ASME® 2020 HACKATHON

CONFERENCE
IMECE®

LOCATION
Virtual
DATES
November 14–15, 2020

2020 ASME-IMECE Hackathon: Identifying, Extracting, Analyzing of Value from Large Unstructured Data Sets in Mechanical Engineering

Virtual Event, November 14-15, 2020

In conjunction with IMECE 2020

Sponsored by

ASME Computers & Information in Engineering Division (CIE)
ASME Manufacturing Engineering Division (MED)
ASME IMECE / Advanced Manufacturing Track (AMT) &
ASME Technical Events and Content (TEC) Sector Council

ASME Manufacturing Engineering Division (MED) Centennial Celebration Event

For more details and sample datasets, please visit the Hackathon GitHub

$25 for Hackathon event (can be done as a conference add-on or stand-alone).

Click to Register for the Hackathon

Access to the Competition Sample Datasets HERE

Meeting Location: Zoom Links TBA

Important Dates:
- **Sign up Deadline November 10, 11:59 PM EDT**
- **November 14, afternoon: Hackathon kick-off**
- **November 15, afternoon: Due for Hackathon deliverables**
- **November 15, evening: Awarding ceremony**

Awards:
- **First Place: $2,000**
- **Second Place: $1,000**
- **Third Place: $500**

Hackathon Problem 1: **Generating an Interpretable Surrogate Model for Predicting Damage Accumulation in Manufacturing**

Problem Statement

The Bernard M. Gordon Learning Factory is a hands-on facility for engineering students, which provides modern design, prototyping, and manufacturing facilities. Many of the machines in the Learning Factory are instrumented using a sensor suite that provides monitoring capabilities. The readings from a heterogeneous set of sensors are used to report metrics continuously for many different machines. These sensors record various values every 10 minutes, such as temperature, velocity, and acceleration. The sensors also provide a computed damage accumulation measure, which is helpful for predictive maintenance.

The objective of this problem is to create an interpretable data-driven surrogate model that predicts the damage accumulation of machines and explains what has caused such damages. Specifically, you will develop a mathematical representation or equation to perform the prediction task. The technical approaches may include but are not limited, neural networks, surrogate modeling, dimensionality reduction, and even simple linear regression. However, your findings cannot merely comprise prediction results. That means, in addition to achieving satisfactory prediction accuracy, you are also expected to interpret your results, e.g., identify and explain which variables are most influential, to what extent they affect machine damage, and why they are important. The interpretation should be based on sound theories and physics underlying the observation, i.e., the damage accumulation. The resulting model and the generated insights and knowledge would be useful to the Learning Factory as a digital twin, enabling them to assess future usage scenarios for the machines and calculate the damage accumulation associated with those scenarios.

Implicit Challenges

Machine learning (ML) has been widely used in the Mechanical Engineering fields and has offered great potentials for improving product design, process control, and manufacturing. But **ML algorithms usually do not explain their predictions**, which is a barrier to the adoption of ML in many engineering disciplines where the underlying physics and science are critical to knowledge discovery. Recently, explainable methods for gaining an in-depth understanding of the problem-solving abilities and prediction of nonlinear ML, such as Long-Short Term Memory (LSTM) units, ensemble learning, and kernel methods, are therefore receiving increased attention.

This data and use case presents several challenges. These include:

- Is it feasible to construct a data-driven digital twin for forecasting? (Kunath et al., 2018)

- What is the best approach to identifying appropriate signals in this data with which to make predictions? (Long et al., 2019)
- How to interpret the findings based on the underlying physics?
- How to differentiate correlation vs. causation?

Datasets

Data is provided for several different machines, including three Bridgeport mills, one drill press, and one lathe. Each machine has several sensors, and each of these sensors collects data such as peak velocity, RMS velocity, peak acceleration, and temperature. A damage accumulation value is also computed from these data. Data is logged approximately every 10 minutes. Specifically, these files are provided for each machine:

1. **[machine name]week1-train.csv**
   This file contains training data for one week, including both independent variables (velocity, acceleration, etc.) and dependent variables (damage accumulation)
2. **[machine name]week2-train.csv**
   Same format as above, but for a second week.
3. **[machine name]week3-test.csv**
   This file contains data that you will use to make predictions for submission and scoring. Specifically, it contains independent variables but not dependent variables.
4. **[machine name]week3-submit.csv**
   You will use this file to submit your predictions. These files are explained in more detail under the Submission section below.

A partial example of the training data is provided below and shows one of the independent variables (peak velocity) and one of the dependent variables (damage accumulation). Every machine will have 11 independent variables and 2 dependent variables (damage accumulation in two different modes).

Machines > Lathe 1 > MIB > Y-Vertical > Peak Velocity		Machines > Lathe 1 > MIB > Y-Vertical > Damage Accumulation	
Time (UTC)	Avg(in/sec)	Time (UTC)	Avg(Damage)
2/15/20 5:08	0.0032806	2/15/20 5:08	0.9889563
2/15/20 5:18	0.0031057	2/15/20 5:18	1.0187886
2/15/20 5:28	0.0035309	2/15/20 5:28	1.012189
2/15/20 5:38	0.0023349	2/15/20 5:38	1.0183065
2/15/20 5:49	0.0040037	2/15/20 5:49	0.9838173
2/15/20 5:59	0.0019277	2/15/20 5:59	0.9948952
2/15/20 6:09	0.0037558	2/15/20 6:09	0.9767354
2/15/20 6:18	0.0027029	2/15/20 6:18	1.0100354
...	...	...	...

Submission

1. You will submit one CSV file for each machine (a total of 5 training files). Templates are provided to you and are named with the format **[machine name]week3-submit.csv**. Do not edit the time values in column 1 or headers in row 1. You should fill the remainder of columns 2 and 3 with your predictions, based on inputs from **[machine name]week3-test.csv** and the time values provided in the submission file.

2. The presentation slides. More information about the presentation and the presentation template will be introduced during the Hackathon kick-off meeting.

A partial example of a filled submission file is provided below.

Time (UTC)	Machines > Lathe 1 > MIB > X-Axial > Damage Accumulation	Machines > Lathe 1 > MIB > Y-Vertical > Damage Accumulation
2/29/20 5:06	0.86683465	0.91679842
2/29/20 5:16	0.33197709	0.3755712
2/29/20 5:26	0.07547059	0.12803265
2/29/20 5:36	0.06430619	0.04984671
2/29/20 5:46	0.41965689	0.36266437
2/29/20 5:56	0.57093488	0.18604864
2/29/20 6:07	0.38318072	0.95258113
2/29/20 6:17	0.17897555	0.48990568
2/29/20 6:26	0.18985331	0.25177106
...	...	...

<u>Judgment Rubric</u>

It is important to note that only 30% of your score will rely on the results from your algorithm, while the rest will be based on your approach, creativity, and presentation.

Category	Criteria	Scoring
Technical Approach (35%): Methods and algorithms of the proposed data analytics and visualization	• Requirement analysis and problem formulation • Literature review and exploration of ideas • The development and design of the idea • The readiness of the idea and the approach • The results are appropriately interpreted and can be supported by existing theories, physics, or principles. • Discovered additional (hidden) features that would be influential to machine damage beyond the provided features.	Excellent (31-35 pts) Very good (24-30 pts) Good (17-24 pts) Limited (9-16 pts) Poor (1-8 pts)
Creativity and innovation (20%): A new direction in the field to approach the problem	• The technology breaks new ground • The project makes a profound break from established design • The project adds a major departure from established design • The code adds a new twist on established design • The chosen technology and design is already deeply established	Excellent (17-20 pts) Very good (13-16 pts) Good (19-12 pts) Limited (5-8 pts) Poor (1-4 pts)
Results (35%)	• The objective is successfully achieved, which is measured by the Mean Squared Error and the R-squared metric.	Team with the best performance (35 pts) Team with the second-best performance (24 pts)

Output performance and V&V		Team with the third-best performance (18 pts) Teams at fourth and fifth ranks (10 pts) Rest (3 pts)
Overall presentation (10%): Organization, structure, and message conveying	• 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)

<u>Subject Matter Expert:</u>

Christopher McComb, Assistant Professor, School of Engineering Design, Technology and Professional Programs, Pennsylvania State University

Zhenghui Sha, Assistant Professor, Department of Mechanical Engineering, University of Arkansas

Binyang Song, Postdoctoral Researcher, School of Engineering Design, Technology and Professional Programs, Pennsylvania State University

Faez Ahmed, Assistant Professor, Department of Mechanical Engineering, Massachusetts Institute of Technology

<u>References:</u>

1. Kunath, M., & Winkler, H. (2018). Integrating the Digital Twin of the manufacturing system into a decision support system for improving the order management process. *Procedia CIRP*, 72, 225-231.
2. Long, Wen, Zhichen Lu, and Lingxiao Cui. “Deep learning-based feature engineering for stock price movement prediction.” *Knowledge-Based Systems* 164 (2019): 163-173.
3. Van Der Maaten, L., Postma, E. and Van den Herik, J. Dimensionality reduction: a comparative. *J Mach Learn Res* 10 (2009): 66-71.

<u>Hackathon Problem 2</u>: Smart Manufacturing – Melt-Pool Size Prediction for Powder-Bed Fusion Additive Manufacturing

<u>Problem Statement</u>

Additive manufacturing (AM) processes build parts layer-by-layer directly from 3D models. AM enables the fabrication of complex parts, which makes it an attractive alternative for high-value, low-volume production. However, the turnkey deployment of the technology hits consistent barriers including poor repeatability and lack of effective part qualification tools. Optimization and control of AM processes remains a challenge. In-situ monitoring provides the capability for early detection of AM process faults and defects, enabling optimization of process parameters and close-loop process control.

This hackathon subtopic aims to promote the use of data science in powder-bed fusion AM to predict the melt-pool size (area) based on build commands with high accuracy. Participants are expected to train a model based on the command files and in-situ coaxial images from 32 parts with more than 40,000 in-situ melt-pool images under different scan strategies to predict the melt-pool area. Teams would be asked to present their approaches to the judges and submit their predictions for validations. The final score of each team would be made based on Judgement Criteria.

<u>Challenges:</u>

- AM in-process data registration – how to align the coaxial melt pool images to real-world coordinates based on build command instructions.
- How to filter, denoise, or pre-process the raw images and segment melt pools from spurious data (e.g., noise or spatter) to get accurate measurements of the melt-pool size
- What features or parameterization of the build command data might affect the melt-pool form, trends, or features of interest.
- How to train an effective and efficient model to achieve high prediction accuracy while minimizing computational cost.
- Find an excellent way to visualize the resulting data and quantified model accuracy.

<u>Datasets:</u>

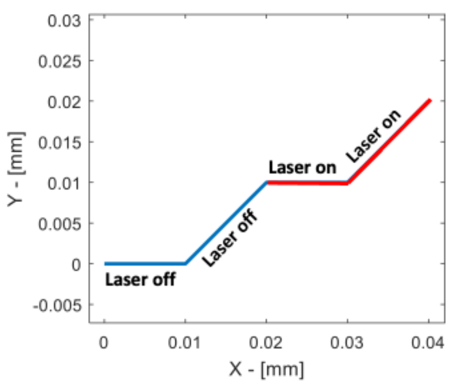
An experimental L-PBF build was conducted on the Additive Manufacturing Metrology Testbed (AMMT) at National Institute of Standards and Technology (NIST) [1]. The AMMT is a fully customized metrology instrument that enables flexible control and measurement of the L-PBF process [2]. A high-speed melt pool monitoring camera was used to capture melt pool images [3]. The galvo mirror system and the beam splitter allow the high-speed camera to observe the laser melting spot at every location the laser scans and melts material. Emitted light from the melt pool is imaged through a 850 nm (40 nm bandwidth) bandpass filter on to the camera sensor. On the AMMT, both the galvo and laser command are updated by field programmable gate array (FPGA) at 100 KHz. The digital commands are developed to specify the motion of the galvo scanner of the L-PBF system. It is transformed into a time series of scanner positions and laser power as control commands.

The dataset used in this problem is “20190711-HY-RHF” pertaining to an AM experiment performed on the AMMT by Ho Yeung on July 11, 2019 [4]. The powder is nickel superalloy 625 (IN625). The experiment uses continuous-varying laser power to scan multiple rectangle single layer parts on a bare build plate (i.e. no metal powder). Each part is a 3 mm x 2 mm rectangle with same scan geometry, but different laser power transient profiles that range from 145 W to 195 W. The 120 pixel × 120 pixel (at 8 µm\pixel) in-situ melt-pool images were captured at 20 000 frames per second.

Data sets and data formats used for the study include:

1) Data sets for build command for all parts (.csv)
    a. Each row is the command at one step. The time interval is 10 µs.
    b. First two columns are the laser beam position represented in the substrate coordinate system.
    c. The third column is the commanded laser power at that position.
    d. The last column is the camera trigger. The camera takes one image when the trigger value changes from 0 to 2 (i.e., rising edge).

X (mm)	Y (mm)	Power (W)	Trigger
0	0	0	0
0.01	0	0	0
0.02	0.01	100	2
0.03	0.01	100	0
0.04	0.02	0	2



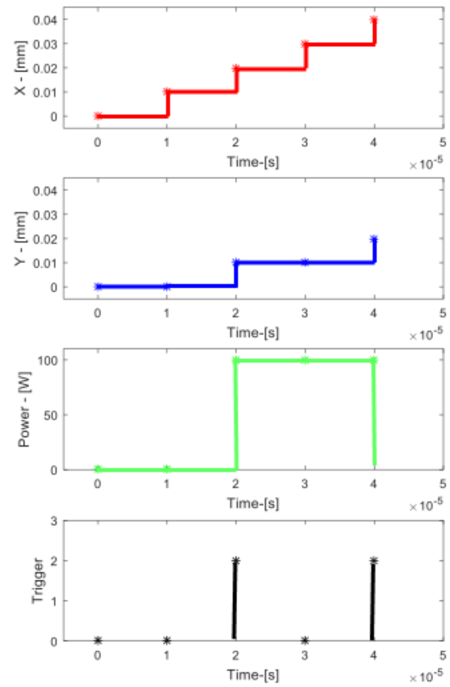


Figure 1. Command file demonstration

2) Coaxial melt-pool images sampled at 20 KHz for each part (.bmp)
    a. Frame number follows the trigger indexing
    b. Image format: grayscale BMP image files, 120x120, unsigned 8-bit integers representing 2^8 = 256 digital levels.
    c. In this problem, the active melting area has grayscale threshold of 80 digital levels
    d. The pixel size is 8 µm x 8 µm
    e. Recommended pre-processing may include removal of noise features such as spatter particles
    f. The melt-pool area of the ground choose is based on the total pixel area of melt-pool

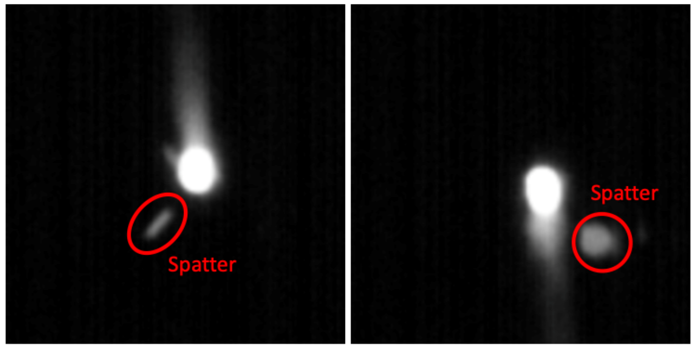


Figure 2. Raw coaxial melt-pool image with spatter

After applying the threshold, the measured melt-pool area is 0.0234 mm^2. Figure 4 shows a simple linear model (time vs. melt-pool area). The RMSE is 0.0029. We will rank each team's RMSE from low to high. The team with the lowest RMSE would receive the most pts.

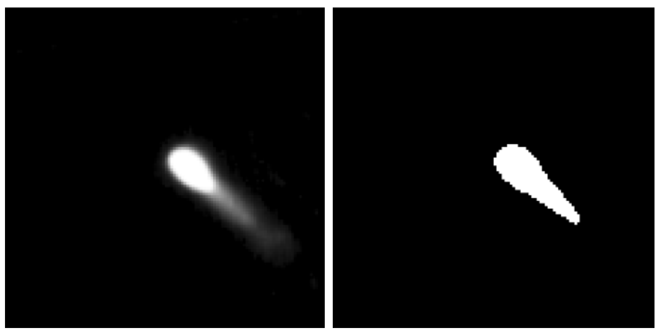


Figure 3. Regular melt-pool (left) area by grayscale threshold 80 (right) is 0.0234 mm^2

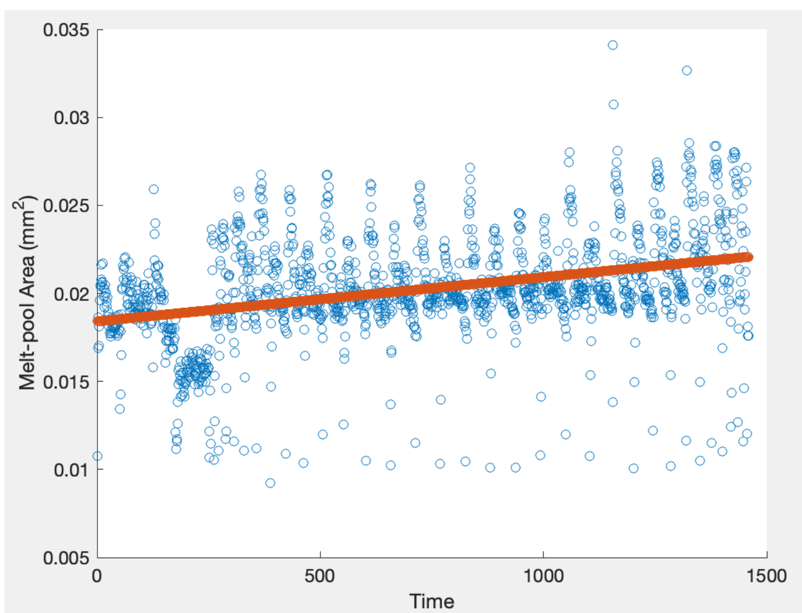


Figure 4. An example linear model – time vs. melt-pool area

Final Submission:

1) Slides for your presentation. For equality purpose, each team must stick to the slides submitted before the deadline. Once the first team start to present, no change would be allowed on your slide
2) Each team should submit a zip file with all the predictive result
    a. The zip file should be named as Team#.zip where # is your assigned team number
    b. Each validation dataset (one part) should be saved in one .csv file
        i. Naming – Team#_Part#.csv where # is the validation part number
        ii. Single column that following the timestamp order

Judgement Criteria:

The final score will be determined by three judges based on the technical approach, results, data visualization, and presentation. Each team should submit a single column .csv file that lists predicted melt-pool size following the triggering index.

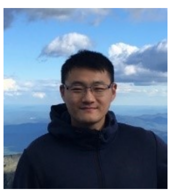
Category	**Criteria**	**Scoring**
Technical Approach (40%) Methods and algorithms of the proposed predictive model	• Requirement analysis and problem formulation • Literature review and exploration of ideas • The development and design of the idea • Scientific soundness of the approach • Creativity of the approach, e.g. exploring melt pool features beyond melt pool size • Soundness of the algorithm (data pre-processing expected) • Readiness of the idea and the approach for implementation, e.g., computational efficiency, code reusability	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)
Results (30%) Output performance and V&V	• Prediction performance measurement based comparison between modeled/measured values evaluated by the Root Mean Squared Error (RMSE)	Excellent (9-10 pts) Very good (7-8 pts) Good (5-6 pts) Limited (3-4 pts) Poor (1-2 pts)
Data Visualization (15%) Clarity, information	• Overall clarity of data presented • Visualization of data alignment/registration • Data structure • 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 (15%): Organization, structure and message conveying	• 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)

Reference:

[1] Lane B, Mekhontsev S, Grantham S, Vlasea M, Whiting J, Yeung H, Fox J, Zarobila C, Neira J, McGlauflin M, Hanssen L. Design, developments, and results from the NIST additive manufacturing metrology testbed (AMMT). InSolid freeform fabrication symposium, Austin, TX 2016 Aug 10 (pp. 1145-1160).
[2] Lane, Brandon, and Ho Yeung. "Process Monitoring Dataset from the Additive Manufacturing Metrology Testbed (AMMT):" Three-Dimensional Scan Strategies"." *Journal of Research of the National Institute of Standards and Technology* 124 (2019): 1-14.
[3] Fox, Jason C., Brandon M. Lane, and Ho Yeung. "Measurement of process dynamics through coaxially aligned high speed near-infrared imaging in laser powder bed fusion additive manufacturing." In *Thermosense: Thermal Infrared Applications XXXIX*, vol. 10214, p. 1021407. International Society for Optics and Photonics, 2017.
[4] Yeung, Ho, and B. Lane. "A residual heat compensation based scan strategy for powder bed fusion additive manufacturing." *Manufacturing Letters* 25 (2020): 56-59.

<u>Subject Matter Expert: Mentors</u>

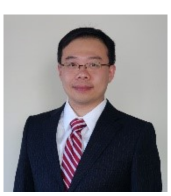
Yan Lu, Senior Research Scientist, Professor, System Integration Division, NIST



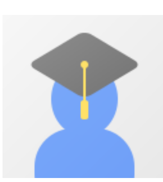
Zhuo Yang, Guest Researcher, NIST

Dehao Liu, School of Mechanical Engineering, Graduate Research Assistant, George Institute of Technology

Anh Tran, Senior Member of Technical Staff, Sandia National Laboratories



Dazhong Wu, Assistant Professor, Department of Mechanical and Aerospace engineering, University of Central Florida



Ho Yeung, Electronics Engineer, Intelligent System Division, NIST