Studying the Effect of Lensing Phenomena in Laser Powder Bed Fusion

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OBJECTIVES & TASKS

GOAL

To study the lensing effect in parts made from laser powder bed fusion additive manufacturing process

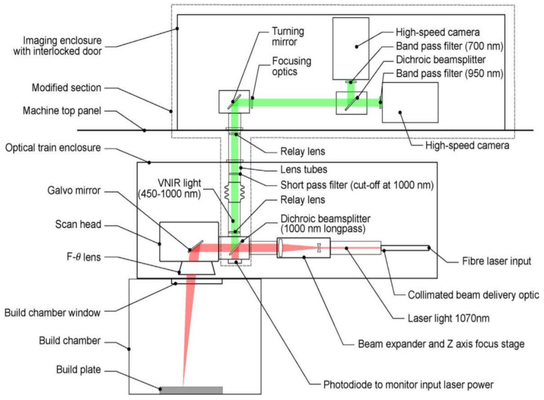
OBJECTIVE

To monitor the variability in part quality due to change in laser focus height by analyzing sensor data using computer vision and machine learning algorithms

TASKS:

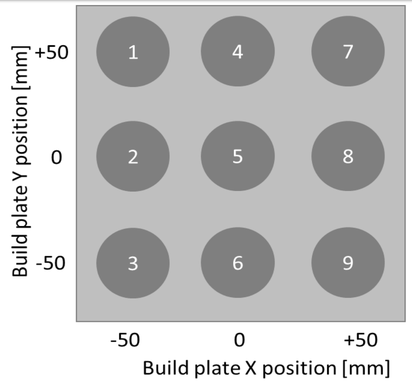
- Analyze sensor data using computer vision algorithms to extract features
- Classify sensor data into focused vs defocused
- Predict nine different laser focus heights given sensor data

EXPERIMENT DESIGN



Build no.	Laser focus height [mm]								
	1	2	3	4	5	6	7	8	9
1	-16	-4	-8	8	-12	4	12	0	16
2	16	4	8	-8	12	0	-12	-4	-16
3	0	8	12	-12	4	-16	-8	16	-4

EXPERIMENT DESIGN

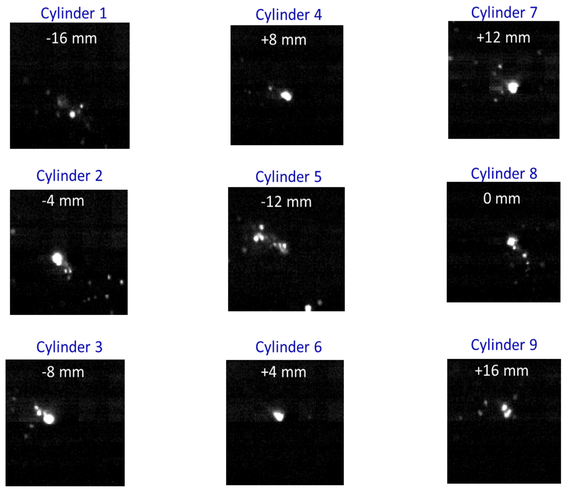


9 titanium cylinders were built with varying laser focus height and position on build plate

- Cylinder diameter = 5 mm, height = 10 mm
- Laser focus height range: -16 to +16 mm [-16:4:16]

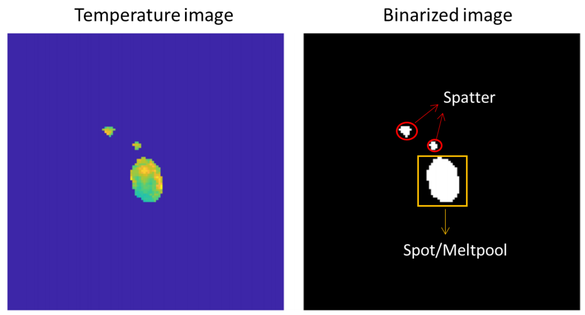
IMAGE ANALYSIS

The training data used to teach our machine learning algorithm originates from an experiment run at the London Imperial College. Below are high-speed camera images taken from the training data at each laser focus height. In order to introduce cost effective measures, a formula was developed to produce temperature images from different intensity values originating from two high speed cameras.



EXTRACTED FEATURES

Computer vision algorithms were used to extract features from temperature, and intensity images



TRENDS OF EXTRACTED FEATURES

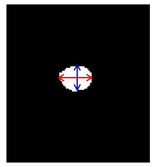
Below are the observations made from intensity images

- Spot roundedness is affected by laser focus height.
  - Highest spot roundedness is observed at +4 mm laser focus height.
- Spot size is affected by laser focus height.
  - More the laser is in-focus, smaller is the spot size.
- Max spot intensity is affected by laser focus height.
  - High spot intensity is seen at +4 mm laser focus height.
- Spatter mean eccentricity is affected by laser focus height.
  - Least spatter mean eccentricity is observed at +4 mm laser focus height.
- Spatter mean diameter is affected by laser focus height.
  - Least spatter mean diameter is observed at +4 mm laser focus height.
- Spatter mean intensity is affected by laser focus height.
  - Least spatter mean intensity is observed at +4 mm laser focus height.

Similar trends are observed in temperature images

Meltpool features are extracted from each high-speed camera frame

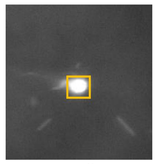
Meltpool area



$A_a^i = \pi \times L_{major} \times L_{minor}$

A_a^i= Area of meltpool
L_{major}= Major axis length
L_{minor}= Minor axis length

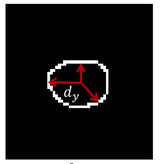
Meltpool intensity



$I_a^i = \sum_{x=1}^{M} I_x$

I_a^i= Intensity of meltpool
I_x= Intensity of a pixel in the meltpool
M= number of pixels in the meltpool

Meltpool circularity



$circ(\mu)_a^i = \frac{\sum_{y=1}^{E} d_y}{E}$

$circ(\sigma)_a^i = \sqrt{\frac{\sum_{y=1}^{E} d_y - circ(\mu)_a^i}{E}}$

d_y= distance from center to edge pixel y
E= number of edge pixels

RESULTS

The confusion matrix below displays the accuracy of each machine learning classification algorithm for different levels of classification. 9-way classification is the highest level as there are 9 categories to be classified. The 5-way and 4-way classification methods redistributed the 9 variables into 5 categories and 4 categories, respectively. The redistribution protocol for these categories is defined below.

500, 1000, 4000 and 12000 data points were used for each LFH. No major difference is seen in accuracy.

	9-way classification	5-way classification	4-way classification
Support vector machine	**42.10%**	**50.30%**	**54.92%**
K-nearest neighbors	38.99%	42.69%	50.88%
Linear discriminant analysis	35.65%	40.33	49.25%
Decision tree	36.66%	39.4%	51.40%

5-way classification

-16 & -12	-8 & -4	0 & 4	8 & 12	16

4-way classification

-16 & -12	-8 & -4	0 & 4	8 & 12 & 16

This methodology does not perform well in LFH classification

CONCLUSIONS & FUTURE RESEARCH

Through the creation of a confusion matrix and using it to analyze the accuracy of meltpool area and intensity to predict laser focus height, we can conclude that current methodology is not accurate enough to perform laser focus height classification.

The features from the meltpool that we extracted are not enough to capture the variability in data caused by changing laser focus height. Fortunately, there are a multitude of other features that we can incorporate into our machine learning algorithm. For example, splatter features could be capable of increasing the accuracy of the classification algorithm. Specific splatter features showing promise of increasing the accuracy include spatter mean eccentricity, spatter mean diameter, and spatter mean intensity.

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