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DIMENSIONAL COMPARISON OF A COLD SPRAY ADDITIVE MANUFACTURING SIMULATION TOOL

R.A. Murray*, G. Foy*, L. Clemon†

*Advanced Manufacturing Alliance, Charles Darwin University, Darwin, 0909, Australia
†School of Mechanical and Mechatronic Engineering, University of Technology Sydney, Ultimo, 2007, Australia

Abstract

High-velocity particle spray greatly increases metal additive manufacturing deposition speed over other commercial methods. Accurate prediction and measurement of this process will improve process control. A LightSPEE3D machine fabricated symmetric copper components. On-board software predicts the build geometry (.stl) given the input geometry and the build settings. Assessment of prediction accuracy is needed to enable rapid part design and print setting optimization. White-light 3D-scanning and high-fidelity optical microscopy scans are compared to the simulation and intended 20mm cubes using hausdorf distance:
1. Control-repeated scans: 0.38±0.48mm, max:2.25mm
2. Intended-original vs. scans: 1.42±1.58mm, max:6.72mm
3. Software-predicted vs. scans: 0.44±0.66mm, max:3.97mm
Discrepancies up to 6.72mm and asymmetric fabrication artifacts were identified. The reduction in the hausdorf distance for simulation vs intended-original, and larger distance of the simulation compared to control, indicate the simulation tool may enable rapid optimization given over/under spray quantification. Recommendations for reducing asymmetric fabrication artifacts and over/underspray are provided.

Keywords: Cold spray, Scanning, Part Inspection, Metal Additive, High-velocity Particle Spray

Introduction

A key challenge in additive manufacturing (AM) is the speed of material deposition for a given precision. For metal AM, post-processing is often necessary for final parts. High velocity particle spray, sometimes referred to as cold spray [1], embraces post-machining as a necessary step and greatly increases the deposition rate metal AM with this consideration. High-velocity particle cold spray greatly increases metal additive manufacturing deposition speed over other commercial methods. Commercial cold spray machines can achieve deposition rates up to 100g/min [2][Spee3D] and 750g/min [3][Titomic]. To achieve such high deposition rates, precision in each deposited track of material is traded. However, accurate prediction and quantification of this trade-off is not well documented. Post-machining relies on excess built material to achieve desired surface finish and dimensional accuracy for a fielded product. Better quantification and prediction of the overbuilt, or potentially underbuilt, areas is needed. Not all small and medium sized enterprises (SMEs) that could benefit from rapid fabrication offered by this technique maintain a metrology laboratory. Lower cost scanning technologies and open source software may offer SMEs access to fully utilize high-velocity cold spray. Part inspection using 3D scanning has been shown to be speedy, reliable and precise [4]–[7]. This manuscript approaches this challenge by establishing a systematic accounting of errors from solid modelling to fabricated part, comparing lower cost scanning techniques with high-end precision measurements, and reporting the deviations at each step. This quantification of errors and error build-up will help improve prediction and measurement of this process and inform future control algorithms.

Methodology

This research quantifies the error in high velocity particle spray additive manufacturing for a LightSPEE3D machine from initial CAD model to 3D scanned part model. Five stages are identified in the process of creating a component model and producing a scan of the final product. These five stages are identified as:

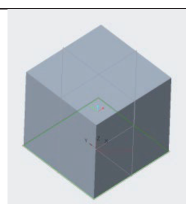
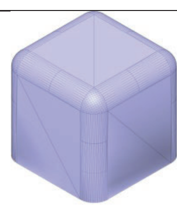
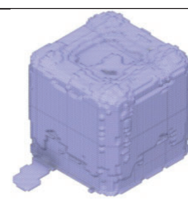
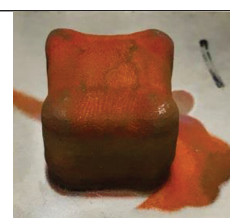
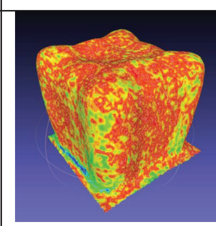
1. Initial solid model (CAD) – the original design of the component prior to adjustment considering machine and process limitations.
2. Print optimised model – the massaged model accounting for known design rules associated with the fabrication machine and process.
3. Machine predicted part model – a simulated/predicted outcome of the part generated by a proprietary software native to the machine, Genesys Simulation for this work.
4. Fabricated Component – the physical object created using the selected process and machine.
5. Scanned part model – a 3D representation of the physical component created using a tactile, optical, or other scanning method.

A solid 20 mm cube was designed in CAD, designated ‘initial solid model’. This initial solid model was adjusted for printability on a LightSPEE3D machine by rounding the corners using known fabrication constraints of the machine, designated ‘print optimised’. The print optimised model was loaded into the LightSPEE3D machine for fabrication preparation. On-board proprietary software (Genesys Simulation at the time of the experiments, now called TwinSPEE3D) predicts the build geometry (.stl) given the input geometry and the build settings. This software converted the print optimised model into a ‘predicted model’ based on the fabrication settings and output a “tool path” for the printer to fabricate the part. Next, the part was fabricated to form a solid copper component affixed to an aluminium plate. A second component was fabricated using the exact same initial model, print optimised model, predicted model, tool path and an identical aluminium build plate and orientation. These components were then scanned using both a Solutionix C500 structured-light 3D-scanner scanner and high-fidelity optical microscopy (Nikon LC15Dx laser scanning coordinate measuring machine). These scanning techniques generate point clouds of data. The point clouds of scans from different orientations are stitched together using software built into each scanning systems. For the Soluntionix, the software is ezScan 2017. For the Nikon, the scanning software is Geomagic. Point stitched and repaired point clouds are then compared in MeshLab [8]. Point clouds are reconstructed using the Poisson surface reconstruction tool [9]. Meshes are aligned using the Align tool, point-based alignment. Then the meshes are frozen in place and Hausdorff distance between them is computed [10]. The results of the Hausdorff distance computation are reported and used in the error quantification. Colorized images are created by using the Colorize by vertex quality tool in MeshLab. The above mesh alignment and comparison process is used for each scan comparison. The following comparisons are computed:

1. Print optimised solid model vs. Scanned Part Model 1
2. Software-predicted vs. Scanned Part Model 1
3. Solutionix C500 scan vs. Nikon LC15Dx scan

For this initial investigation, the simplest model possible has been generated, a unit square. This component allows for initial fundamental examination of errors as they change over the 5 stages of production. The discrepancy between each stage of production is of interest as errors may compound at later stages.

Table 1: Stages of fabrication

Model	Initial solid model (CAD)	Print Optimised (CAD)	Software-predicted Model	Fabricated Part	Scanned Part Model
File types	.stl, .prt, .stp	.stl, .prt, .stp	.stl, .ot	n/a	.stl, .ply, points
					

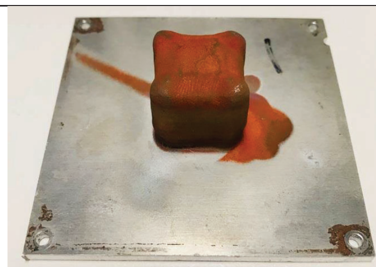
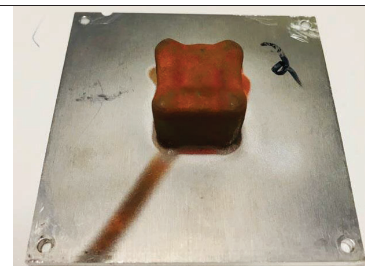
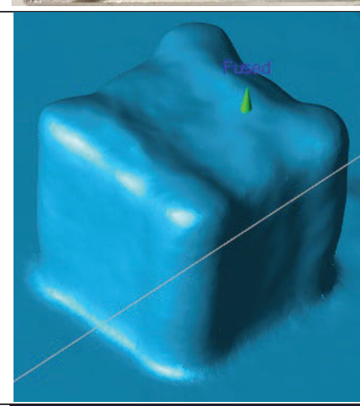
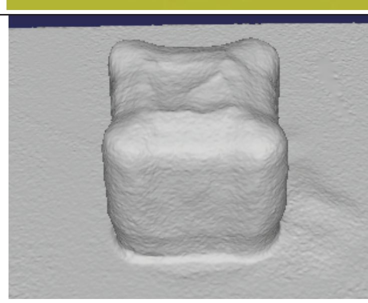
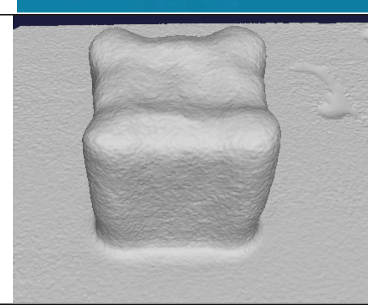
We measure the difference between electronic representations of the component at each stage. For each comparison we designate a reference and a target model.

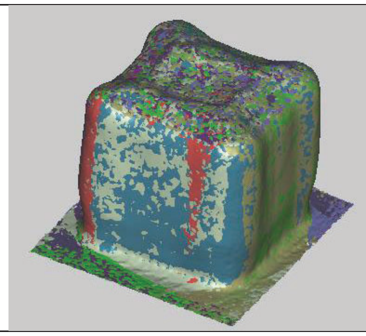
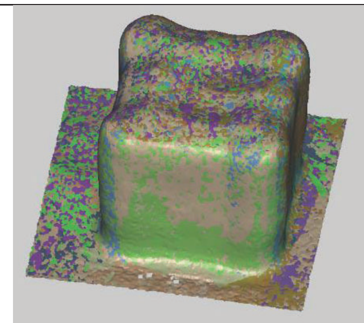
Discrepancy between the CAD file and an achievable component using this machine is computed using the CAD model as a reference and comparing the predicted model from the native machine tool controller. Discrepancy between the predicted achievable component from the onboard controller and the actual component is computed.

Results

The original CAD model and software prediction for both components is identical and depicted in Table 1 above. The actual components and scans are slightly different. Visual inspection shows a clear asymmetric artifact in component one on the top surface (Table 2), as well as numerical comparison (Figure 1). This asymmetric fabrication is less obvious in component 2, indicating a statistical variation in fabricated components for the same machine inputs. Two scanning methods are depicted, a high-end high-resolution scan using a Nikon LC15Dx laser scanning coordinate measuring machine. The grey colored sections of the overlayed components indicate areas where the reference scan (Nikon generated) protrudes. The color indicates distance of difference between the two scanning techniques. Cooler colors going toward blue represent less deviation, where warmer colors going toward red indicate a higher deviation.

Table 2: Comparison of fabricated components using different scanners

	Part1	Part2
Picture		
High-end scanner (Nikon)		
Low-end scanner (Solutionix C500)		

High-end vs low-end scan comparison		

Scans of each block were repeated 5 times using the Solutionix C500. Repeated scans show a consistent deviation between the two scanning methods, where the maximum deviation is 0.316 mm. This deviation is significantly lower than the deviation generated by other steps in the fabrication process. The results of comparing the low-end scanner to the reference scans (Nikon) are summarized in Table 3.

Table 3: Comparison of low-end scanning with reference scan.

Part1	Scan1	Scan2	Scan3	Scan4	Scan5	**Average**
Max (mm)	0.190	0.218	0.219	0.242	0.316	**0.237**
Mean (mm)	0.019	0.018	0.020	0.019	0.023	**0.020**
RMS (mm)	0.026	0.024	0.027	0.026	0.030	**0.026**

Part2	Scan1	Scan2	Scan3	Scan4	Scan5	**Average**
Max (mm)	0.142	0.133	0.164	0.148	0.152	**0.148**
Mean (mm)	0.014	0.016	0.016	0.016	0.013	**0.015**
RMS (mm)	0.019	0.021	0.021	0.019	0.017	**0.020**

The deviation of pairwise comparisons for each stage of fabrication are as follows:

1. Print optimised solid model vs. Scanned Part Model: 1.42±1.58mm, max:6.72mm
2. Software-predicted vs. Scanned Part Model: 0.44±0.66mm, max:3.97mm
3. Solutionix C500 scan vs. Nikon LC15Dx scan: average 0.017 mm, max=0.32 mm

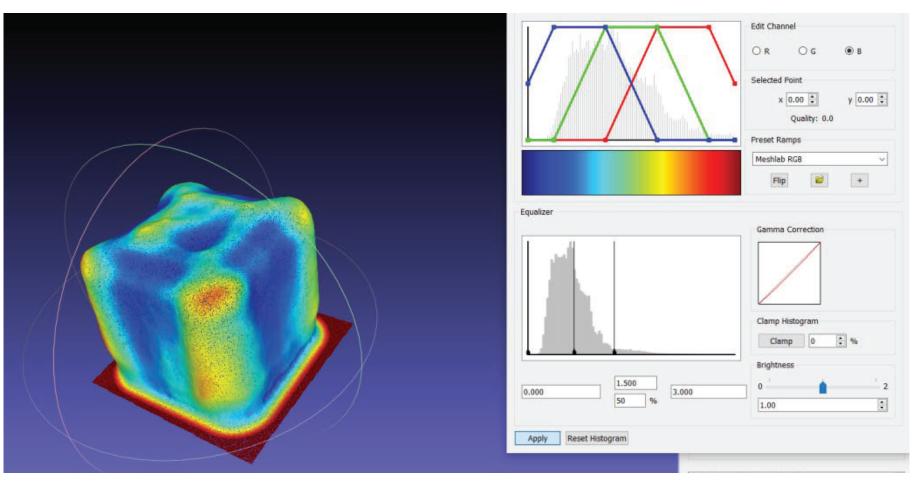


Figure 1: Hausdorff distance color map for scans Scanned Part Models printed with the same settings

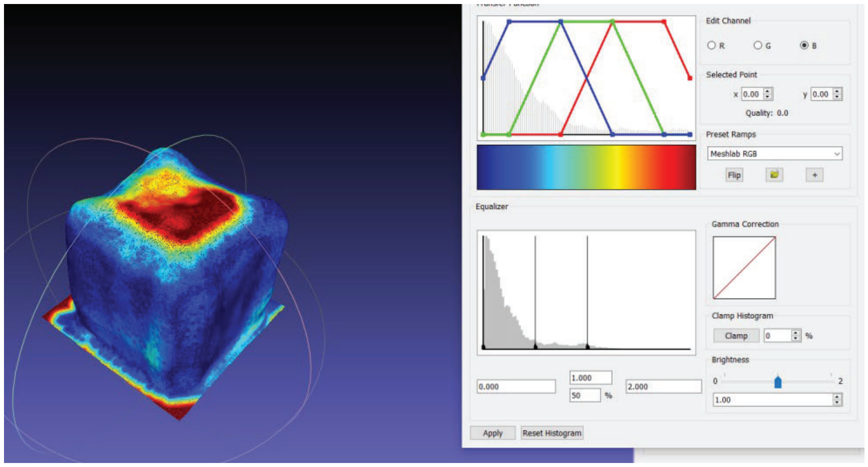


Figure 2: Hausdorff distance color map for Software-predicted model and Scanned Part Model

The highest deviation comes from the initial solid model designed and the scanned part model. The second largest deviation comes from the software-predicted model and the scanned part model (Figure 2). Third largest deviation comes from the repeatability of the machine to make identical rough parts (Figure 1). Deviation between the two tested scanning techniques was the smallest of all deviations.

Conclusions

The results indicate a deviation in scan size using an inexpensive scanning system when compared to a high resolution scanner. This is positive toward enabling SMEs to utilize this process for a subset of work without need for a full metrology laboratory and high-end equipment. The results provide an order of areas that should be addressed to improve prediction and execution of this process. While the highest deviation occurs between the initial solid model and the scanned part model, this is expected as the high-velocity spray process intentionally overbuilds parts so they can be machined later. Effort could focus on reducing this overbuild to the minimum possible, but underspray should be strictly avoided. The error in the software-predicted model represents an opportunity for improvement. While on average, this deviation is less than 1mm, the maximum deviation is significant at almost 4 mm, which occurs near the base of the components. The base of the components is likely to be consumed in post-machining. This deviation for simple component, such as the 20 mm cube here, a 4 mm deviation is 20% error in one direction. Improving the software prediction for final part geometry is highlighted as a need going forward. More complex components may also change the overspray, or underspray, areas as the spray angle varies.

We identified a breakdown of the stages of fabrication and inspection for high velocity particle spray additive manufacturing. The difference in scanning methods for a cost effective scanner and a high end scanner for a simple part were measured. The differences indicate potential for adoption of low cost scanning methods for AM parts in this process. The results provide a prioritization of focus areas for future improvement in each of the identified 5 stages, both the software prediction and desired final part could be improved. Discrepancies up to 6.72 mm and asymmetric fabrication artifacts were identified. The reduction in the Hausdorff distance for simulation vs initial-original, and larger distance of the simulation compared to control, indicate the simulation tool may enable rapid optimization given over/under spray quantification. Recommendations for reducing asymmetric fabrication artifacts and over/underspray are provided.

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