Increase Additive Manufacturing Yield: Project Proposal

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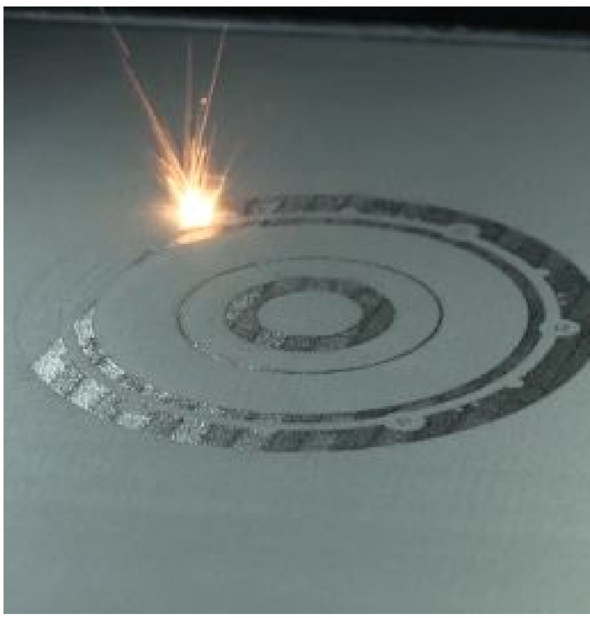

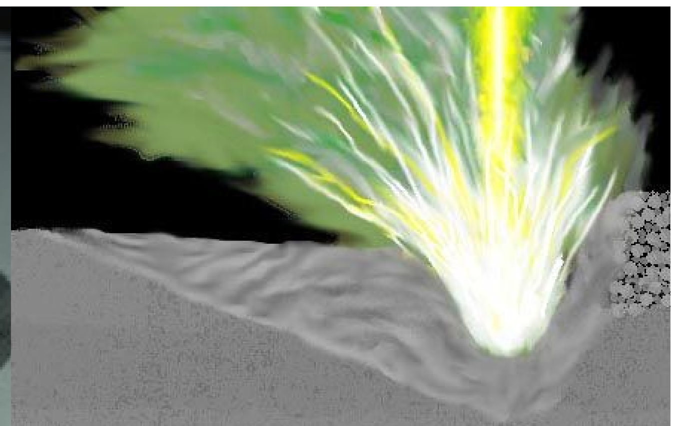

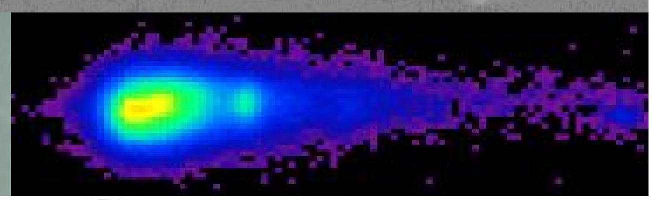

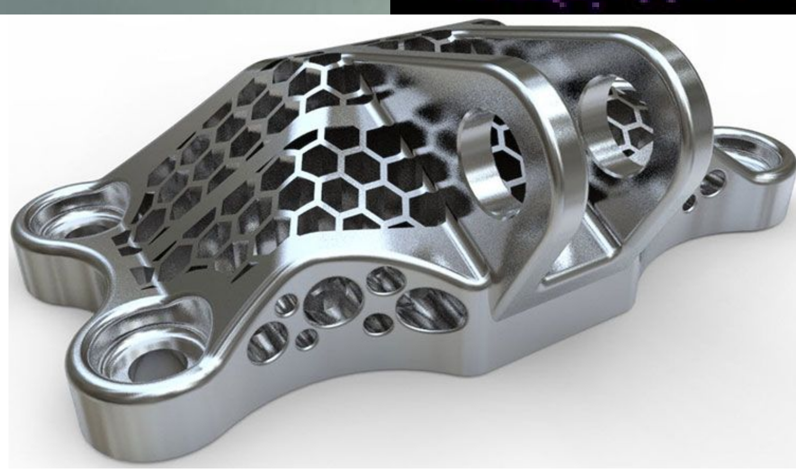

Disclaimer

This project proposal is a dynamic document. At the end of each phase, this plan will be reviewed for progress and achievements, and updates will be made accordingly.

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1) Business Understanding

Objective

The primary business objective is to increase the yield of metal 3D printed parts.

Current Situation

Producing metal 3D printed parts with Additive Manufacturing (AM) technology can be a very lucrative business. There are huge potential benefits to the manufacturing industry, however, the immaturity of the technology currently produces a part yield of approximately 30%, in other words 3 out of 10 parts are approved for quality. Therefore, a business is required to produce roughly 3 times the amount of parts to fulfill an order, increasing the operational costs and significantly decreasing the profit margin.

Project Plan

This project will run approximately 10 weeks. Three sets of data have been collected; before, during, and after the build. By correlating the three sets of data, the process of printing parts can be streamlined and better understood. This new understanding of how the data before the build affects the data after the build, and in turn the quality of the final part, this will allow 3D printers to have increased yield.

Success Criteria

A successful outcome of this project would be to increase the yield of parts due to using the ideal print parameters selected from the model.

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2) Data Understanding

Objective

The primary data objective is to determine which print parameters correlate best with porosity.

Current Situation

The current state of Additive Manufacturing (AM) technology is that there is no digital thread throughout the entire process. This leads to inconsistent results in the final part and no way of tracking what input affects what output. The only way to understand this complex process further is to digitally connect each sub-process to the next one, piece by piece and begin to understand the physics of the whole manufacturing process through empirical data.

Project Plan

There are three sets of data; before, during, and after the build, called “Print Parameters” (PP), “Melt Pool Metrics” (MPM), and “Material Properties” (MP), respectively. A “Condition” is a collection of PP’s for a single build, and with that comes a corresponding set of MPM’s and MP’s. By linking together the PP’s, MPM’s, and MP’s, a correlation can be drawn between the input and the output. The ideal material property in this project is a Porosity of 0%, or in other words, a fully dense part.

- PP = Print Parameters
- MPM = Melt Pool Metrics
- MP = Material Properties

Success Criteria

A successful outcome of this project would be to find a significant correlation between a set of Print Parameters and a Porosity of ~0%.

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3) Data Preparation

Steps

1. Data Wrangling
    a. Create a Diagram (Condition - Average Metric - Average Porosity)
2. Data Description
    a. Describe each of the variables, parameters, metrics, etc.
3. Data Exploration and Visualization
    a. Explore the data using some basic visualization tools to create first findings, an initial hypotheses, and their impact on the remainder of the project. Indicate data characteristics that suggest further examination of interesting data subsets.
4. Data Quality
    a. Address the quality of the data in regards to the completeness, the correctness, and if there is any missing data. Address how the quality of the data might affect the outcome of the project.
5. Data Selection
    a. Split the data into two main categories: data that is going to be used and data that is not going to be used. This will be related to the relevance of the data to the project objectives, the quality, and the technical constraints. Then a reasoning will be applied to each attribute or record.
6. Data Cleaning
    a. Raise the data quality to the level required by the analysis techniques. This may include selecting clean subsets of the data, insertion of suitable defaults, or estimating data by modeling. Address data quality problems and consider how the transformations for cleaning purposes and their impact on the analysis results.
7. Data Construction
    a. Derived Attributes
        i. Construct new attributes by using one or more existing attributes. For example, using the Melt Pool Length and Width to compute a L/W Ratio.
    b. Generate Records
        i. Create completely new records for missing data, for example, image frames that were saturated by the process, or dark images due to the exposure time being too short.
8. Data Integration
    a. Merge Data
        i. Merge the three tables into one combining different information about the same objects. Sort the MPM's into Print Direction (either X or Y).
    b. Aggregations

i. Average each column of MPM's into a single row, per metric, per condition

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4) Modeling

Steps

1. Linear Regression will be the modeling technique used for this project with a Continuous Variable.
2. The data will be split into 2 categories (70-30). This will allow the data to be used to train and test the model.
3. Model parameters will be set to chosen values with a reasoning for each.
4. The models will be created and a description for each.
5. Interprete the models and any difficulties along with their meanings. Summarize the results and qualify each of the models in terms of accuracy.
6. Revise the parameters settings with a new understanding of the models and their output and iterate through the process again until the best model is found.

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5) Evaluation

Evaluate the Results

Assess the degree to which the model(s) meet the business objective(s). If possible, test the model(s) in a new real world application. In this case, the model would be evaluated with print data from a new experiment. Summarize the results in terms of business success criteria and if the project meets the initial business objectives. The models that meet the criteria become approved models.

Review the Process

Review quality assurance issues: a correctly built model, allowed data usage, and will the same data used available for use in the future? Does the field of view of the sensor restrict the maximum build size of 3D printed parts?

Next Steps

Review the remaining resources, time, and budget and consider the following options:

- Finish the project and deploy the model
- Initiate further iterations
- Set up a new data mining project

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6) Deployment

Plan

Create a strategy for deployment based on the evaluation of the results, which includes a list of steps and how to perform them. If possible, sketch this out early in the Business Understanding section, as this is a crucial step in the success of this project. If the models become integrated into the daily operations of the company, it’s paramount to include monitoring and maintaining the model(s) in this plan.

Final Report

The final report includes a written document and presentation. This summarizes the experiences, results, and deliverables. Review what went right, wrong, done well, and needs to be improved. List any mistakes, misleading approaches, or techniques that may be used in a future similar application.

Appendix

Print Parameters

These are values set prior to the printing process. A couple examples are Laser Power and Print Speed. Below is an example table of the combinations of parameters. Each colored cell in the table below represents a single condition or printed sample. The file format is CSV.

		Laser Power		
		LP1	LP2	LP3
Print Speed	PS1	Condition #1	Condition #2	Condition #3
	PS2	Condition #4	Condition #5	Condition #6
	PS3	Condition #7	Condition #8	Condition #9

Values Tracked

- Laser Power (watts)
- Print Speed (mm/s)
- Hatch Spacing (microns)
- Print Direction (X or Y)

Melt Pool Metrics

These are values collected by a sensor during the printing process. A couple examples are Temperature and Area. These are time dependent metrics. Each printed sample will have its own table of values, similar to the one below. Technically the metrics are generated and create two separate tables, but they will be combined into a single table before analyzing. There are roughly 12,000 rows per condition. The file format is CSV.

Time	Temperature	Area
1	T1	A1
2	T2	A2
3	T3	A3

Values Tracked

- Intensity
    - Peak Intensity Short WL
    - Peak Intensity Long WL
    - Avg Intensity 3x3 Pixels Short
    - Avg Intensity 3x3 Pixels Long
    - Avg Intensity 5x5 Pixels Short
    - Avg Intensity 5x5 Pixels Long
    - Avg Intensity in Thresholded Region Short
    - Avg Intensity in Thresholded Region Long
- Temperature
    - Hybrid Reference Temp
    - Peak Temperature
- Threshold 1
    - Threshold 1 Avg Temperature
    - Threshold 1 Region Length
    - Threshold 1 Region Width
    - Threshold 1 Region Orientation
    - Threshold 1 Region Area
    - Threshold 1 Number of Satellite Regions
    - Threshold 1 Area in Satellite Regions
- Threshold 2
    - Threshold 2 Avg Temperature
    - Threshold 2 Region Length
    - Threshold 2 Region Width
    - Threshold 2 Region Orientation
    - Threshold 2 Region Area
    - Threshold 2 Number of Satellite Regions
    - Threshold 2 Area in Satellite Regions
- Threshold 3
    - Threshold 3 Avg Temperature
    - Threshold 3 Region Length
    - Threshold 3 Region Width
    - Threshold 3 Region Orientation
    - Threshold 3 Region Area
    - Threshold 3 Number of Satellite Regions
    - Threshold 3 Area in Satellite Regions
- Threshold 4
    - Threshold 4 Avg Temperature
    - Threshold 4 Region Length
    - Threshold 4 Region Width

  - Threshold 4 Region Orientation
  - Threshold 4 Region Area
  - Threshold 4 Number of Satellite Regions
  - Threshold 4 Area in Satellite Regions

Material Properties

These are values collected after the printing process. Each printed sample is tested for an average porosity and recorded in a table similar to the one below. The file format is CSV.

Condition (#)	1	2	3
Porosity (%)	P1	P2	P3

Values Tracked

- Porosity
