMSE, as shown in Table 1.

Table 1: GPR model's performance metrics for depth prediction given different inputs

GPR Model Inputs	MAE (μm)	RMSE (μm)
Laser Power, Scan Speed, Powder Feed Rate, Track Width, Track Height	**18.89**	**25.50**
Laser Power, Scan Speed, Track Width, Track Height	27.40	37.78
Laser Power, Scan Speed, Powder Feed Rate	**52.15**	**31.85**
Track Width, Track Height	41.29	59.11

CONCLUSIONS AND REMARKS

- Findings point to a promising potential for these developed methods to eventually eliminate the need for external post-processing in characterizing the melt pool dimensions of printed tracks by solely relying on a laser scanner.
- Automated point cloud processing operates efficiently, irrespective of the print regime — be it conduction, transitive, or keyhole.
- **Future work:** Implementing data fusion techniques to integrate laser scanner data with information from various sensors for real-time monitoring of melt pool behavior in both single-track and multi-layer DED prints.

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