

Fitting, Filtering and Analysis:

Feature Extraction in Dimensional Metrology Applications

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*International Dimensional
Workshop 2002*

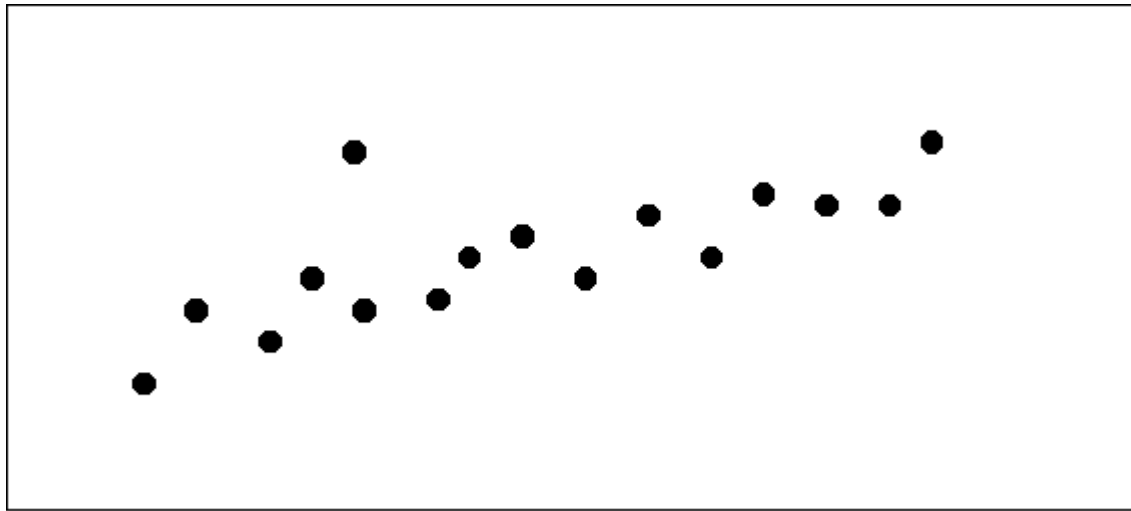
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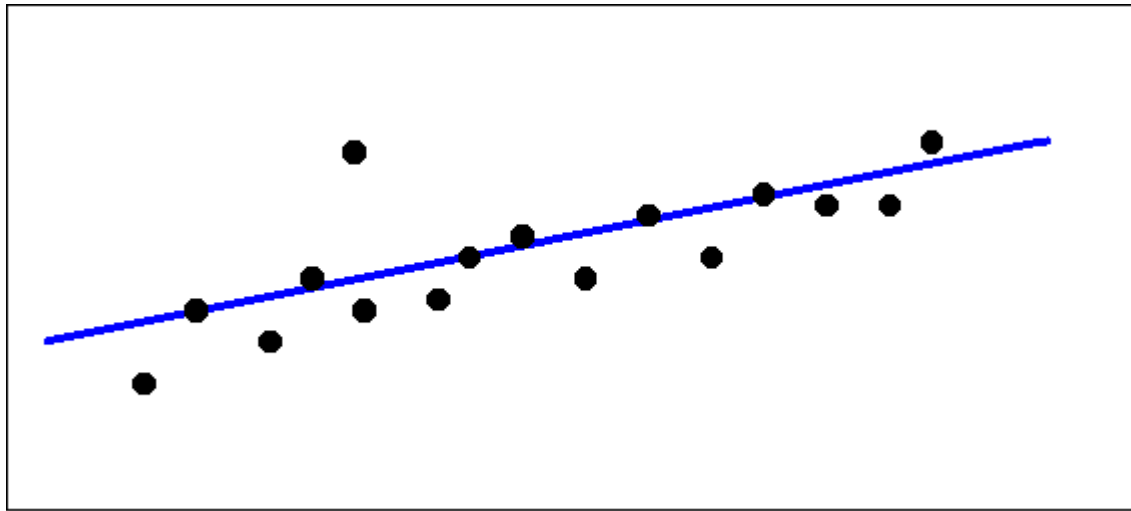
Inside the “Box”

- A “cloud” of data points.



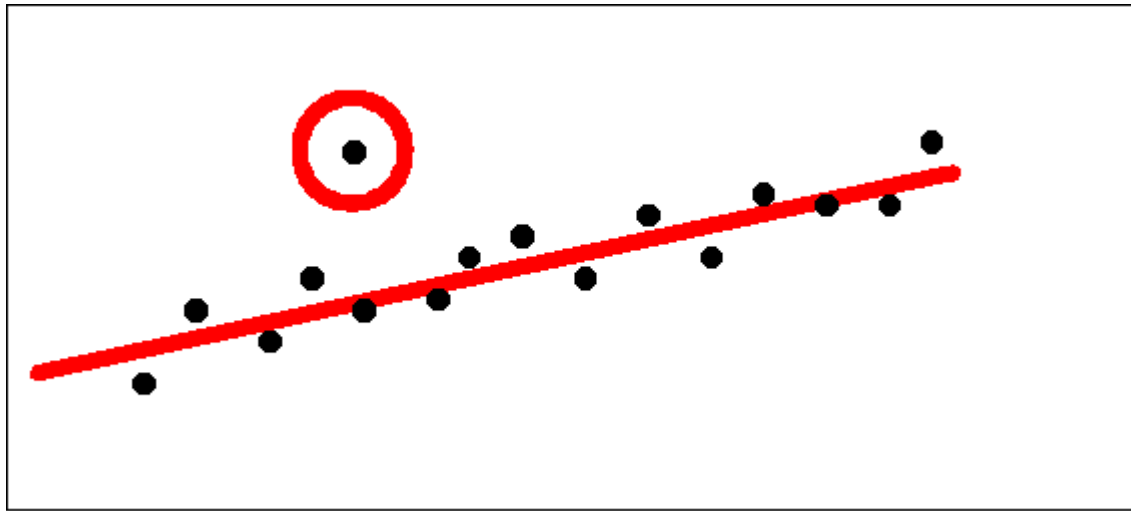
Inside the “Box”

- Fitting



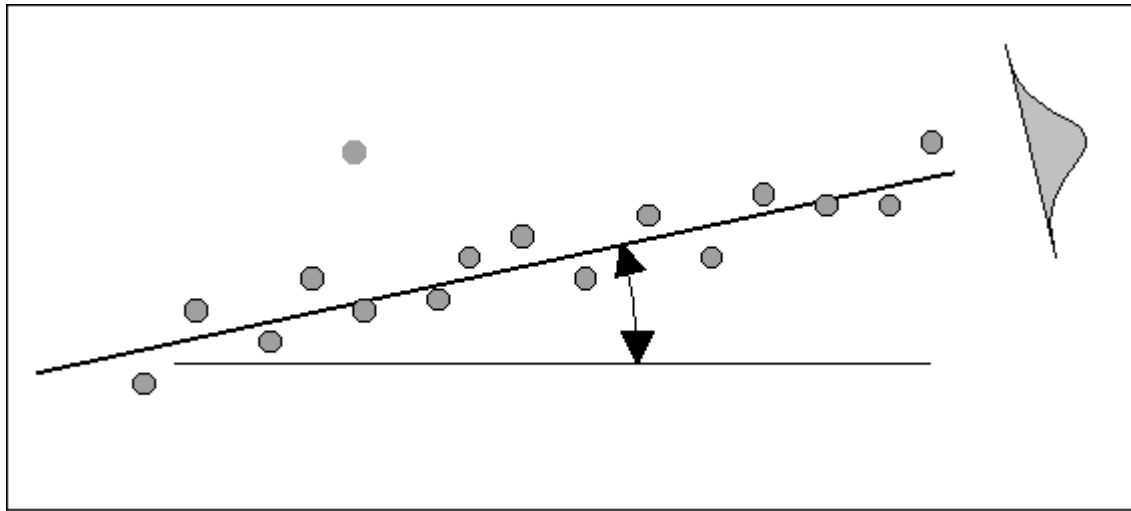
Inside the “Box”

- 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?

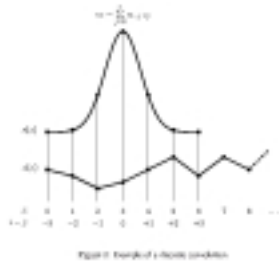
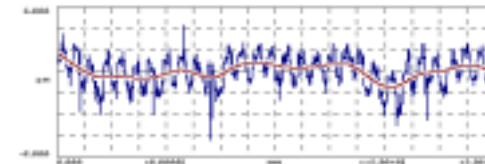
Why measure?

Information!!!

Fitting, Filtering & Analysis

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

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

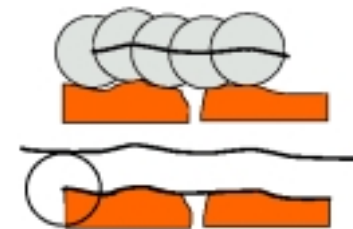


$$s(x) = \frac{\pi}{\lambda_c} \sin\left(\sqrt{2}\frac{\pi}{\lambda_c}|x| + \frac{\pi}{4}\right) \exp\left(\sqrt{2}\frac{\pi}{\lambda_c}|x|\right)$$

$$A(k) = \frac{1}{n-k+1} \frac{\sum_{i=1}^{n-k+1} z_i z_{i+k}}{\frac{1}{n} \sum_{i=1}^n z_i^2}$$

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

$$\sum_{l=1}^n \left[\rho \left(z_l - w_k - \sum_{i=1}^N \beta_{k,i} \cdot ((l-k) \cdot \Delta x)^i \right) \cdot s((l-k) \cdot \Delta x) \cdot \Delta x \right] \rightarrow \text{Min}_{w_k, \beta_{k,i}}$$



Fitting, Filtering & Analysis

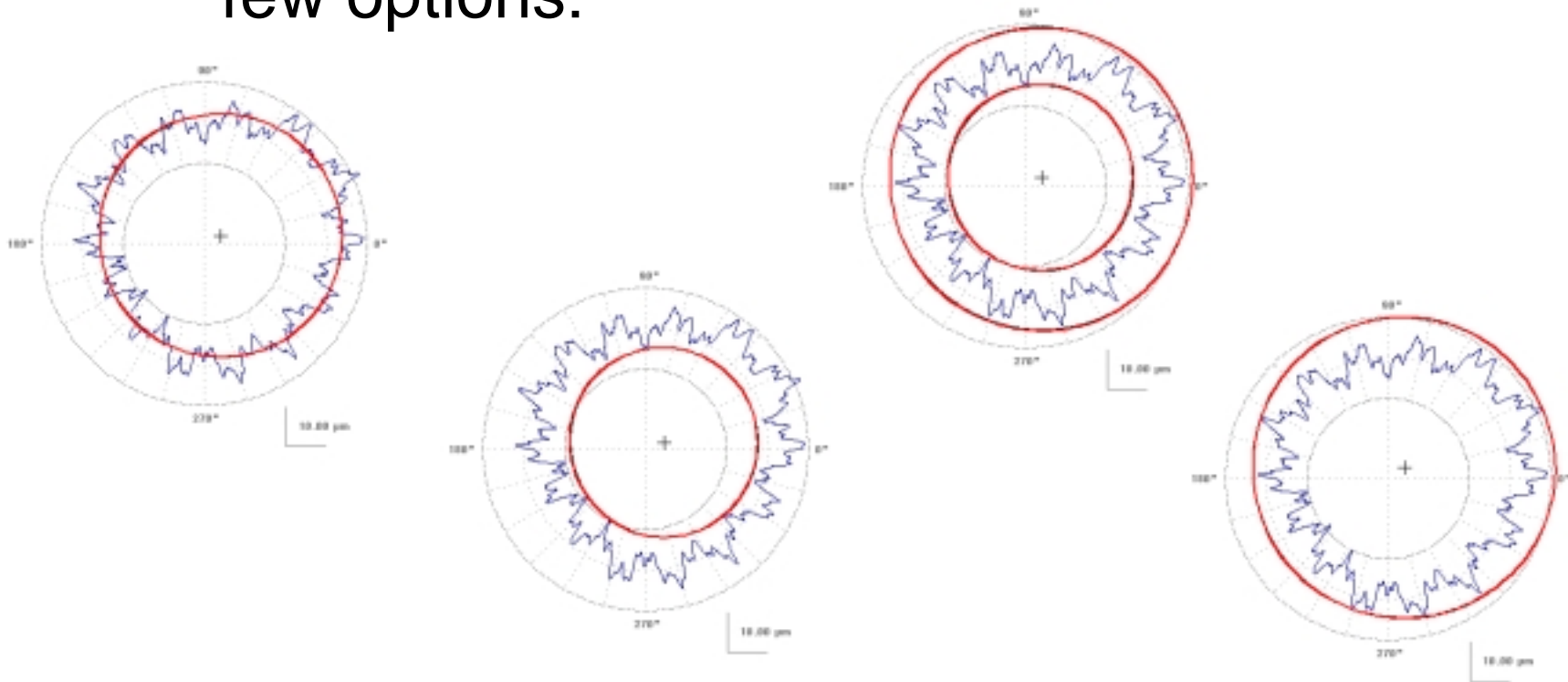
- An overview of some of the tools
- Applications
- Getting the tools into my “box”

Goal:

Make you think differently
about what you are measuring.

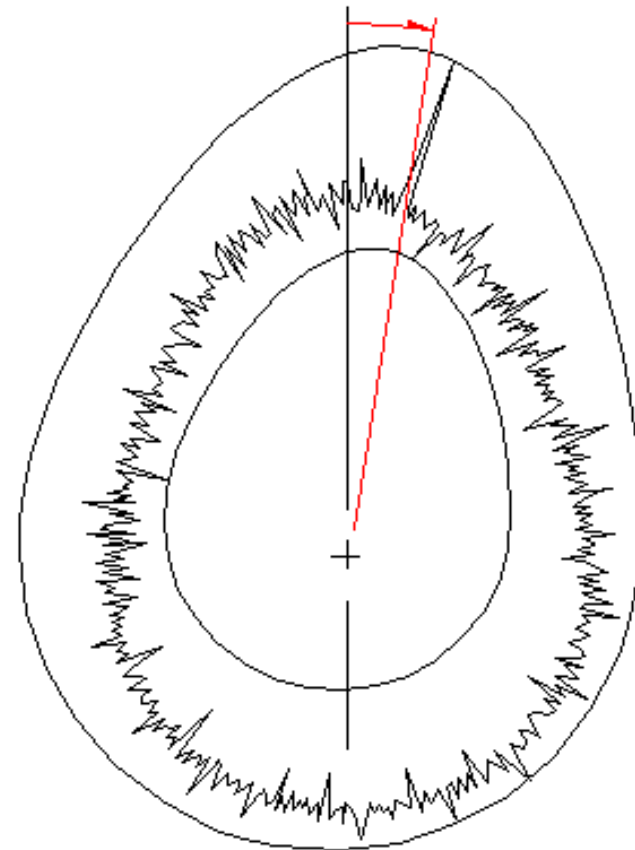
Fitting

- Not much has changed!
 - Depending on the geometry there are a few options:



Fitting

- Fitting alone doesn't address all of the issues



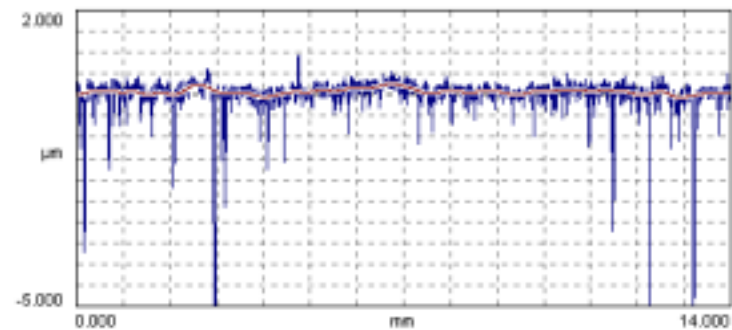
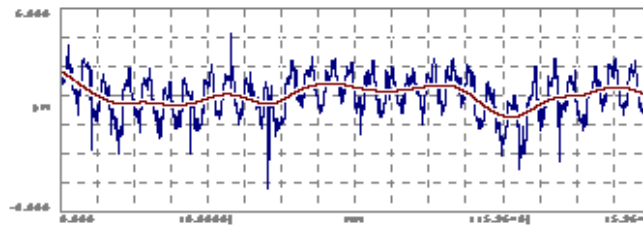
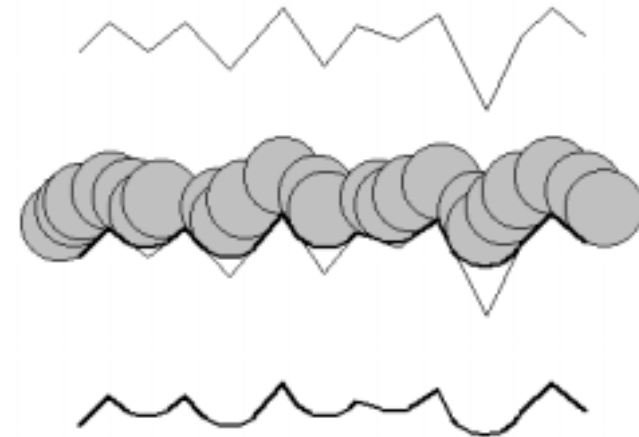
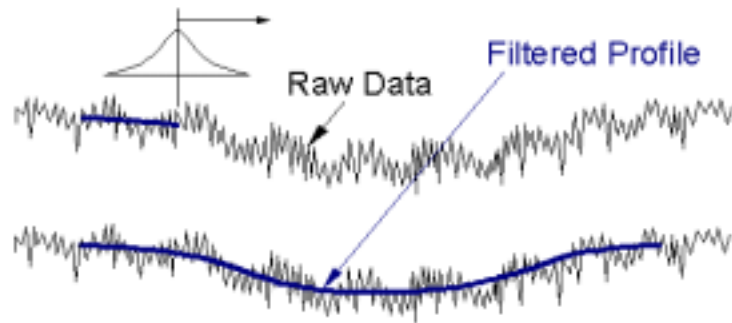
Filtering

- 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

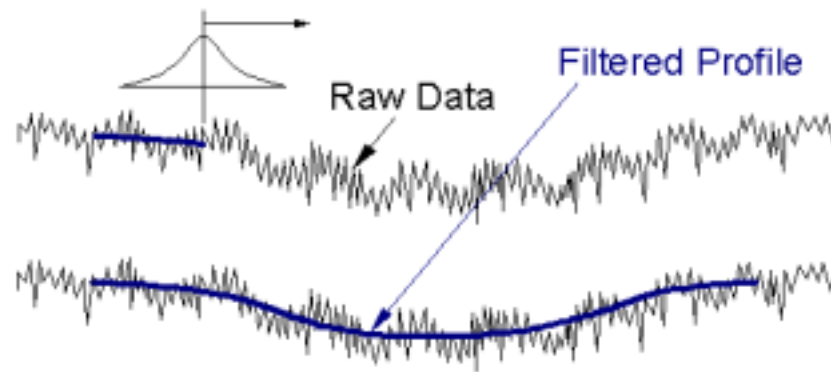
- ISO/TC213 Advisory Group 9
 - *“GPS Extraction Techniques”*
 - Linear Filters
 - Morphological Filters
 - Spline Filters
 - Spline Wavelet Filters
 - Alternating Sequence Filters
 - Robust Filters
 - Technical Specifications are being produced

An easier view...

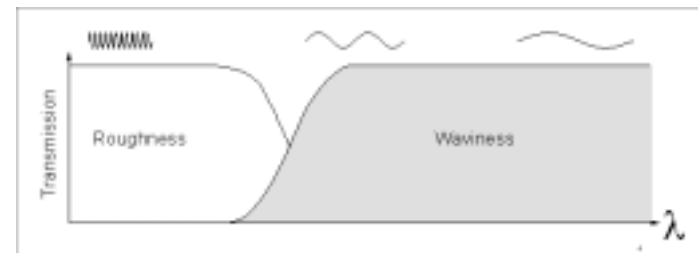


Traditional Filtering

- Gaussian Filter



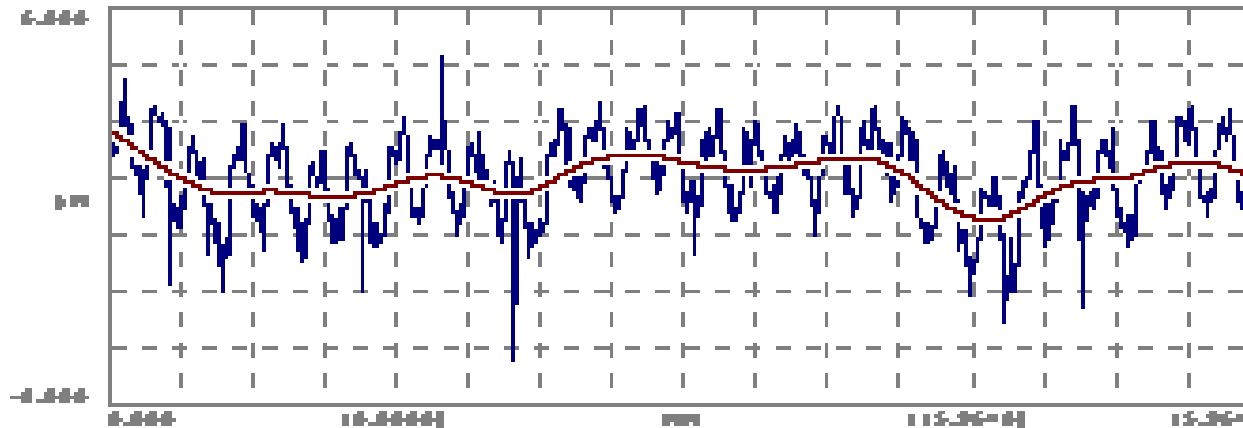
$$s(x) = \frac{1}{\alpha\lambda_c} e^{-\pi \left[\frac{x}{\alpha\lambda_c} \right]^2}$$



– End regions are not valid!

Improved Gaussian Filtering

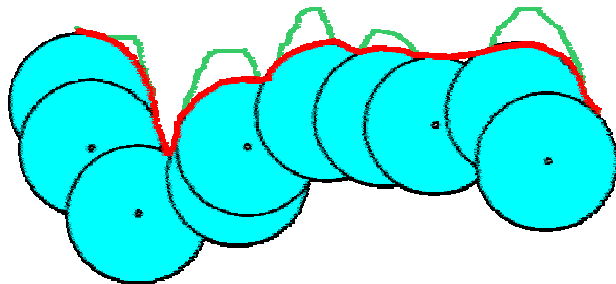
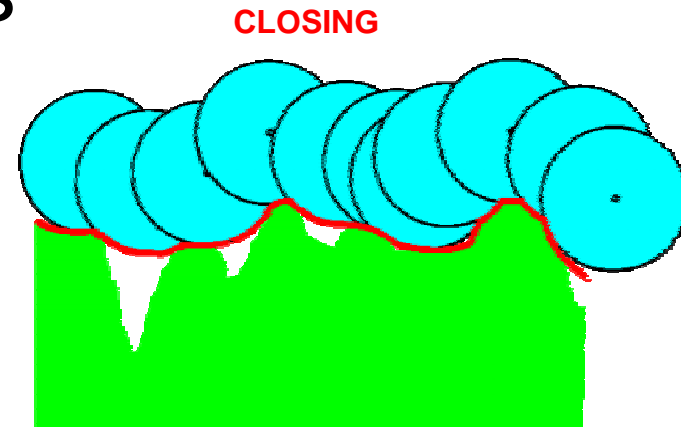
- Spline-based Gaussian Filtering



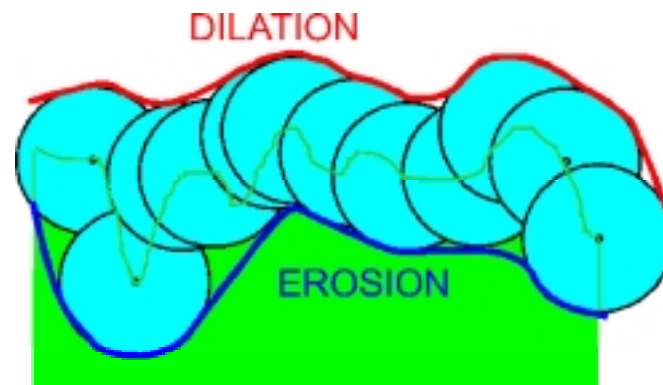
- Filtered data is available all the way to the ends of the raw data set!

Mechanical Filtering (by Math)

- Morphological Filters

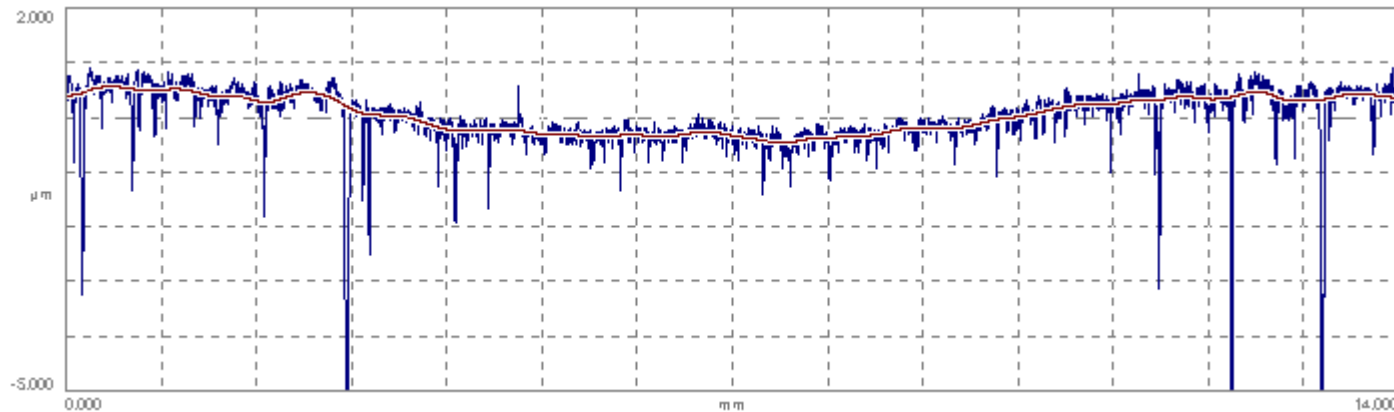


OPENING



Powerful filtering...

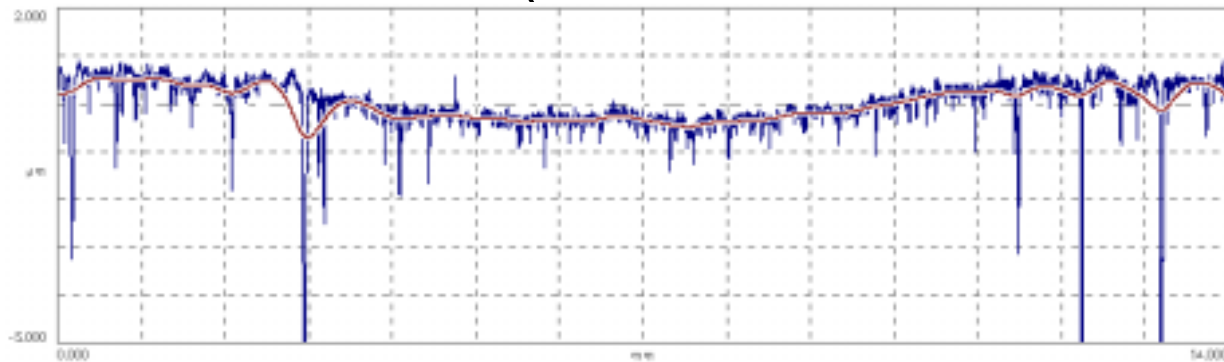
- Robust Filters



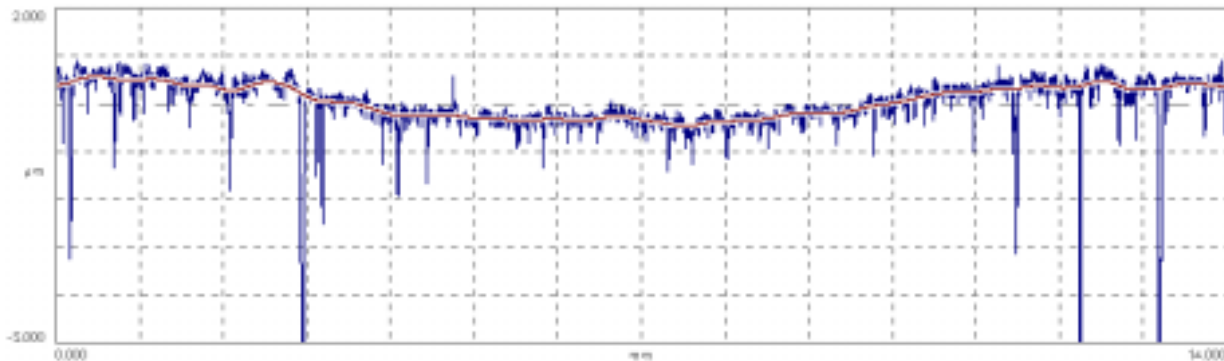
- These filters are insensitive to extreme points.

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”

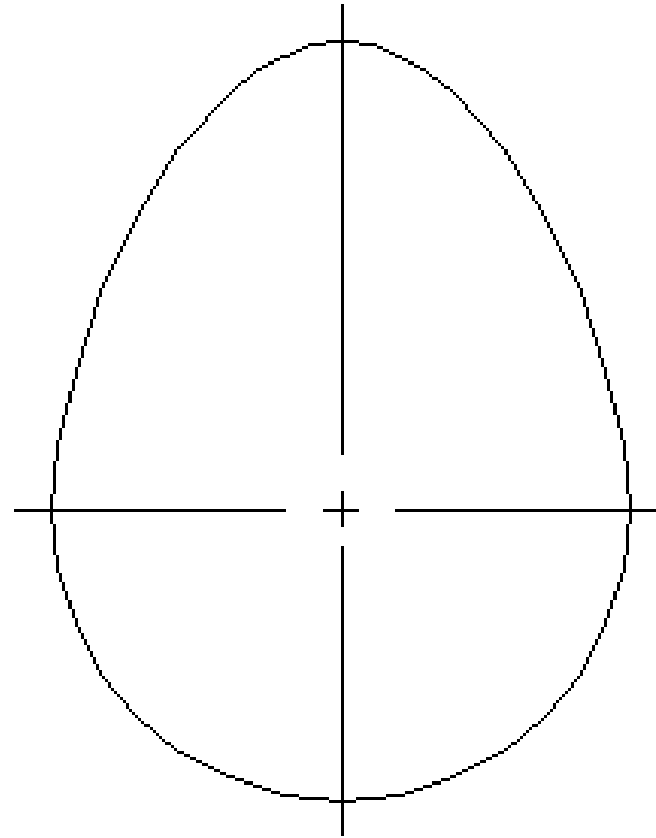
- However, many other fields could benefit from some additional numerical descriptions.

Analysis

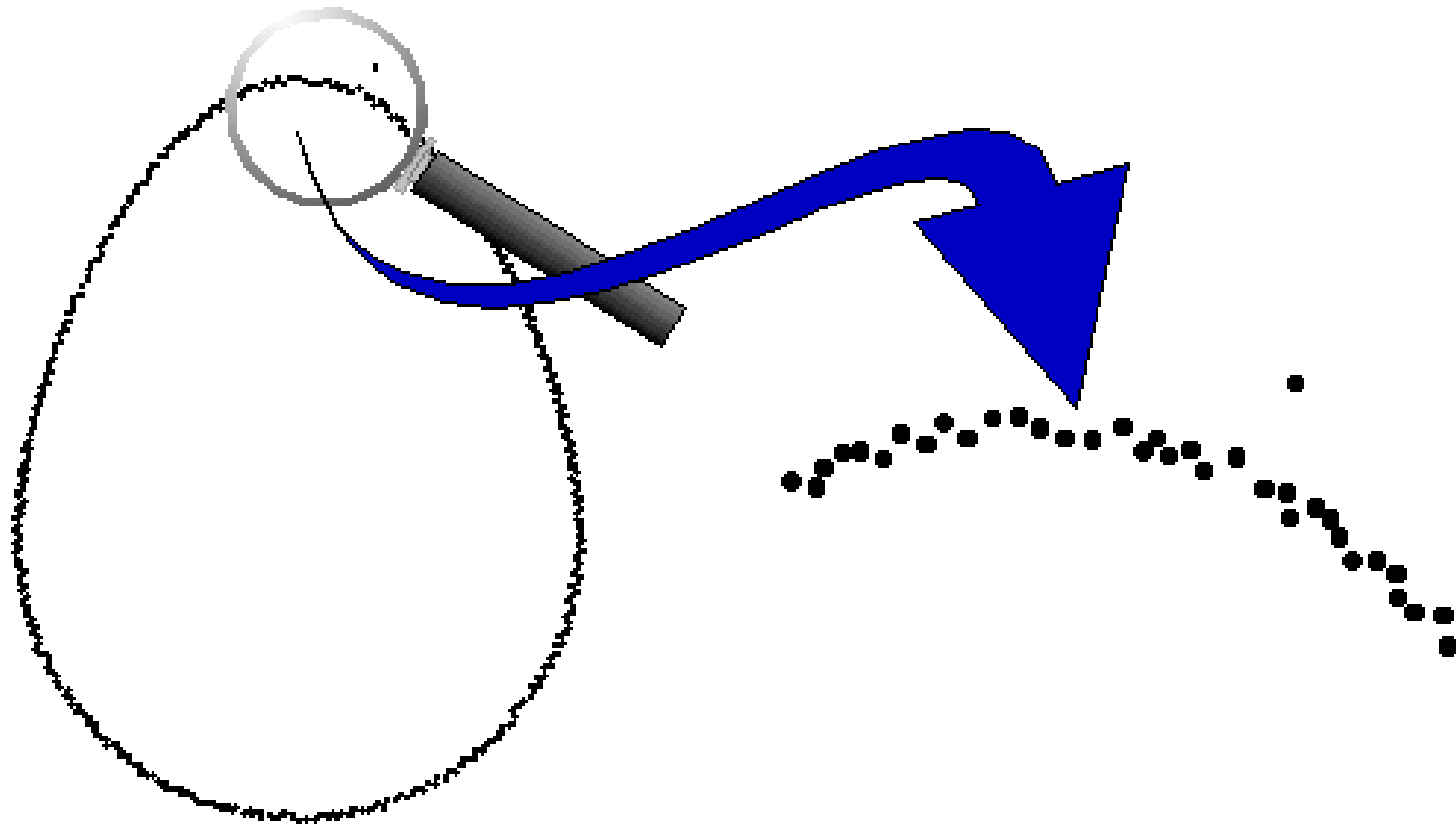
- A single “number” doesn’t always describe the functionality of a surface or interface.
 - Examples:
 - Peak to valley distance, RMS
 - Rates of change, slope
 - Bearing Ratio, volumetric analysis
 - Harmonic Content

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.

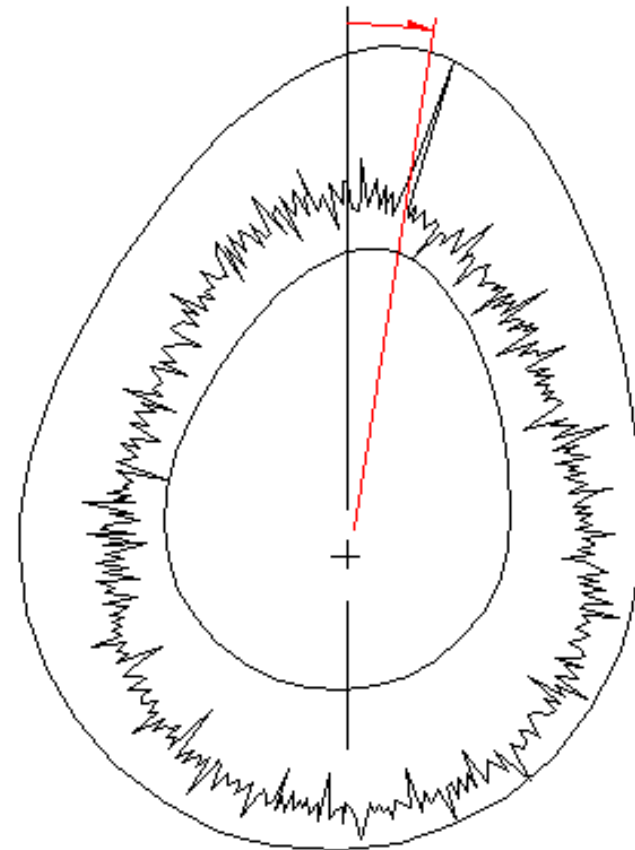


Sampling the Cam Lobe

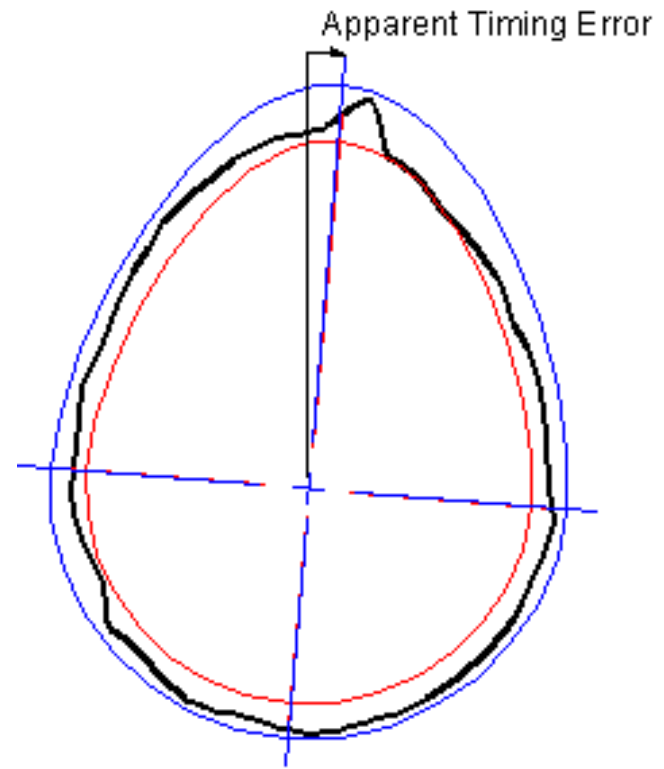
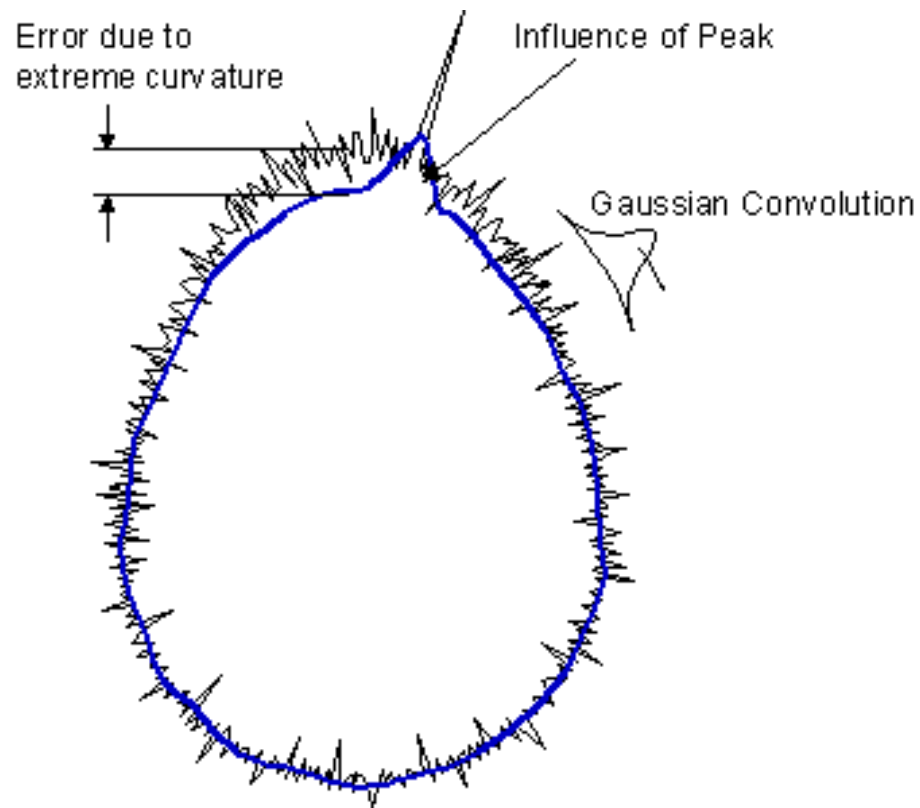


Analyzing the Cam Lobe

- Simple fitting does not yield functional information.
 - The outlier influences the form and orientation.
- Simple filtering corrupts the underlying “*shape*”

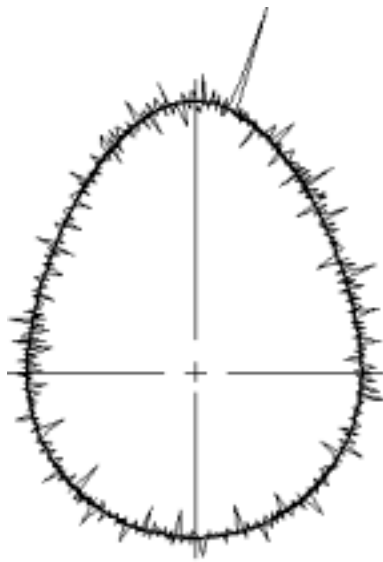


Simple filtering isn't enough...

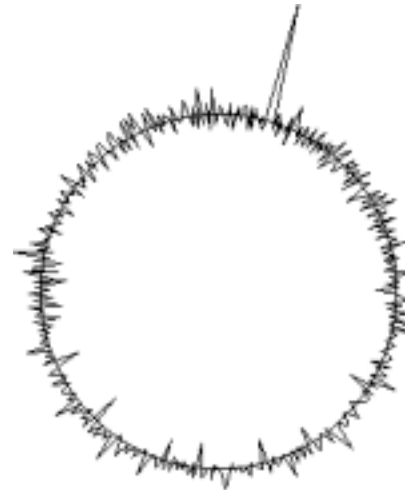


Combined Fitting/Filtering

- Suppress the nominal geometry via Least Squares fitting.



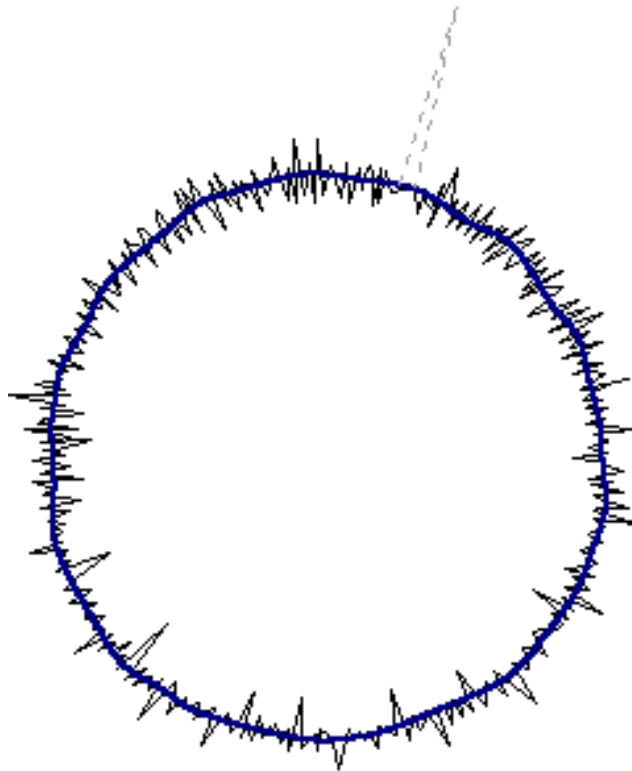
Initial Least
Squares Fit



Suppression
of Geometry

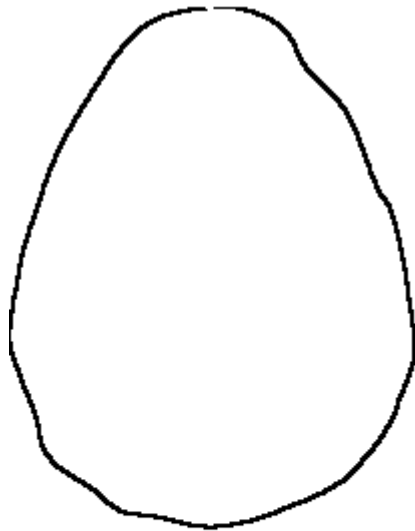
Combined Fitting/Filtering

- Remove outliers or apply robust filtering on the residuals.

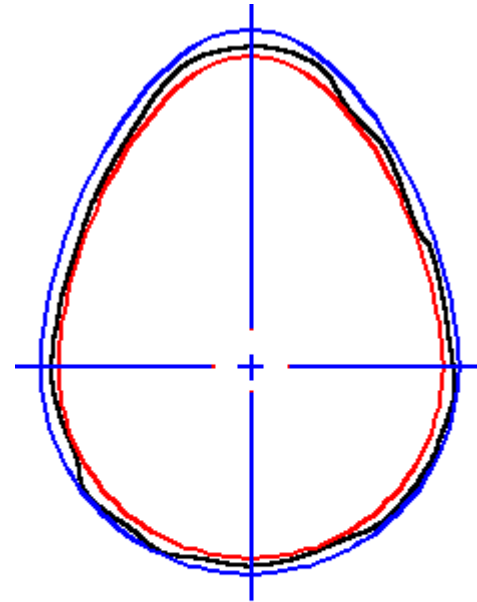


Combined Fitting/Filtering

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



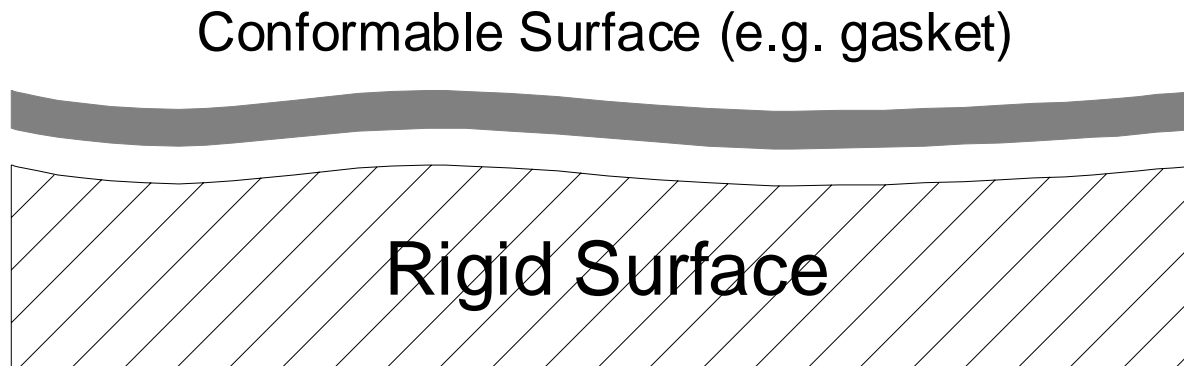
Re-application
of Geometry



Analysis of
the Feature

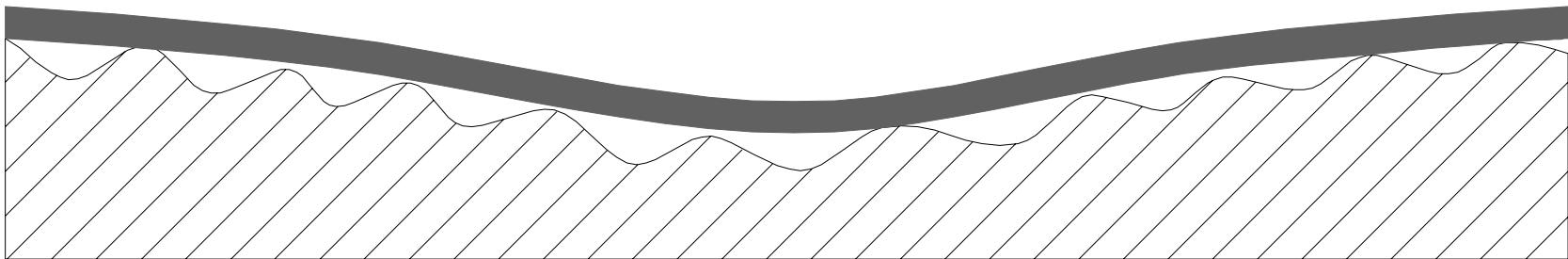
Application Example #2

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



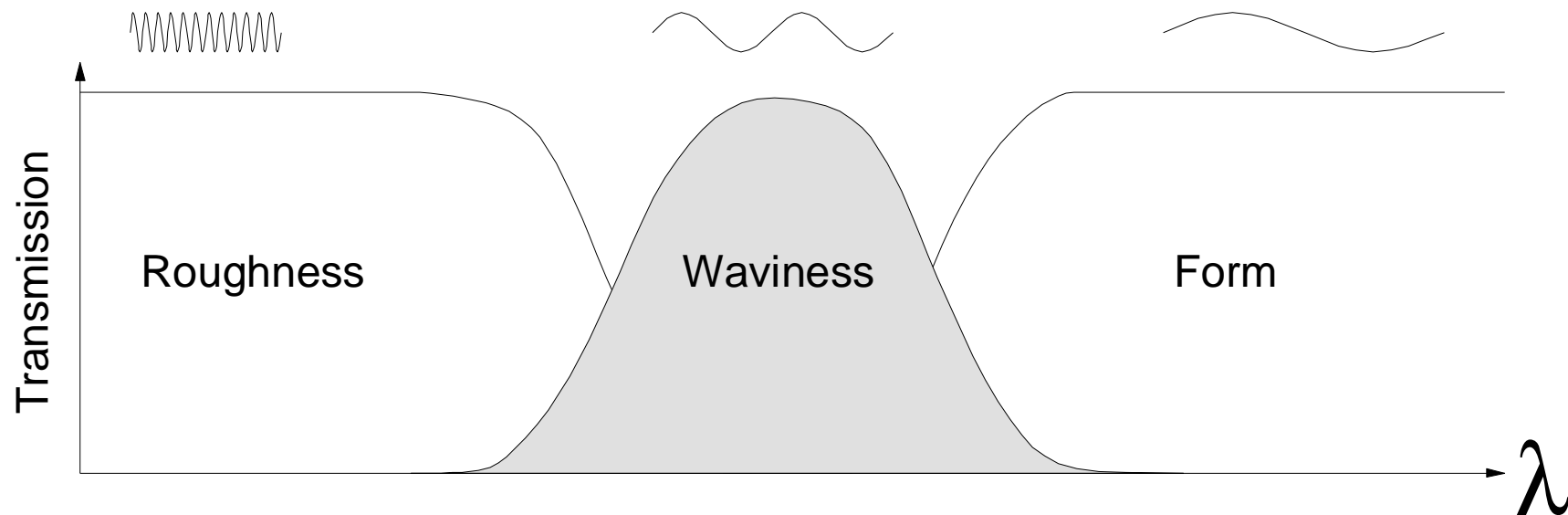
Conformable Interfaces...

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



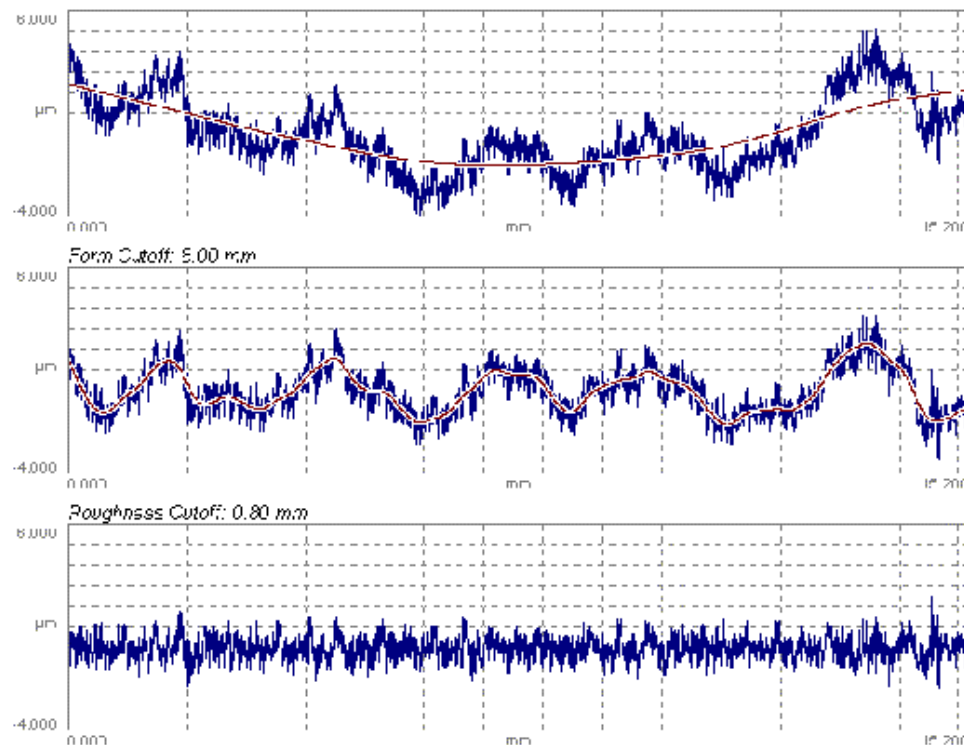
Traditional Filtering

- Bandpass waviness analysis is somewhat useful.



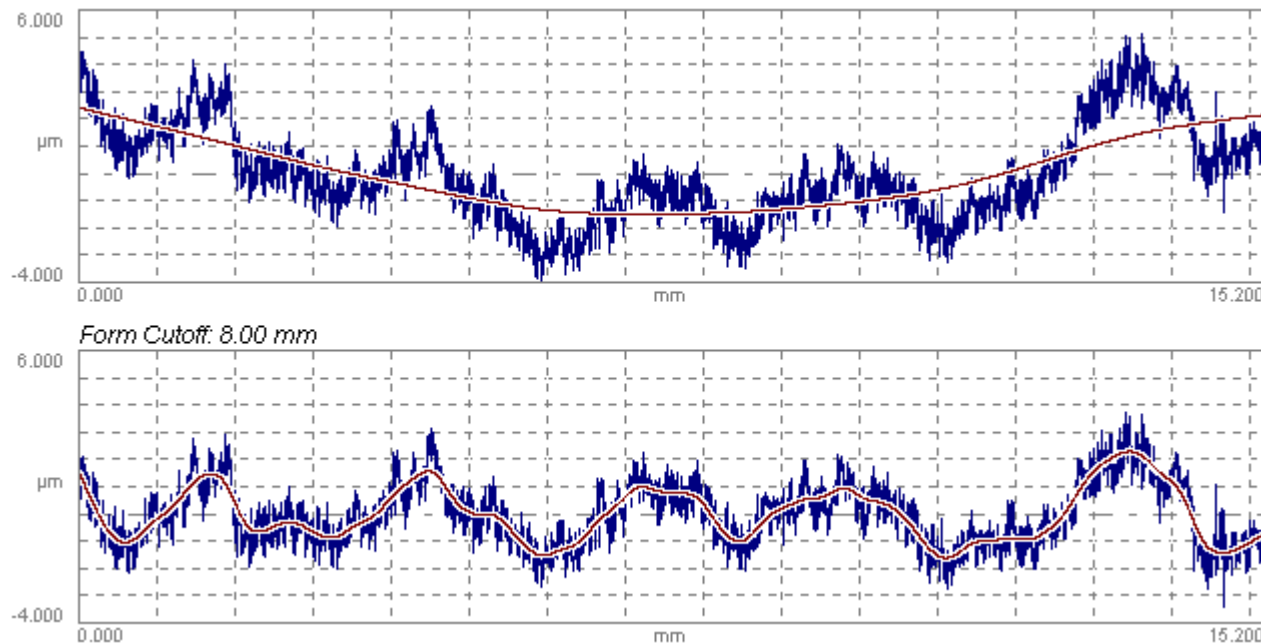
Bandpass Waviness

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



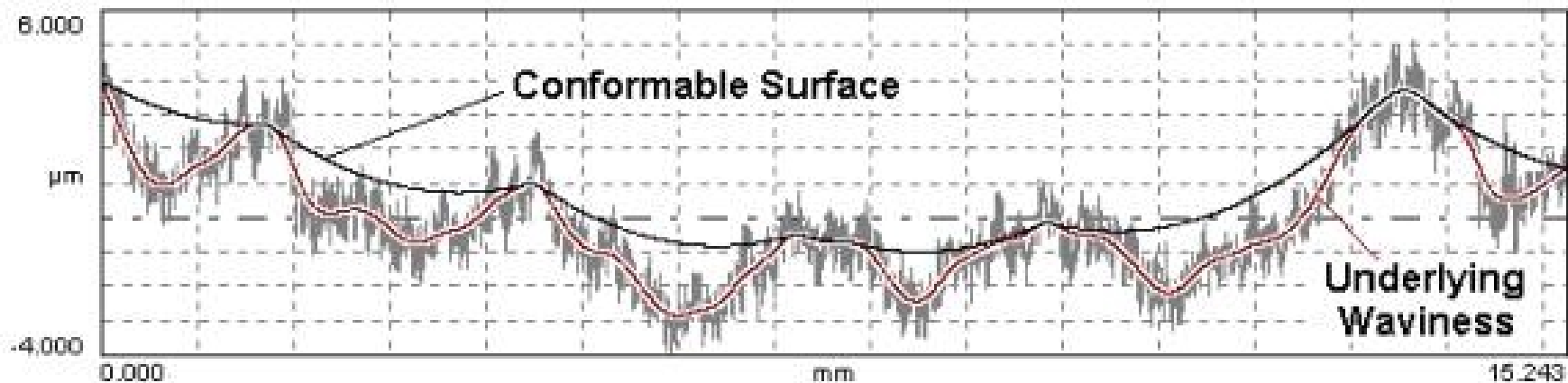
Bandpass Waviness

- The bandpass waviness approach does not adequately model the interface.
 - It's good, but not great.



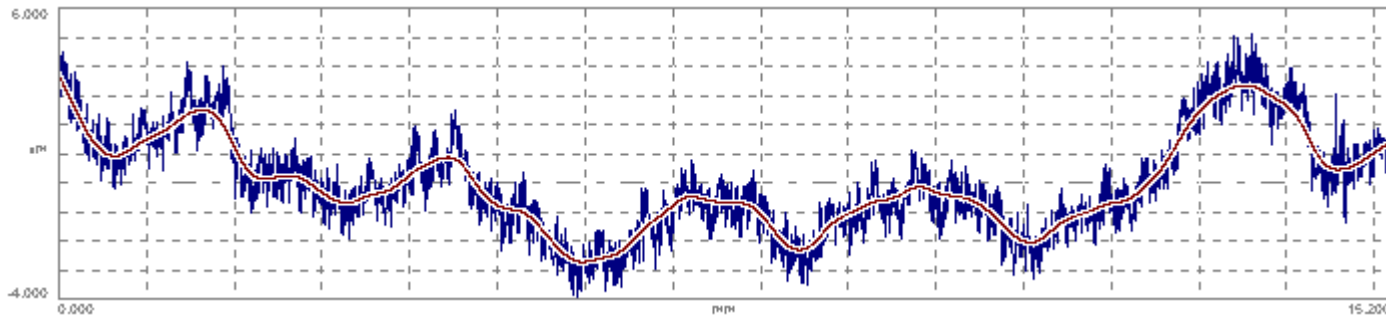
Combined Filtering & Analysis

- A better approach is to combine robust filtering with morphological filtering.



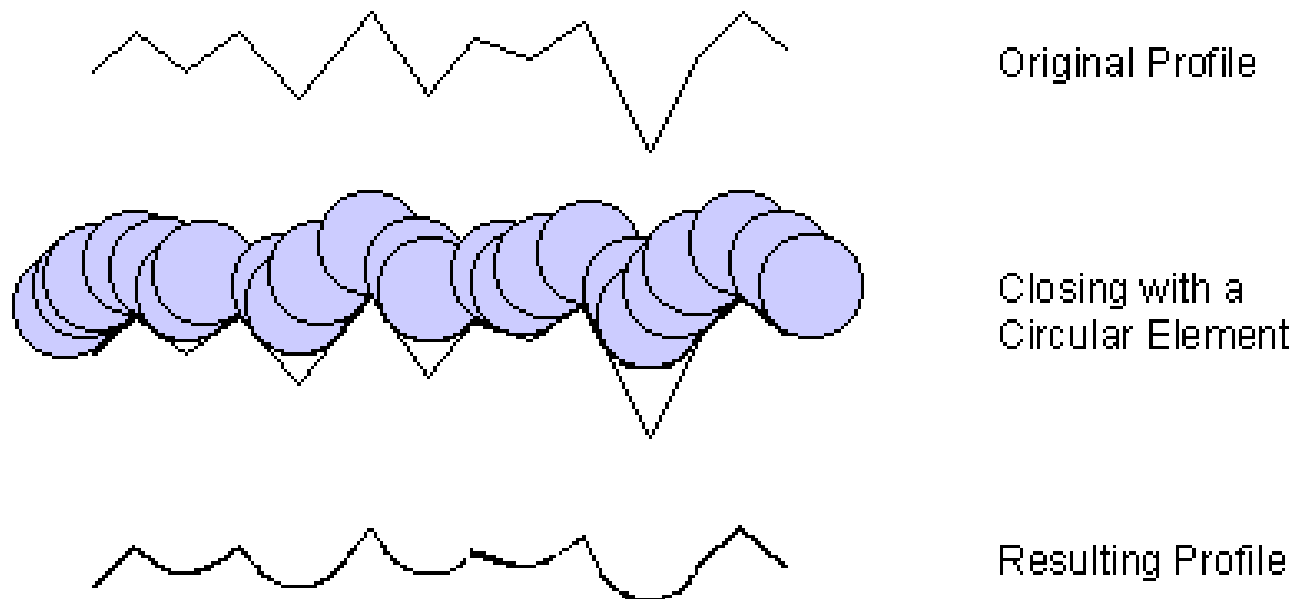
Combined Filtering & Analysis

- First a robust filter is applied.



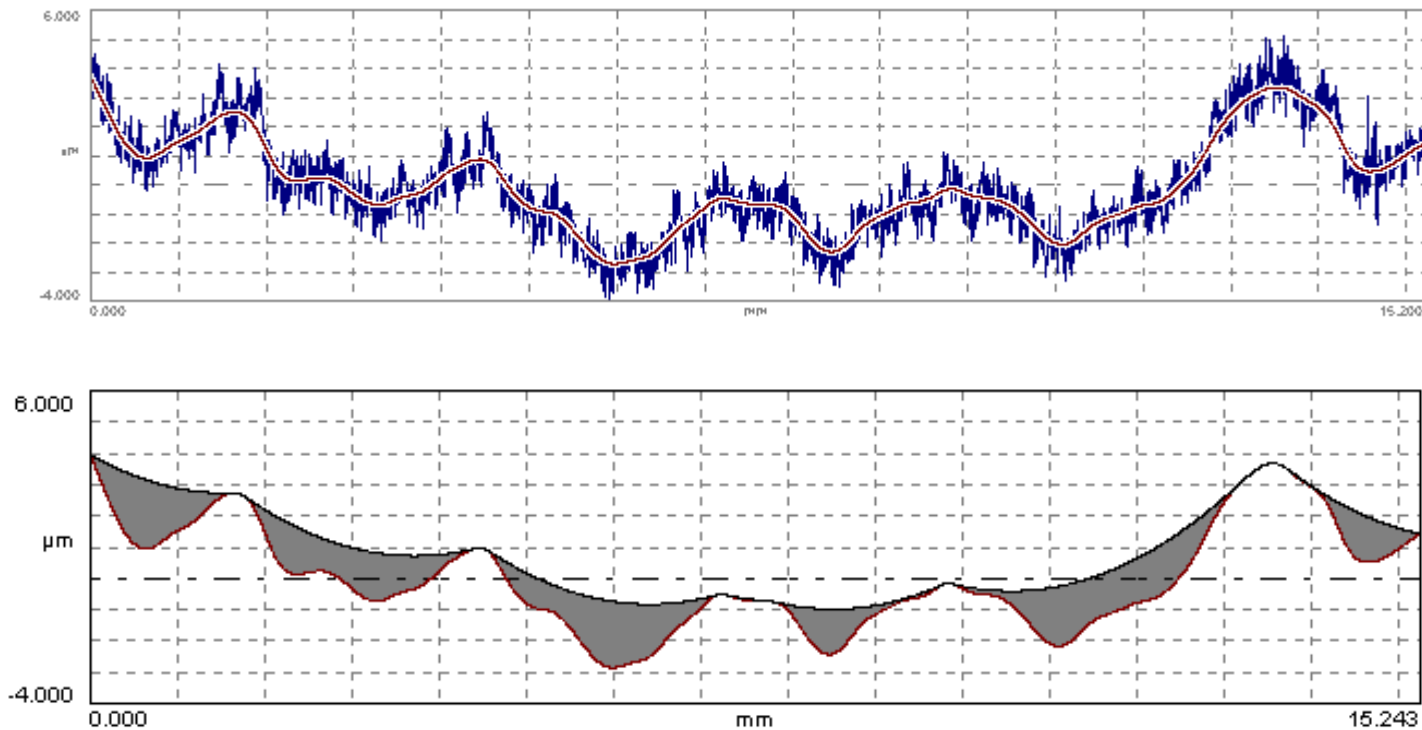
Combined Filtering & Analysis

- Next a morphological closing filter is applied to the waviness profile.



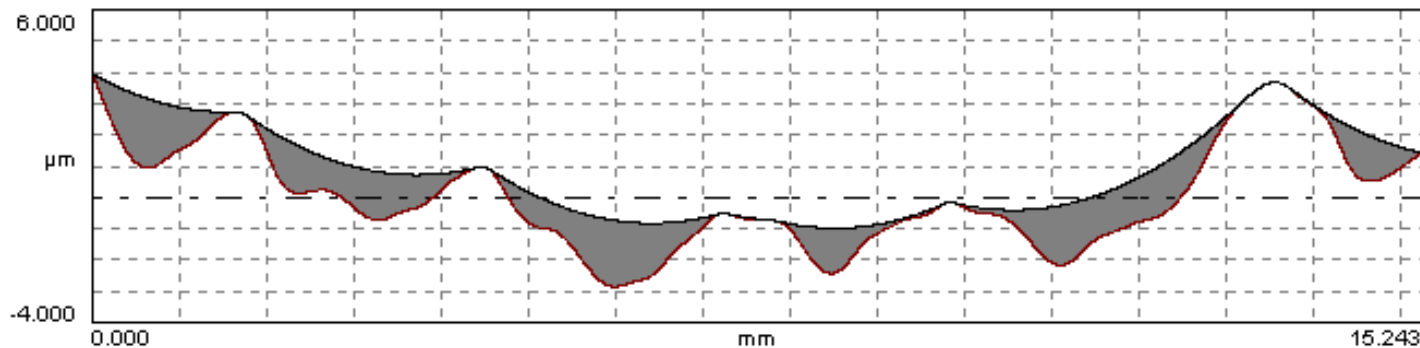
Combined Filtering & Analysis

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



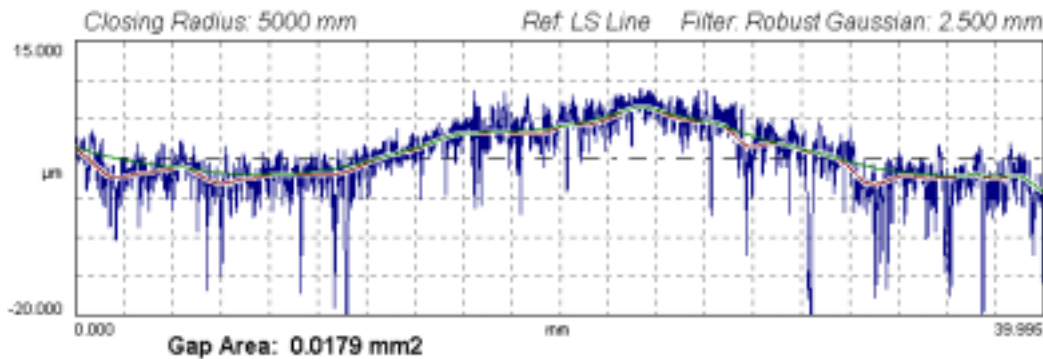
Combined Filtering & Analysis

- 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.

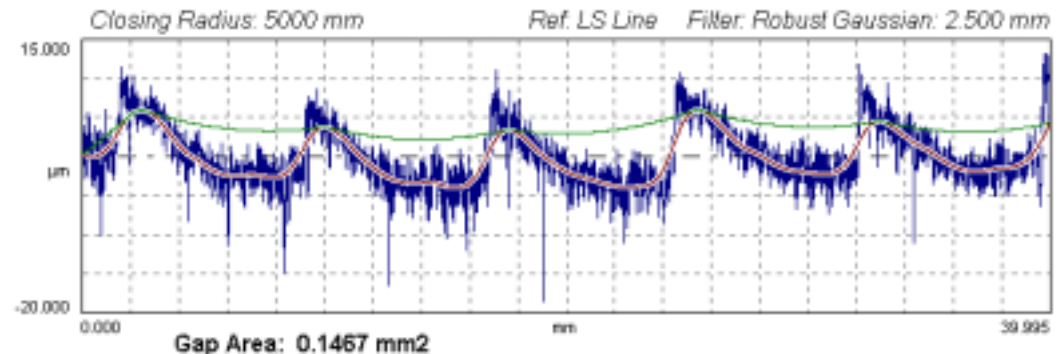


Combined Filtering & Analysis

- 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?*

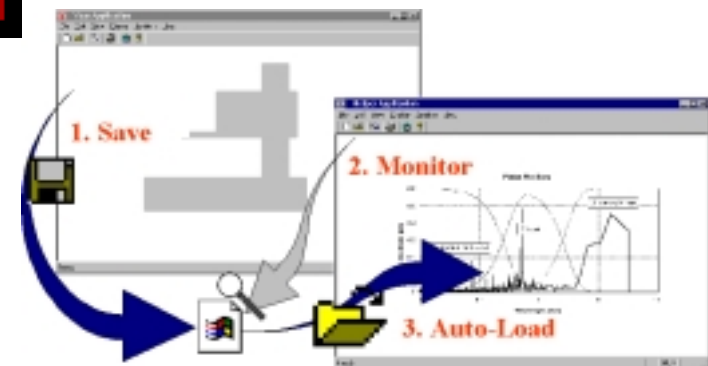
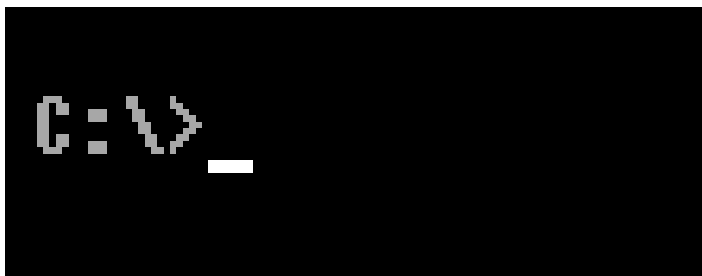
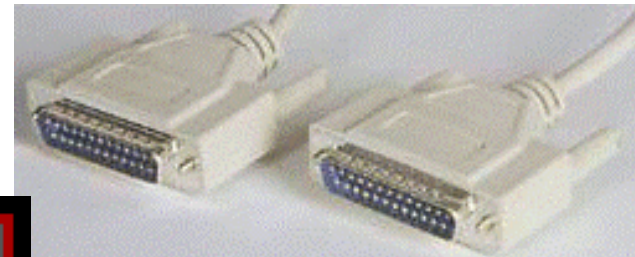
Answer: Software Add-Ins (Helpers)

Software Add-Ins (Helpers)

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



DDE/OLE



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

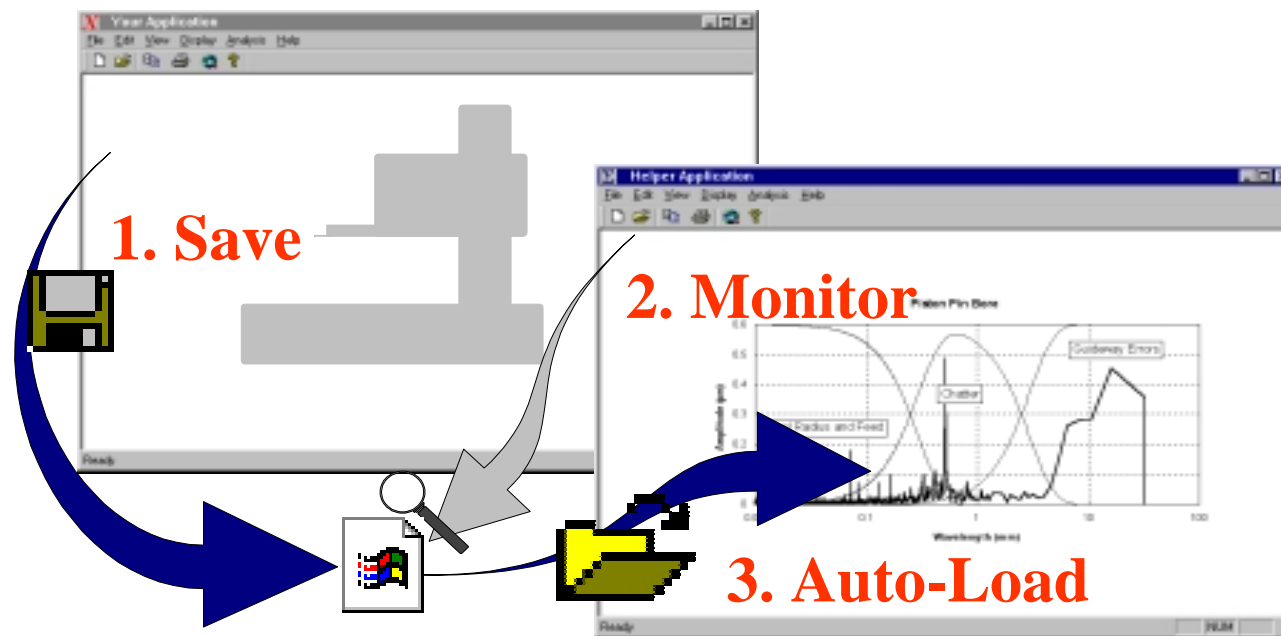
- Some instrument software packages provide an interface for external applications.
 - Spawning of external applications
 - Dynamic Data Exchange (DDE)
 - Object Linking and Embedding (OLE/COM)



DDE/OLE

File Based Interfacing

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



Fitting, Filtering & Analysis

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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