

Melt Pool Monitoring Data Registration for Powder Bed Fusion Additive Manufacturing

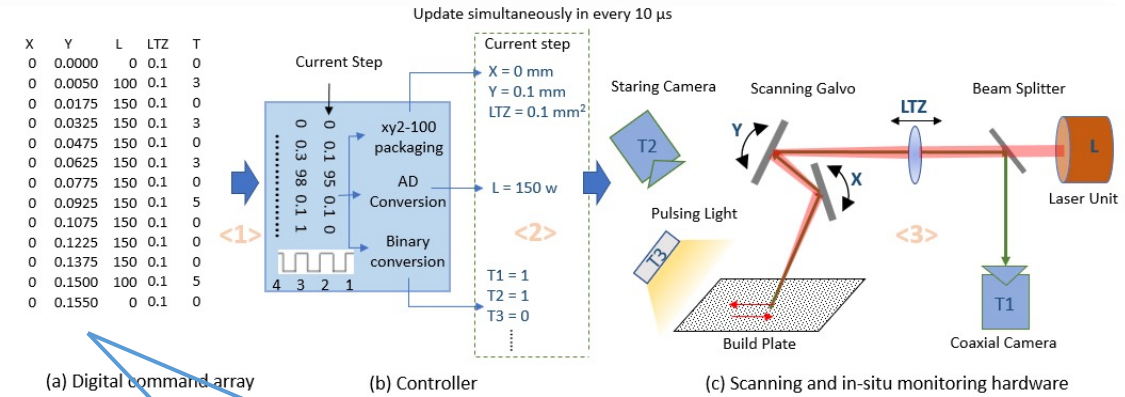
National Institute of Standards and Technology (NIST)

Mentors: Dr. Yan Lu (NIST) and Dr. Zhuo Yang (NIST)

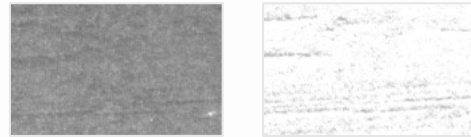
Judges: Dr. Brandon Lane (NIST), Dr. Hui Yang (PSU), Dr. Hyunwoong Ko (ASU)

Background – AM and PBF

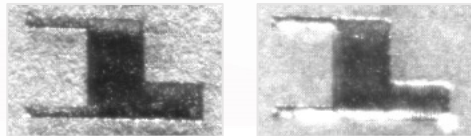
- Powder bed fusion process
- Fully control the laser scan path
- Advanced scan pattern
- In-situ monitoring data



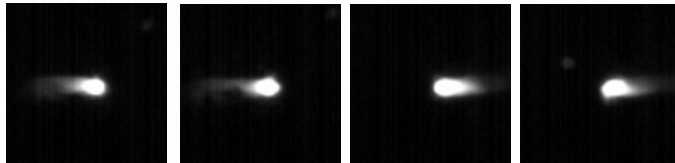
Paved powder



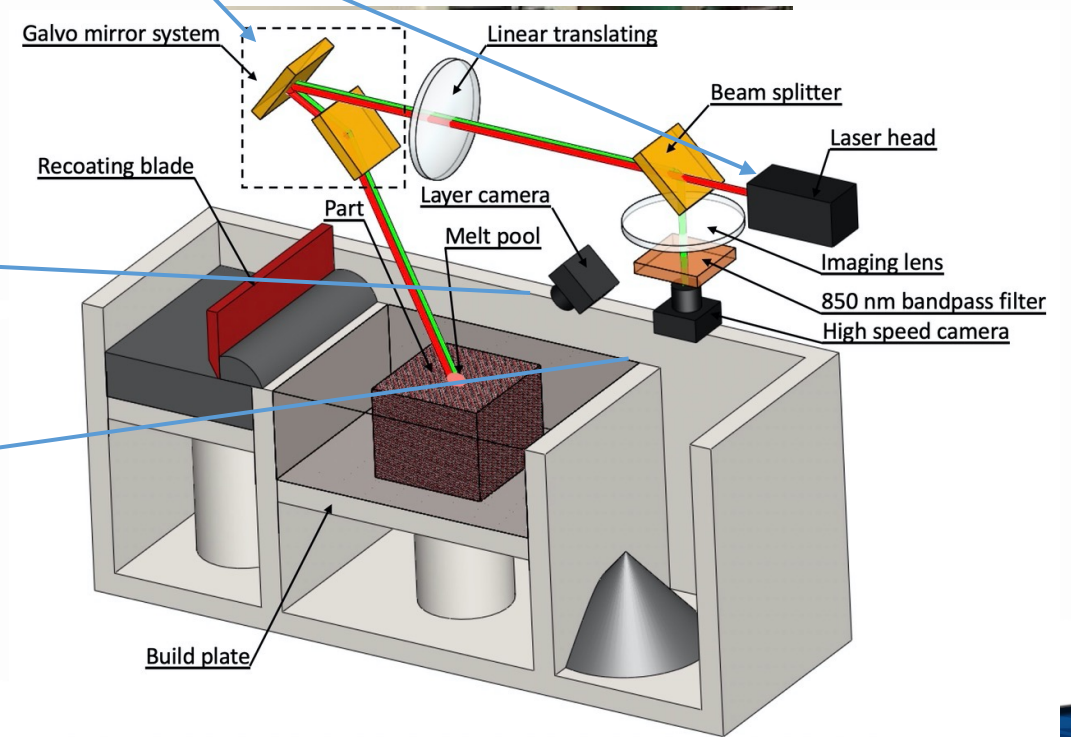
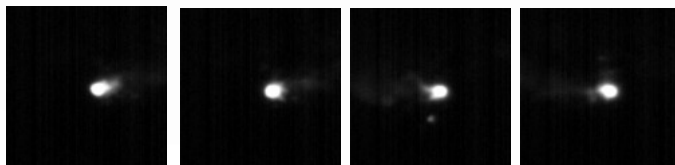
Burned layer



Regular



Irregular

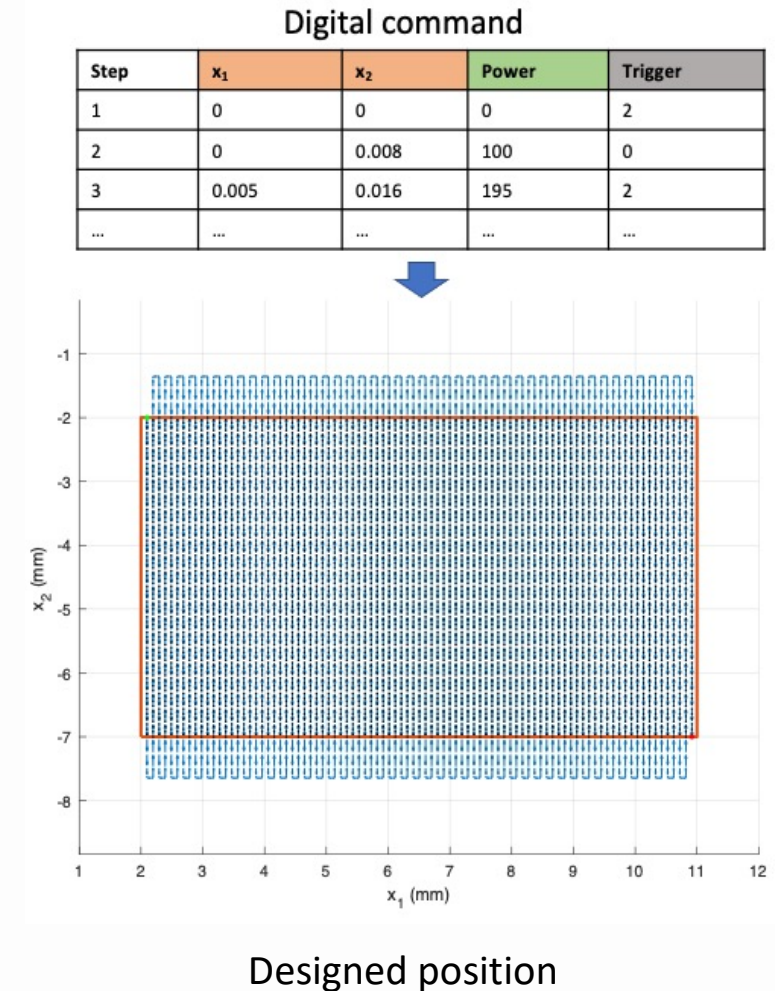
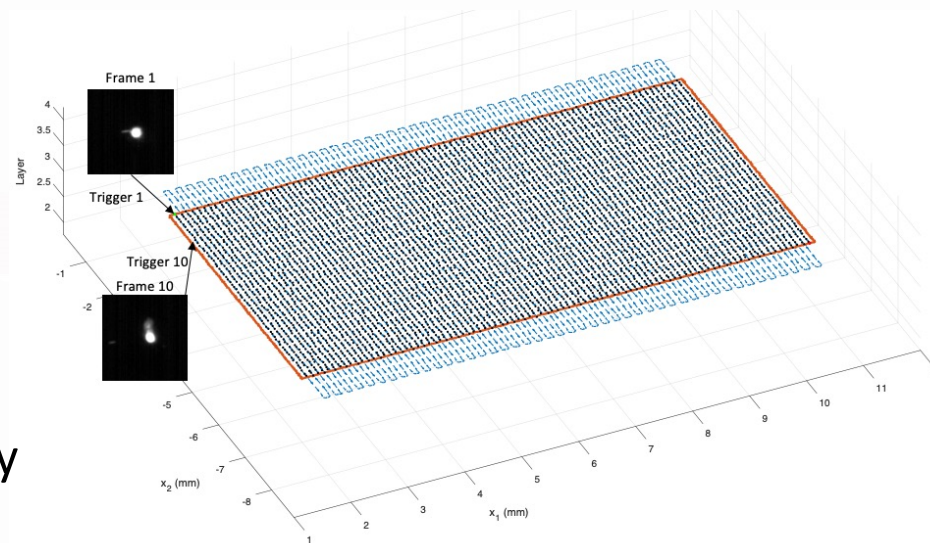


Challenges when dealing with all data together

- Data from different sensors and saved independently
 - Timestamp
 - Coordinate system
 - Format
 - ...
- Without data alignment & synchronization, it is hard to
 - Analysis
 - Evaluation
 - Build model
 - ...
- Solution – AM data registration

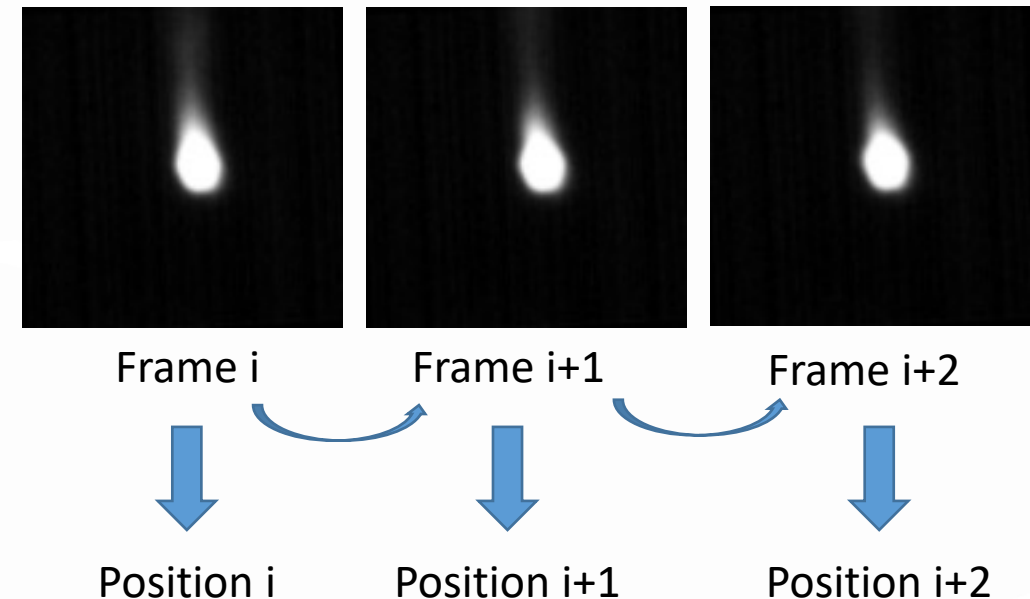
What is Image Data Registration?

- Alignment and synchronization
 - Laser positions were saved in command data
 - In-situ images were saved separately
- Challenges
 - Sensor delay
 - Missing data
- How?
 - In-situ image
 - File name
 - Feature
 - Scan strategy
 - Part shape
 - Pattern
 - Sample frequency
 - Command file
 - Camera trigger



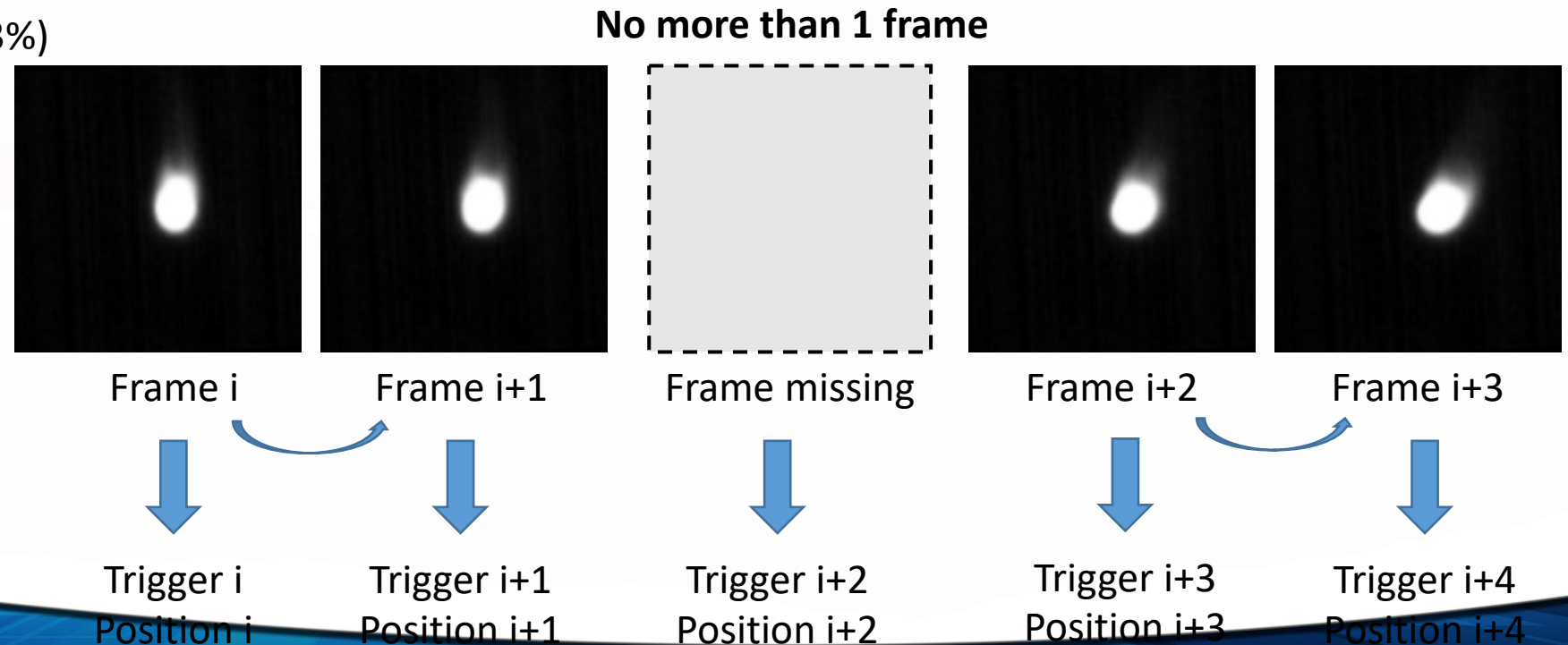
Part A – register ideal data

- Goal
 - Register the melt pool images to where they were taken in machine coordinate system
- Given information
 - Laser information at every step – position & power
 - Scan pattern – start point & sampling frequency
 - All images
- Features
 - No missing images
 - Constant frequency (10,000 fps – every 100 μ s)
 - Regular scan pattern
 - Images only taken when laser is on
 - Start point == the first effective laser beam



Part B – register data with defect

- Same goal
- Given information
 - Laser information at every step – position & power & camera trigger (new)
 - Scan pattern – start point & sampling frequency
 - Image data
- Features
 - Few missing frames ($< 3\%$)
 - Continues scan path



What to submit?

	A	B	C	D
1	frame#	time(μ s)	x(mm)	y(mm)
2	1	0	0	0
3	2	0	0	0
4	3	0	0	0
5	4	0	0	0
6	5	0	0	0
7	6	0	0	0
8	7	0	0	0
9	8	0	0	0

Empty table

	A	B	C	D
1	frame#	time(μ s)	x(mm)	y(mm)
2	1	0	-0.55973	4.3275
3	2	100	-0.569	4.2894
4	3	200	-0.569	4.2462
5	4	300	-0.569	4.1994
6	5	400	-0.569	4.1453
7	6	500	-0.569	4.0816
8	7	600	-0.569	4.009
9	8	700	-0.569	3.931

Final table ready for submit
(example)

- Register the data
- Fill in time/position for each frame

Evaluation

- Average error (Euclidean distance)

$$\varepsilon = \frac{\sum_{i=1}^n \sqrt{(x_i^a - x_i^r)^2 + (y_i^a - y_i^r)^2}}{n}$$

- i: frame number
 - n: total frames
 - (x_i^a, y_i^a) : actual position
 - (x_i^r, y_i^r) : registered position
- Result worth 40% of final score
 - Part A – 20%, Part B – 20%

Example

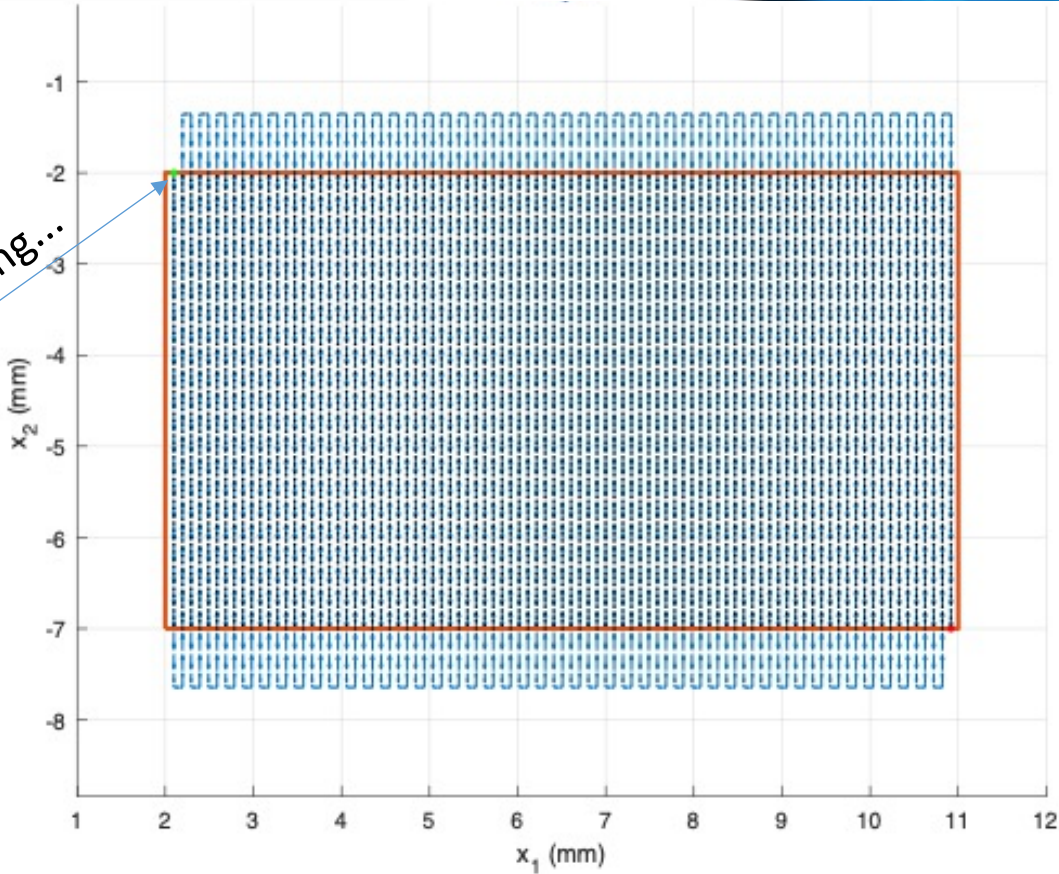
1	2	3	4
time(μ s)	x(mm)	y(mm)	power(w)
103390	2.1960	-7.1120	0
103400	2.1960	-7.1040	0
103410	2.1960	-7.0960	0
103420	2.1960	-7.0880	0
103430	2.1960	-7.0800	0
103440	2.1960	-7.0720	0
103450	2.1960	-7.0640	0
103460	2.1960	-7.0560	0
103470	2.1960	-7.0480	0
103480	2.1960	-7.0400	0
103490	2.1960	-7.0320	0
103500	2.1960	-7.0240	0
103510	2.1960	-7.0160	0
103520	2.1960	-7.0080	0
103530	2.1960	-7	195
103540	2.1960	-6.9920	195
103550	2.1960	-6.9840	195
103560	2.1960	-6.9760	195
103570	2.1960	-6.9680	195
103580	2.1960	-6.9600	195

Command file



frame000001?

Registering...



Plot

	A	B	C	D
1	frame#	time(- μ s)	x(mm)	v(mm)
2	1	103530	2.1960	-7
3	2	0	0	0
4	3	0	0	0
5	4	0	0	0
6	5	0	0	0
7	6	0	0	0
8	7	0	0	0
9	8	0	0	0

command_part_a.csv	Aug 8, 2021 at 23:23	1.7 MB
file_part_a.csv	Aug 8, 2021 at 23:23	39 KB
PA_MPM.zip	Aug 9, 2021 at 00:24	34.3 MB

Presentation

- 10 – 15 minutes for presentation, 3-5 minutes Q&A
- Tell the judges the story in the next 24 hours...
 - Data
 - Features
 - Methodologies
 - Result
 - Findings
 - Problems
 - Visualization
 - ...

Category	Criteria	Scoring
Technical Approach (30%) Methods and algorithms	<ul style="list-style-type: none"> Requirement analysis and problem formulation Literature review and exploration of ideas The development and design of the idea Scientific soundness of the approach Creativity of the approach Soundness of the algorithm (data pre-processing expected) Readiness of the idea and the approach Automated workflow: data/meta data acquisition through open interface 	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)
Results (40%) Output performance	<ul style="list-style-type: none"> The objective is successfully achieved, with distance between the estimated position and the ground truth evaluated by the Root Mean Squared Error (RMSE) Uncertainty analysis 	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)
Data Visualization (10%) Clarity, information	<ul style="list-style-type: none"> Overall clarity of data presented Visualization of data registration Model development Trend or correlation analysis 	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)
Overall Presentation (20%): Organization, structure and message conveying	<ul style="list-style-type: none"> Title, headings, labels: Appropriate size, location, spelling, and content The demonstration of teamwork Structure and Clarity Boarder impact of the idea to ME subfields 	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)

Good Luck!