Batch Modeling and Process Monitoring

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Agenda

- CAMO
- Batch analysis background
- Challenges
- CAMO’s approach
- Example
- Alternative strategies
- Demo
- Next Steps
We Develop Multivariate Data Analysis Software & Solutions

- Founded in 1984, we’re pioneers and leaders in the field
- Used in 3,000 organizations and by over 25,000 people around the world
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The CAMO World

- Resellers
- OEM Partners
- Consulting Partners
- Technology Partners
- Training Partners
- Academic Partners

PHARMA, PAT/QBD
INDUSTRIAL, CHEMICAL/ENERGY
AGRICULTURE/FOOD/FEED (AFF)
The CAMO Strategy
Batch - Objective

- Real time monitoring
- Real time troubleshooting
Background

Batch definition: Transition from raw materials to product [intermediate]

Batch process control is recipe driven and the operations are in most cases not automatically adjusted to accommodate raw material variations, changes to uncontrollable factors and other circumstances.
Background – Batch Process Questions

• How can I analyse the batch data from design experiments for process optimisation?
• Are the batches similar?
• Can I find the reason why product quality for some batches lies outside the specifications?
• Are there any effects from raw materials/season/operator/equipment?

• Multivariate Batch Monitoring is important for several reasons:
  – Quality control and event detection
  – Continuous process improvement
Challenge 1: Inequal length and start time

Most batch modelling approaches assume equal lengths of batches:
Same $t_0$ and the same number of time points for each batch
Challenge 2: Phase transitions and rate changes

Multiphase stages exhibit non-linear system dynamics which makes modelling of phase transitions challenging.
CAMO’s approach

Perform Principal Component Analysis and validate the model across batch

Note the non-linear behaviour!

Score plot of golden batches

Using CAMO’s methodology relative time trajectories are calculated with a new PCA model

Mean trajectory and dynamic SD limits calculated

95% confidence limit
Visualising individual Process Variables

Raw data - Looks like the batches are different

... but in reality: The same trajectory
Monitoring a New Batch

- New Batch (Batch 5) ran outside dynamic control limits for portions of the process.
- Drill down for sample 104 showed that Pressure and Temp B variables had high contributions in comparison to golden operations for that relative time.
## Method comparison

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CAMO</th>
<th>Time-wise</th>
<th>Batch-wise</th>
</tr>
</thead>
<tbody>
<tr>
<td>All batches are linear with common start and end</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>The model shows scores for individual samples</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>The model requires equal batch lengths</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Historical batches have various relative times</td>
<td>+</td>
<td>Warping?*</td>
<td>Warping?*</td>
</tr>
<tr>
<td>Projection of new batch showing non-linear behaviour</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>New batch has different sampling rate</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Warping may distort the relative time

+ = handled, - = not handled
Example Case

- Chemical reaction
- 3 historical batches
- Three variables: Reactant, intermediate and product (predicted online with a model based on Spectroscopic data)
- PCA on the three batches
- Projecting one new batch
Line plot

Reactant, 3 batches

Consecutive

Folded
Correlation loading plot

Not so exiting, but shows how the reaction progresses
2D score plot—historical batches

Uneven number of data points per batch does not affect the chemical time in the 2D score space.

2D score plot

Scores, PC1

Common starting point for all three batches

Common end point

Does not reflect the relative reaction time!
2D score plot – trajectory model

Start

End

95 % limit

Trajectory

Scores

PC-1 (90%)
As the method estimates relative time it also enables *individual* variables to be displayed in relative time.

Line plot: Reactant, 3 batches

Folded

Relative time
Trajectory model distance

A one-dimensional representation of the limits in the 2D score plot
Trajectory F-Residuals
Projecting a new batch Score plot with limits (95%)

Independent of the sampling rate and number of points
Line plot of the raw data

As sample number

No progress

Sample number 55, reaction is finished

In relative time
Trajectory model distance

Note how the end of the reaction is visualized correctly due to the relative time axis.
One method for all?
Various approaches depending on application

1. Prediction of the yield/quality directly with suitable in-line sensors, e.g. spectroscopy
2. Projecting the new batch onto an endpoint model and decide if the process has reached its end
3. Project the new batch on one existing batch for a qualitative visual assessment
4. Follow the batch progression with a moving-block method; suitable e.g. for mixing processes
5. Project onto a batch model where dynamical limits for distance to model and residual distance have been established from so-called golden batches
Case 1: Direct prediction

1. Establish a model for prediction of product quality
2. Apply model in real-time

Example: Prediction of moisture in a fluid bed dryer operation with NIR spectroscopy, RMSE; validation over batch = 0.30

Scores with phases of drying in color (Blue = 1, Red = 2, Green = 3)

Predicted values (loss on drying)
Case 2: Endpoint model

1. Establish a model for the endpoint for a number of good batches
2. Project new observations onto this model

Example: Fluid bed dryer using six process variables

The ellipse describes the endpoint
Case 3: Visual projection

1. Establish a model for the one (or more) batch(es)
2. Project new observations onto this model

Example: Chemical reaction with three variables; Temperature A and B, pressure

PCA for batch 1

Project batch 2
Case 4: Moving block method

1. Establish a moving block model for one batch and set limits for standard deviation, mean value and with an f-test; whatever is applicable

2. Project new observations onto this model

Example: Mixing process with NIR spectroscopy
- Fluid bed dryer operation
- NIR-spectra, 1093 variables
Case 5: Batch model with critical limits

1. Establish a model for golden batches
2. Project new observations onto this model

Example: Fluid bed dryer, six process variables (as above but for the whole batch duration)

Score plot with confidence limits

[Diagram of score plot with PC-1 and PC-2 axes, showing start and end points and a 95% limit]

Correlation loadings

[Diagram of correlation loadings with variables such as Inlet Air Temperature, Product Temperature, and Air Flow]
The CAMO Strategy
Offline analysis with The Unscrambler X & Online process monitoring with Process Pulse II

Applications
- Fermentation
- Chemical reactions
- Drying
- Mixing

On-line monitoring

Solution
- Modeling of batch progression in relative time
- The method is independent of the sampling frequency
- Automatic pretreatment of data
- Dynamic critical limits

Graphical presentation and alerts

Data in real-time

Model repository

Unscrambler X
Process Pulse
Next steps

- www.camo.com/testdrive/
- Demo video, www.camo.com
- Book a live demo, grf@camo.com
- Paper:
THANK YOU!

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