Supplementary Information
A Process for Estimating Minimum Feature Size in Selective Laser Sintering

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Abstract

This document provides additional information, data, and results removed for conciseness from the publication, “A Process for Estimating Minimum Feature Size in Selective Laser Sintering” by Weiss, Diegel, Storti, and Ganter, Rapid Prototyping Journal, 2017.

Test Artifact Iteration

When a statistically reasonable logistic fit to the data is possible (i.e. if p < 0.5 and the fit region stays roughly within the range of manufactured features), the Green boundary is taken to be the 95% probability of a Green feature. To help prevent inverted results, an artificial data point of Not Green is included at 0 thickness. The transition is reported with a 90% Wald confidence interval, which highlights the uncertainty present when few trials have been used.

When a sharp Green transition occurs, no probability distribution is present and the 95% Green transition is approximated from the largest Not Green characteristic dimension d_{yr} and the smallest Green diameter d_g according to,

$$p_{95} = \frac{d_g + d_{yr}}{2} + \max(|d_g - d_{yr}|, d_\Delta)$$

where d_Δ is the dimension step size in the previous iteration. No confidence interval is possible for this case.

When a reasonable logistic fit is possible, the range of feature sizes to include in the next iteration is set to be the 5%-95% probability interval. When no logistic fit is available, a heuristic is utilized. The procedure utilized is summarized in the following pseudocode.

Listing A. Feature Range Update Heuristic Logic

```
Given:  last_min, last_max (minimum and maximum feature thickness of last run)
        all_min, all_max (minimum and maximum feature thickness over all runs)
        lowest_green, highest_notgreen (data over all previous samples of this feature)
        logistic_05, logistic_95 (5% and 95% probability from a logistic fit)
        logistic_p_value (p value from the logistic fit)
        min_allowed (smallest allowable feature thickness)
Return: next_min, next_max (minimum and maximum feature thickness for next run)
Function NextFeatureRange:
   IF logistic_p_value < 0.5 AND logistic_95 – logistic_05 < 2 * (all_max – all_min):
      next_min ← logistic_05
      next_max ← logistic_95
   ELSE:
      center ← (lowest_green + highest_notgreen) / 2
```

```
center_percent ← (center – last_min) / (last_max – last_min)
centered ← (center_percent > 0.35) AND (center_percent < 0.65)
IF NOT centered AND last_min == min_allowed AND center_percent < 0.5:
    centered ← True
IF centered:
    new_span ← (last_max – last_min) * 0.75
    new_center ← center
ELSE IF lowest_green NOT FOUND:
    new_span ← (last_max – last_min) * 2
    new_center ← last_max
ELSE IF highest_notgreen NOT FOUND:
    new_span ← (last_max – last_min) * 2
    new_center ← last_min
ELSE:
    new_span ← (last_max – last_min)
    new_center ← center
next_min ← MAX(min_allowed, new_center – new_span / 2)
next_max ← MAX(min_allowed, new_center + new_span / 2)
```

Suitability of Logistic Regression

Underlying the use of logistic regression to analyze the data for each feature shape and orientation assumes that the physical system follows a logistic probability curve. To evaluate this, an additional test artifact with five features shapes was selected and manufactured 16 times, to produce 96 data points (6 copies per part x 16 manufacturing runs). No iteration was performed over the 16 manufacturing runs, and the 16 parts produced were of identical design. Figure A(a) shows the coding for a single feature shape at 6 scales over the manufacturing runs, and Figure A(b) shows a plot of the logistic fit obtained and the percentage of green features in each scale “bin”.

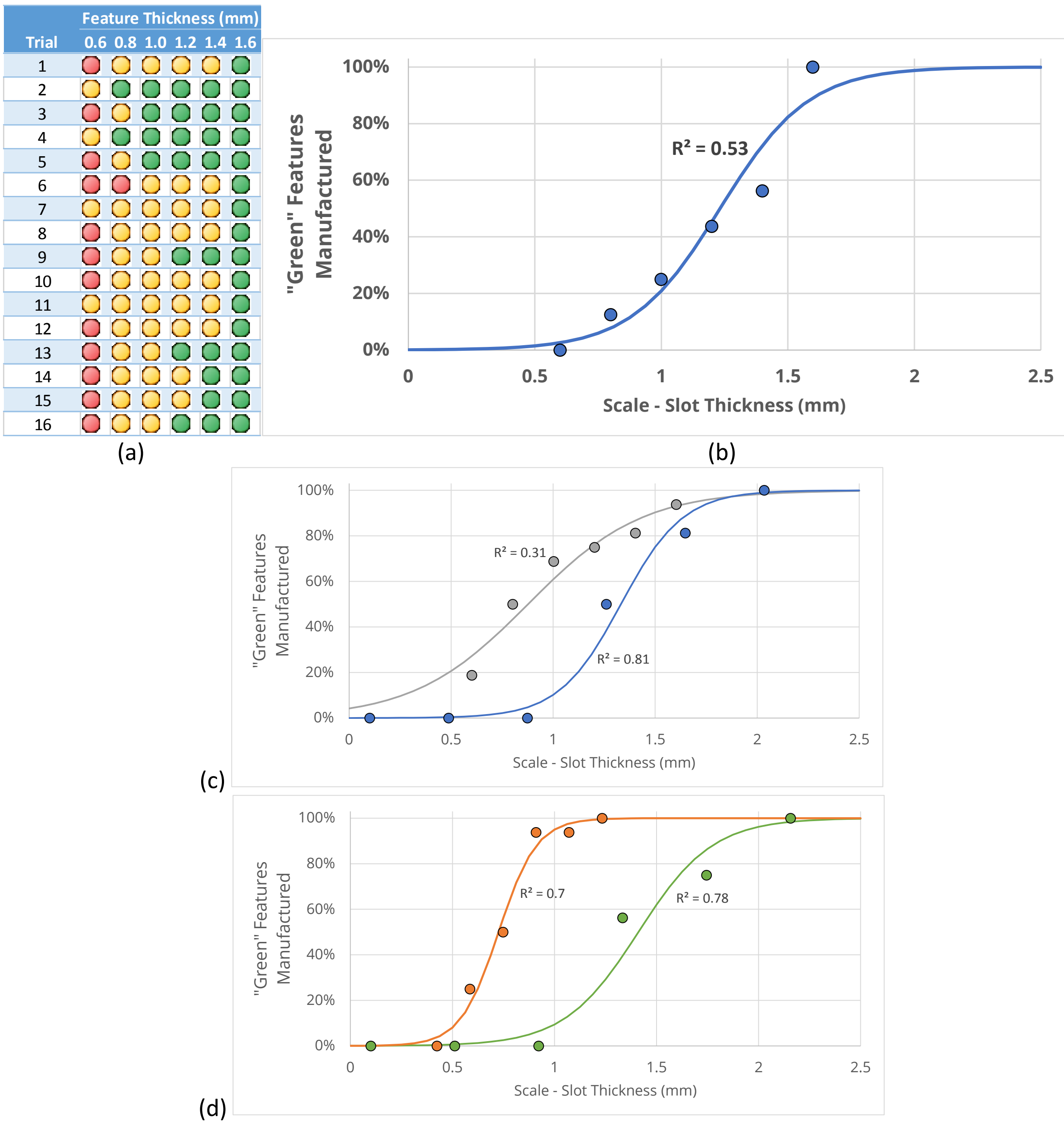
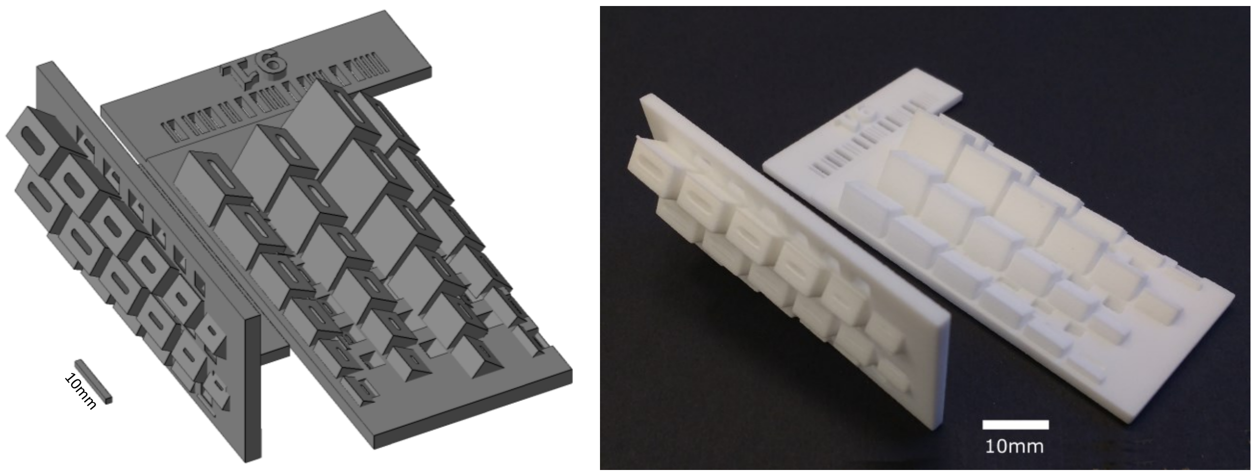


Figure A. Logistic Regression fit evaluation. (a) Coding of six scales of a single feature over 16 manufacturing runs. (b) Experimentally-determined probability of success (points) plotted with the obtained logistic regression. (c), (d) Results obtained for the other four feature shapes and orientations evaluated.

Validation

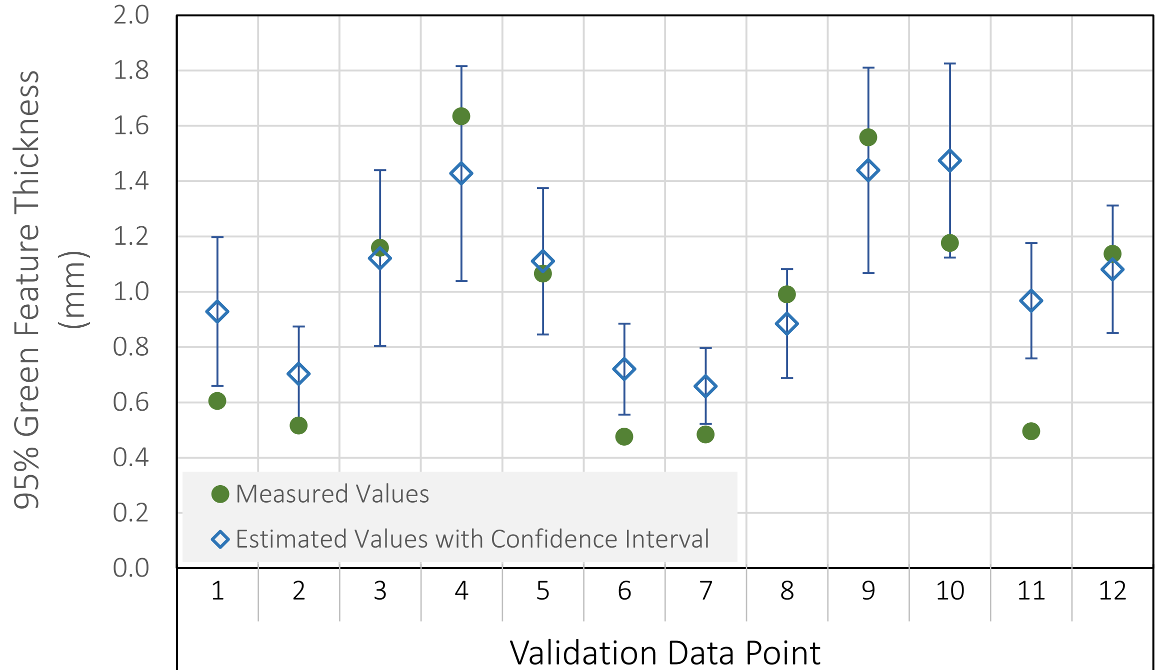
The validation test artifact provides an iterative mechanism to evaluate features of arbitrary coordinate in the parameter space in a manner similar to that used in the main test artifact. The validation test performed in this study involved a series of points sampled on a sphere in the parameter space (see the main paper for the sphere size chosen). Figure B shows a digital rendering and photograph of this test part in its first iteration.



(a) (b)

Figure B. Validation test artifact, first iteration. (a) model (b) as manufactured.

The results of the validation study are shown in Figure C. Each validation data point corresponds to one coordinate sampled as described above and reported in the data table attached to the plot in Figure C. The measured values obtained from the manufacture of five copies over three iterations of the validation test artifact are compared with the expected value based on the trilinear interpolation from the main test artifact, and good agreement is shown.



		1	2	3	4	5	6	7	8	9	10	11	12
Measured 95% pt. (mm)		0.605	0.516	1.159	1.634	1.065	0.476	0.484	0.991	1.558	1.176	0.496	1.138
Est. 95% pt. (mm)		0.928	0.704	1.122	1.428	1.111	0.720	0.659	0.885	1.439	1.474	0.968	1.081
Est. Confidence Interval (mm)		0.268	0.171	0.318	0.388	0.265	0.165	0.137	0.197	0.371	0.351	0.209	0.231
Error (mm)		0.323	0.188	-0.037	-0.206	0.045	0.244	0.175	-0.106	-0.119	0.298	0.471	-0.057
Error (%)		53.4%	36.3%	-3.2%	-12.6%	4.3%	51.3%	36.1%	-10.7%	-7.7%	25.4%	95.0%	-5.0%
Coordinate	r_l	5.86	3.38	5.38	7.38	6.62	4.15	2.62	3.38	5.85	6.62	4.62	4.14
	r_w	0.125	0.143	0.166	0.190	0.181	0.152	0.210	0.219	0.248	0.257	0.234	0.275
	ϕ	45.0	39.5	27.1	39.5	59.5	59.5	50.5	30.5	30.5	50.5	62.9	45.0
Green Features		19	20	16	16	16	16	18	18	14	17	13	18
Total Features		30	30	30	30	30	30	30	30	30	30	30	30

Figure C. Measured and estimated 95% Green Transition thicknesses for the 12 points in the validation dataset. Estimates use Equation 1; measurements represent five manufacturing runs over three iterations of the validation test artifact.

Additional Information

The raw data associated with the experiments run is included with this submission as an attachment.

Models, the Excel program used to process the data, and other information are available upon request to the corresponding author, Duane Storti, who can be contacted at storti at uw dot edu.

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