Fitting, Filtering and Analysis:
Feature Extraction in Dimensional Metrology Applications

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Inside the “Box”

- A “cloud” of data points.
Inside the “Box”

- Fitting
Inside the “Box”

- Filtering
Inside the “Box”

• Analysis
Thinking “Outside the Box”

• Do the current analysis methods provide the information that you are looking for?
  – Modeling of performance
  – Correlation with process controls
  – Failure analysis
  – ?? ??

• Why measure in the first place?
Why measure?

Information!!!
Fitting, Filtering & Analysis

• There are many tools at our disposal for the “better” analysis of data!

\[
\frac{dz_i}{dx_i} = \frac{[z_{i+3} - 9z_{i+2} + 45z_{i+1} - 45z_{i-1} + 9z_{i-2} - z_{i-3}]}{60 \cdot \Delta x}
\]

\[s(x) = \frac{\pi}{\lambda_c} \sin \left( \sqrt{2} \frac{\pi}{\lambda_c} |x| + \frac{\pi}{4} \right) \exp \left( \sqrt{2} \frac{\pi}{\lambda_c} |x| \right)\]

\[s(x) = \frac{1}{\alpha \lambda_c} \exp \left[ -\pi \left( \frac{x}{\alpha \lambda_c} \right)^2 \right]\]

\[A(k) = \frac{1}{n-k+1} \sum_{i=1}^{n-k+1} z_i z_{i+k}\]

\[\frac{1}{n} \sum_{i=1}^{n} z_i^2\]

\[\sum_{l=1}^{n} \left[ \rho \left( z_l - w_k - \sum_{i=1}^{N} \beta_{k,i} \cdot (l-k) \cdot \Delta x \right)^2 \right] \cdot s((l-k) \cdot \Delta x) \cdot \Delta x \rightarrow \text{Min} \quad w_k, \beta_{k,i}\]
Fitting, Filtering & Analysis

- An overview of some of the tools
- Applications
- Getting the tools into my “box”

Goal:

Make you think differently about what you are measuring.
Fitting

• Not much has changed!
  – Depending on the geometry there are a few options:
Fitting

- Fitting alone doesn’t address all of the issues
Filtering

• Filter-phobia
  – “I don’t want to corrupt my data”
  – “I don’t use filters; they hide things”
  – “I want to see the real surface”

• The proper use of filtering:
  – Exploit the features of interest
A Filtering Toolbox

- ISO/TC213 Advisory Group 9
  “GPS Extraction Techniques”
  - Linear Filters
  - Morphological Filters
  - Spline Filters
  - Spline Wavelet Filters
  - Alternating Sequence Filters
  - Robust Filters

  - Technical Specifications are being produced
An easier view...
Traditional Filtering

- Gaussian Filter

\[ s(x) = \frac{1}{\alpha \lambda_c} e^{-\pi \left( \frac{x}{\alpha \lambda_c} \right)^2} \]

- End regions are not valid!
Improved Gaussian Filtering

- Spline-based Gaussian Filtering

- Filtered data is available all the way to the ends of the raw data set!
Mechanical Filtering (by Math)

- Morphological Filters

OPENING

CLOSING

DILATION

EROSION
Powerful filtering...

- Robust Filters

- These filters are insensitive to extreme points.
What makes these cool…

– Gaussian Filter (sensitive to extremes)

– Robust Filter (insensitive to extremes)
Disclaimer

- It should be noted that the concept of “sampling” is closely connected to the concept of filtering (mechanical, electronic or mathematical).

  – *There, I said it.*
Analysis

• Surface texture has been suffering for many years with a condition known as:  

   “The Parameter Rash”

• However, many other fields could benefit from some additional numerical descriptions.
Analysis

• A single “number” doesn’t always describe the functionality of a surface or interface.

  – Examples:
    • Peak to valley distance, RMS
    • Rates of change, slope
    • Bearing Ratio, volumetric analysis
    • Harmonic Content
Application Example #1

- The Cam Lobe
  - The underlying, load carrying geometry is of interest.
  - The orientation and “shape” of this underlying surface is to be characterized.
Sampling the Cam Lobe
Analyzing the Cam Lobe

- Simple fitting does not yield functional information.
  - The outlier influences the form and orientation.
- Simple filtering corruptions the underlying “shape”
Simple filtering isn’t enough...
Combined Fitting/Filtering

- Suppress the nominal geometry via Least Squares fitting.
Combined Fitting/Filtering

- Remove outliers or apply robust filtering on the residuals.
Combined Fitting/Filtering

- Re-apply the suppressed geometry and analyze the resulting data.

Re-application of Geometry

Analysis of the Feature
Application Example #2

- A gasket interface.
  - A solid surface in contact with a conformable component.
Conformable Interfaces…

- There is a strong sensitivity to localized surface variations (curvatures).
  - Typically these are “middle wavelengths”.
Traditional Filtering

- Bandpass waviness analysis is somewhat useful.
Bandpass Waviness

- Traditional filtering is used to separate the data into 3 domains.
Bandpass Waviness

- The bandpass waviness approach does not adequately model the interface.
  - It’s good, but not great.
A better approach is to combine robust filtering with morphological filtering.
Combined Filtering & Analysis

• First a robust filter is applied.
Combined Filtering & Analysis

- Next a morphological closing filter is applied to the waviness profile.
Combined Filtering & Analysis

- The resulting profiles represent conformability and the resulting “gaps”.

![Graphs showing combined filtering and analysis results]
Combined Filtering & Analysis

- The cutoff and closing radius can be tuned to simulate gasket properties.
  - The gap area (between the morphological and robust filtered profiles) can be calculated as a “functional” analysis.
Combined Filtering & Analysis

- Similar peak-to-valley values, but different performance:

  Gap area is key!
Old dogs, new tricks…

How can I use this stuff on my machine?

Answer: Software Add-Ins (Helpers)
Software Add-Ins (Helpers)

- Several approaches are available for extracting data from instrumentation for further analysis.

DDE/OLE

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Direct Hardware Interfacing

• Example: Analog to digital conversion of analog probe signal
  – Requires calibration and often requires other control interfacing.
Serial Interfacing

• Many instruments provide data output via a serial (RS-232 or other) port.
Software Interfacing

- Some instrument software packages provide an interface for external applications.
  - Spawning of external applications
  - Dynamic Data Exchange (DDE)
  - Object Linking and Embedding (OLE/COM)
File Based Interfacing

- The control software simply stores a file.
  - *The “add-in” package monitors the file and loads it when changed.*
Summary:

- Several analysis tools are available to better exploit the features of interest.
  - *Choose wisely Grasshopper!*

- These tools can be applied to many existing measurement systems.
Thank you!

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