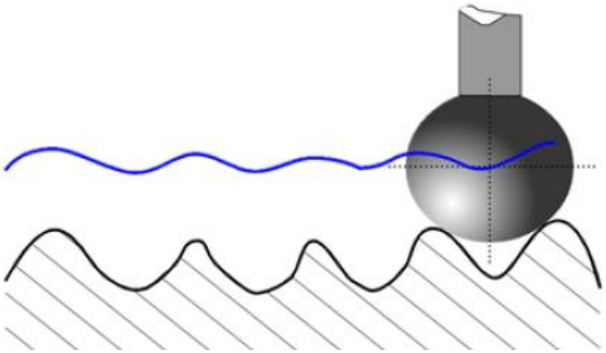
Filters
&
Outlier Elimination

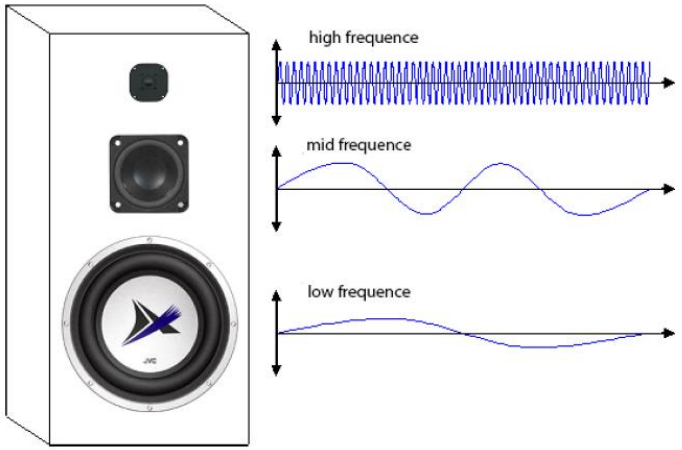
Filtering

- Why?
  - When we scan we are picking up everything about a surface
  - Filtering separates the different types of errors
    - Form (Low Frequency)
    - Waviness (Mid Frequency)
    - Surface Finish (High Frequency)
- A CMM can’t check surface finish
  - Including surface finish will falsify the form measurements

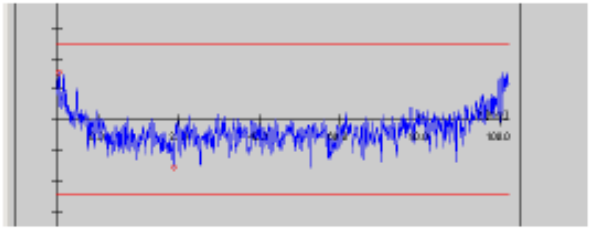
Filter Types

- Mechanical - Size of Stylus *(pg 54)*
- Morphological – Digital *(pg 55)*
  - Low Pass
    - Keeps low frequency (Sub-woofer)
    - Used on CMMs (size, form, & location)
  - High Pass
    - Keeps high frequency (Tweeter)
    - Used for Surface Finish
  - Band Pass
    - Removes very low & very high (mid range)
    - Used for Waviness

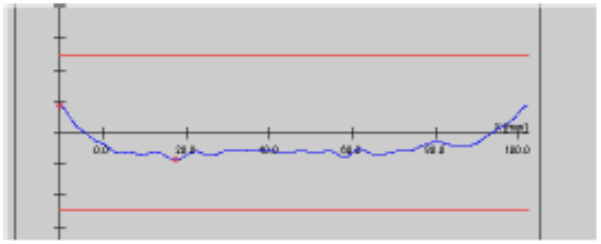




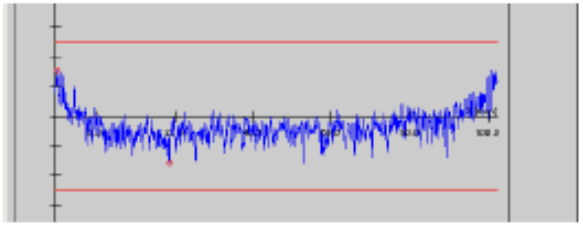
Filter Types



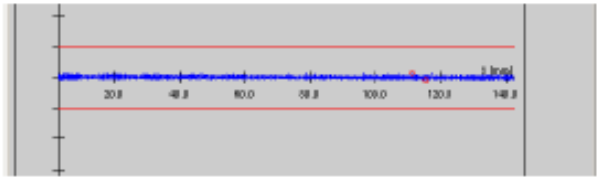
Low pass



Band pass



High pass

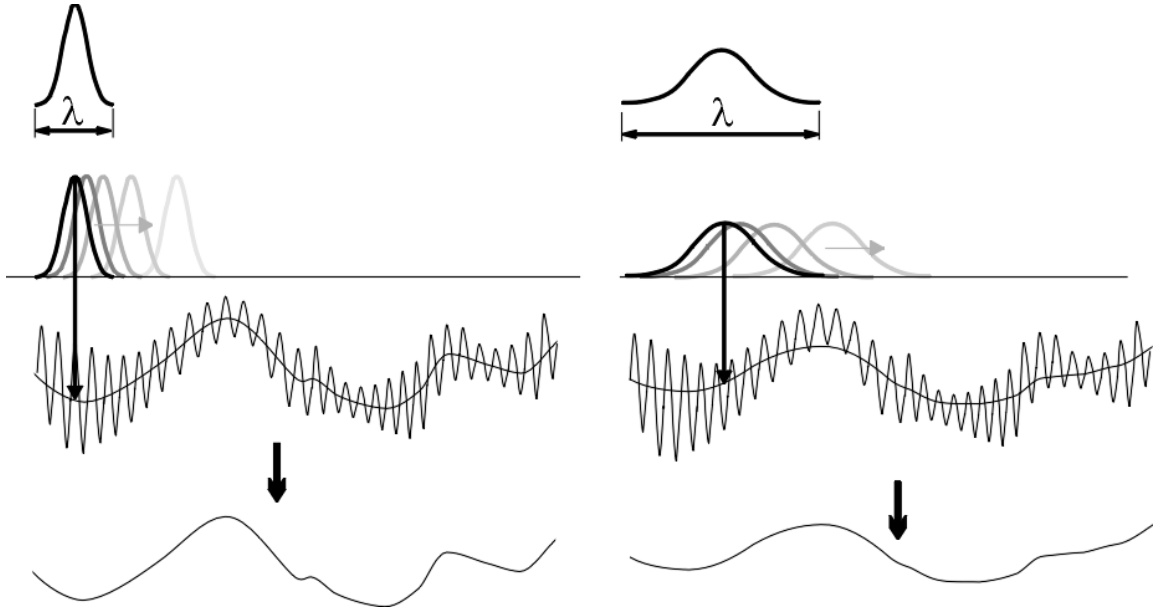


Filter Basics

- The main setting for a filter is the length of the filter wave or the number of waves
  - Wavelength for linear features (λc)
  - Undulations for round features (UPR)
- Length determines amount of filtering
  - Linear: Shorter wavelength is less filtering
  - Round: More undulations is less filtering

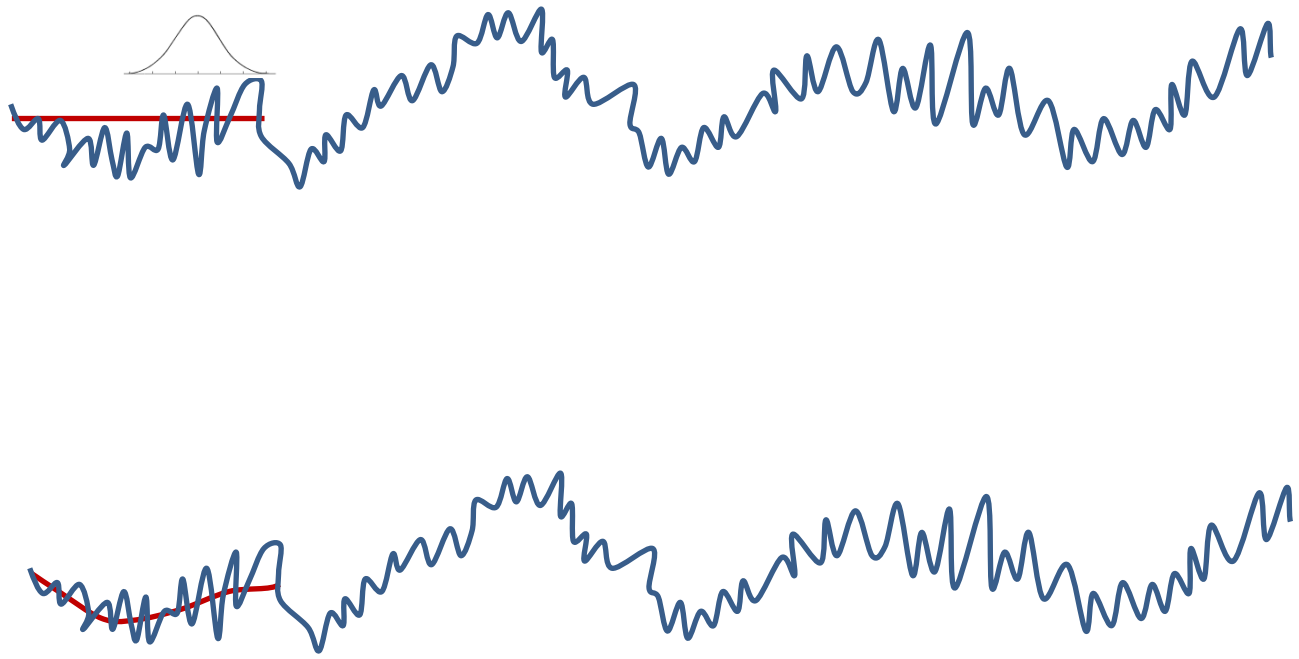
Filter Basics

- Using a weighting function at each point, a new point is calculated using this point and surrounding points within the length of the weighting function.



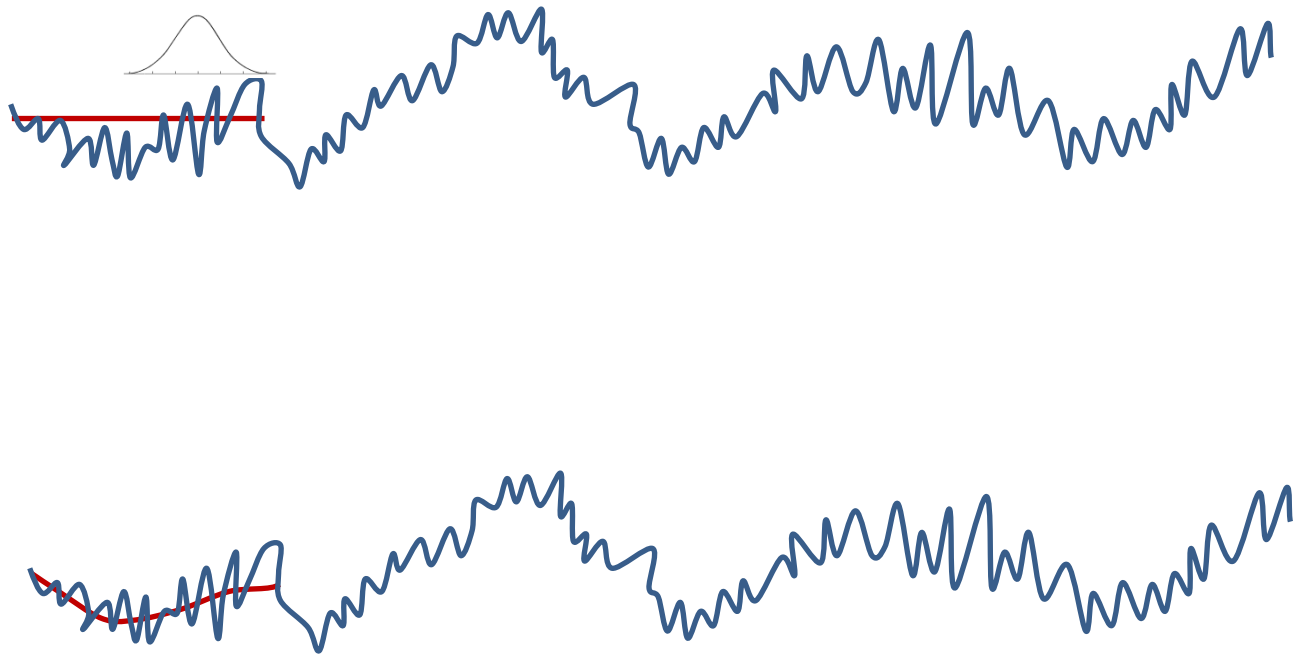
Filtering (Example)

Gaussian Filter



Filtering (Example)

Gaussian Filter



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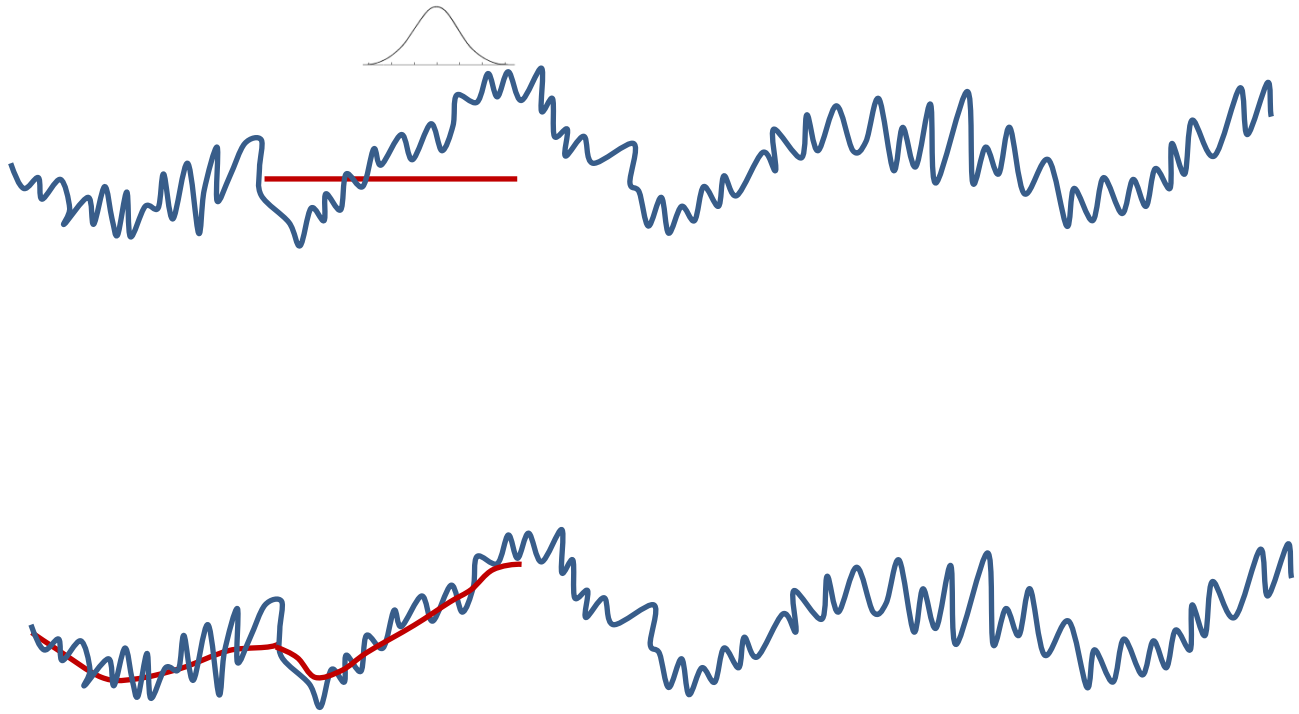
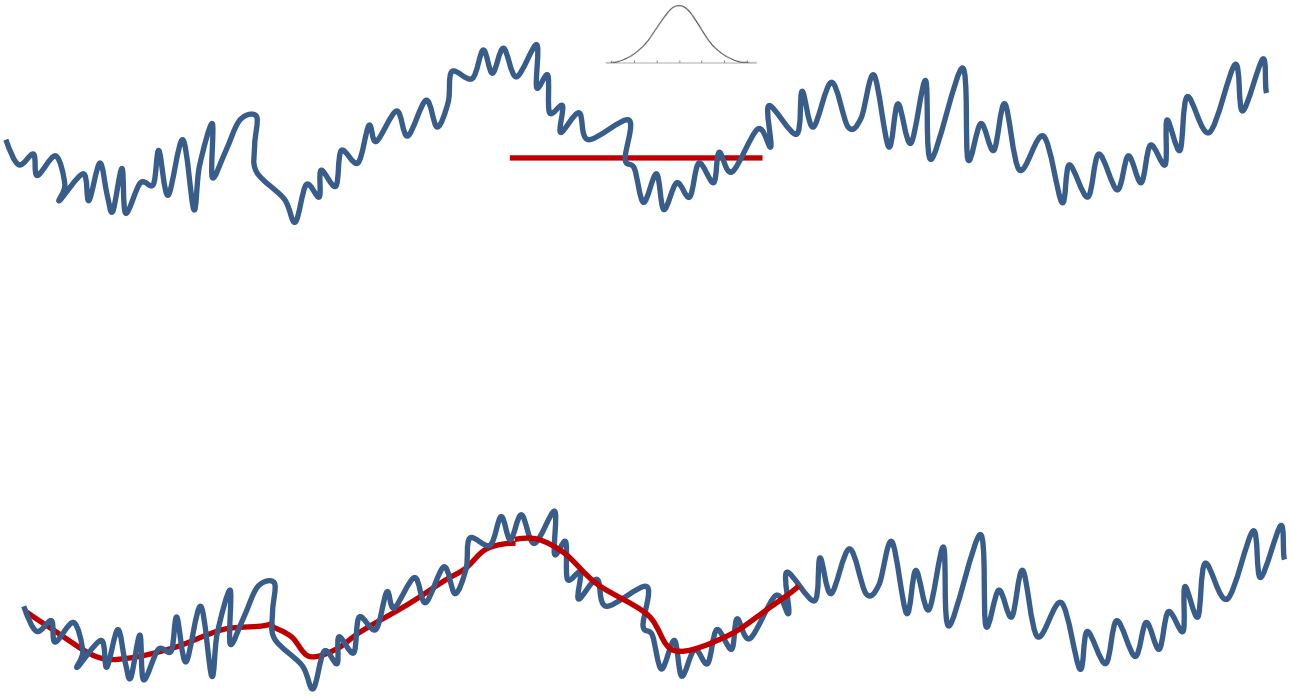


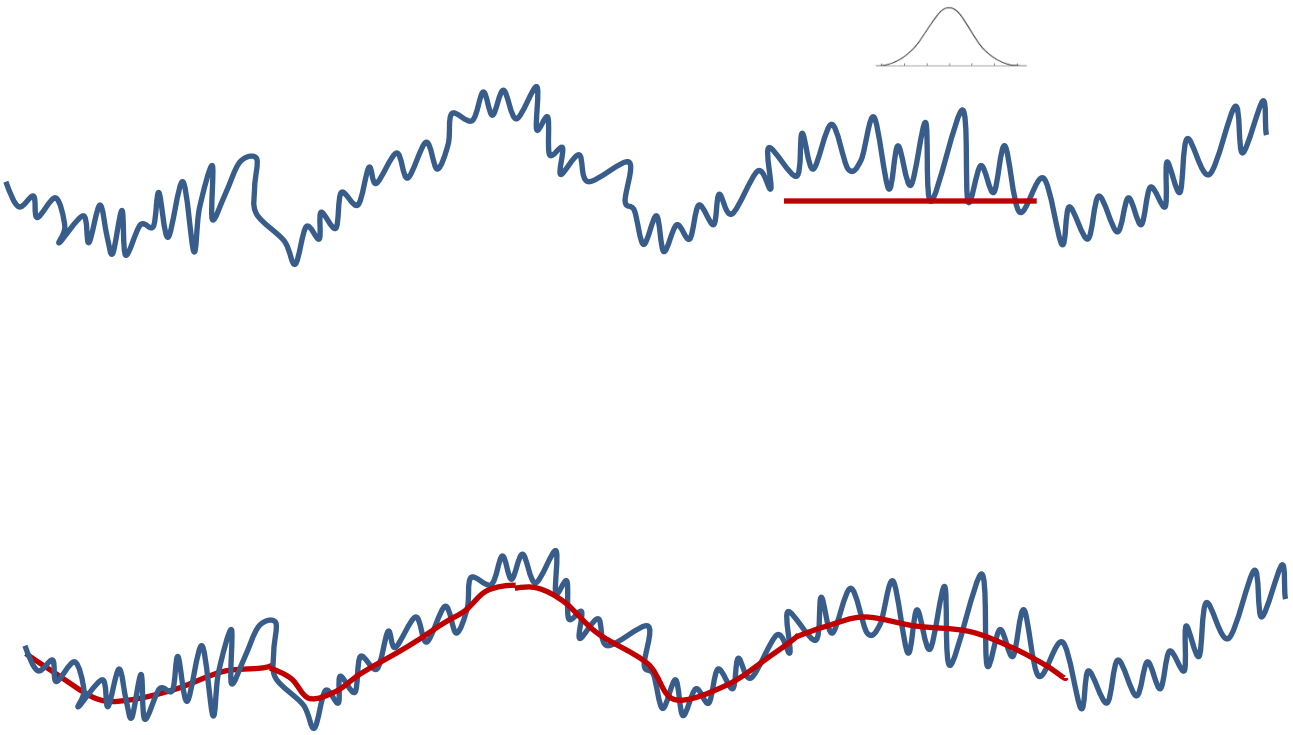
Filtering (Example)

Gaussian Filter



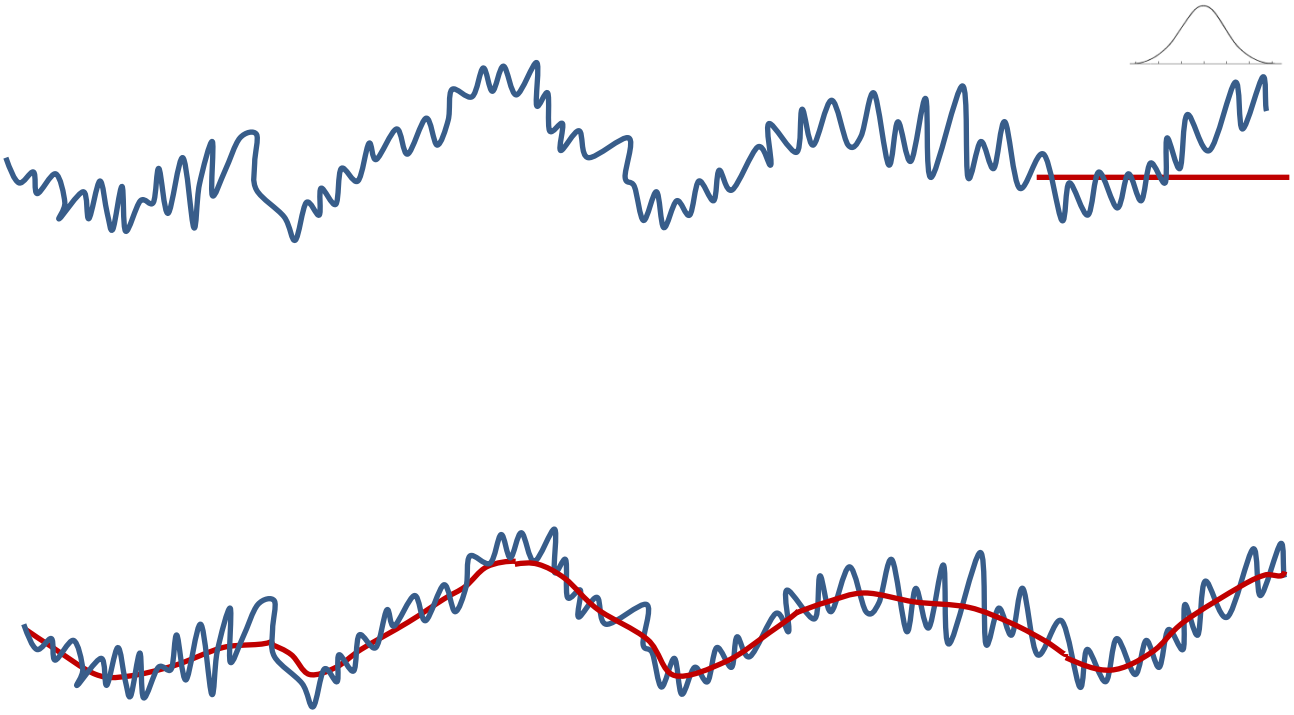
Filtering (Example)

Gaussian Filter



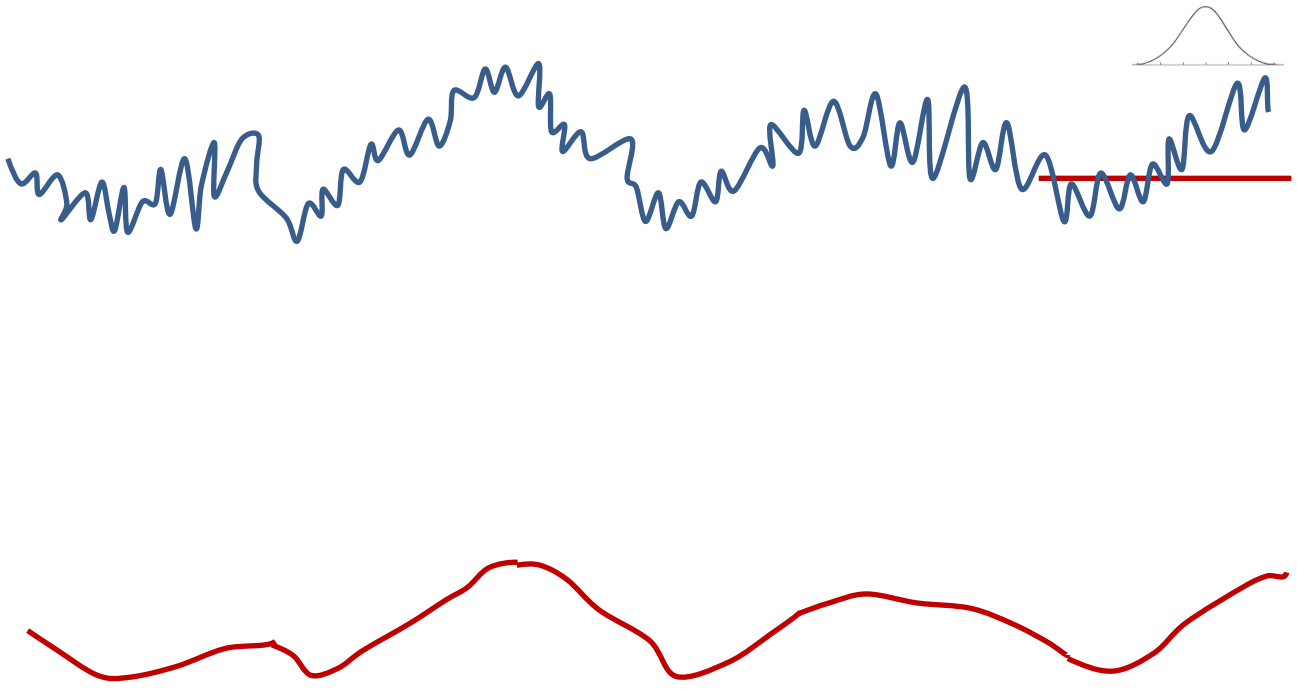
Filtering (Example)

Gaussian Filter



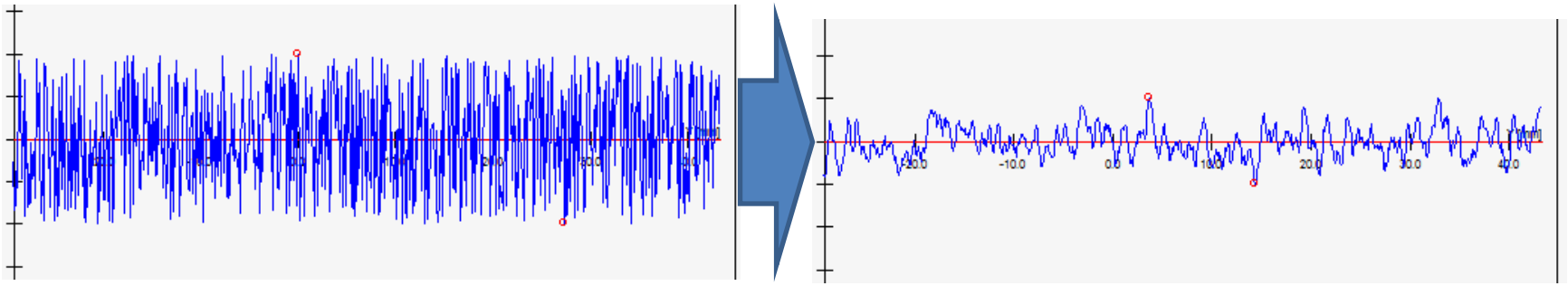
Filtering (Example)

Gaussian Filter



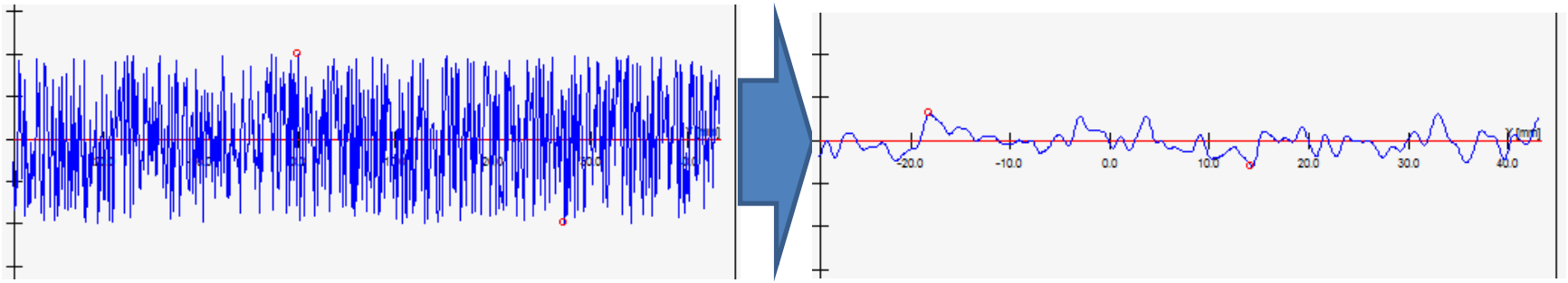
Filter Methods

- 2RC (ISO 4291)
  - Mathematical representation of electrical circuit (R=Resistor, C=Capacitor)
  - 75% of values are accepted (damped by ¼)
  - Not commonly used



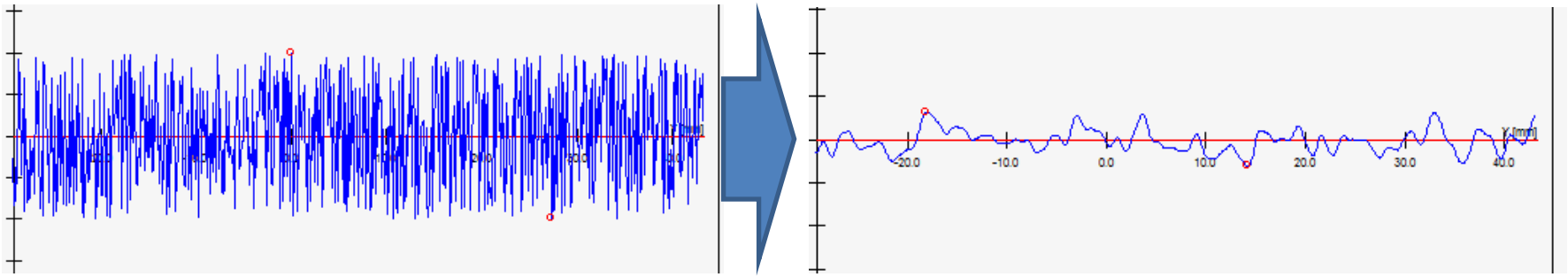
Filter Methods

- Gauss (ISO 16610-21/28)
  - Uses a bell curve to weight & recalculate points
  - 50% of values are accepted
  - Most Industry Accepted
  - Doesn't do well with outliers or open contours



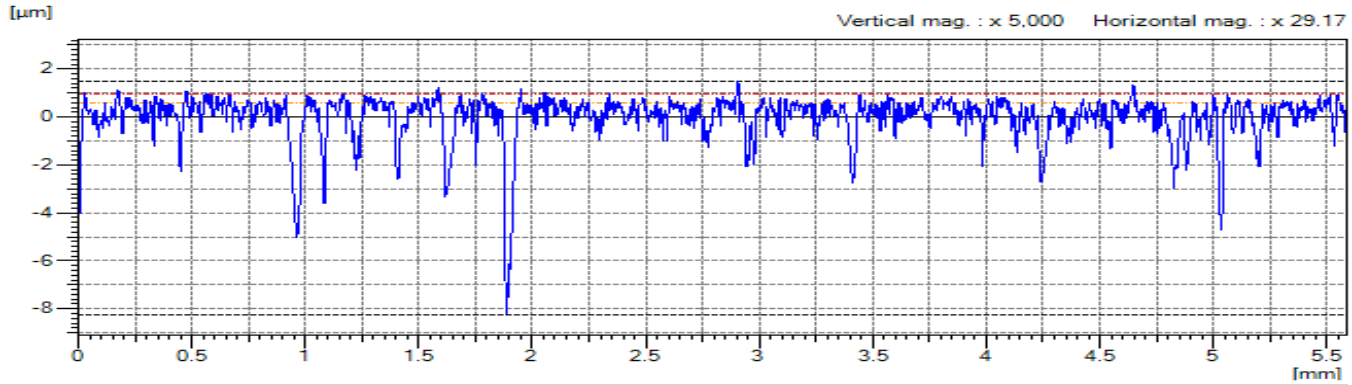
Filter Methods

- Spline (ISO 16610-22)
  - Uses a cubic spline function (3rd order polynomial)
  - Faster calculation than Gauss (no weighting)
  - Better functionality with outliers & open contours
  - Newer & not as widely accepted as Gauss

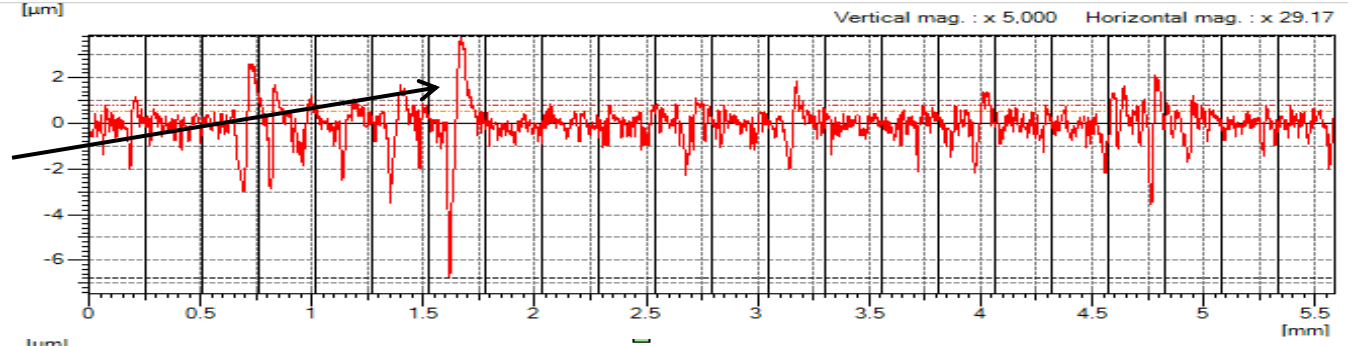


Method Comparison

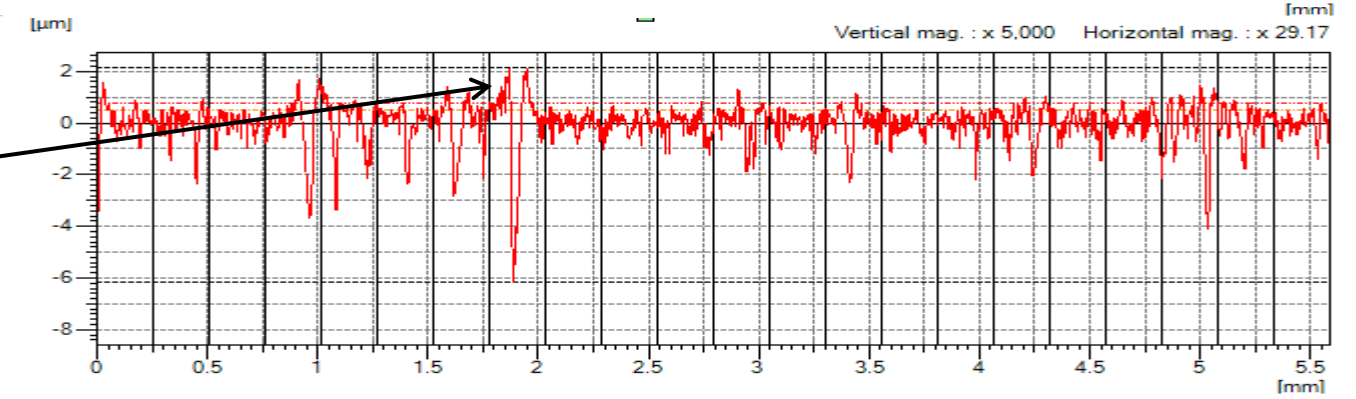
P Profile



2RC R-Profile “Overshoot”

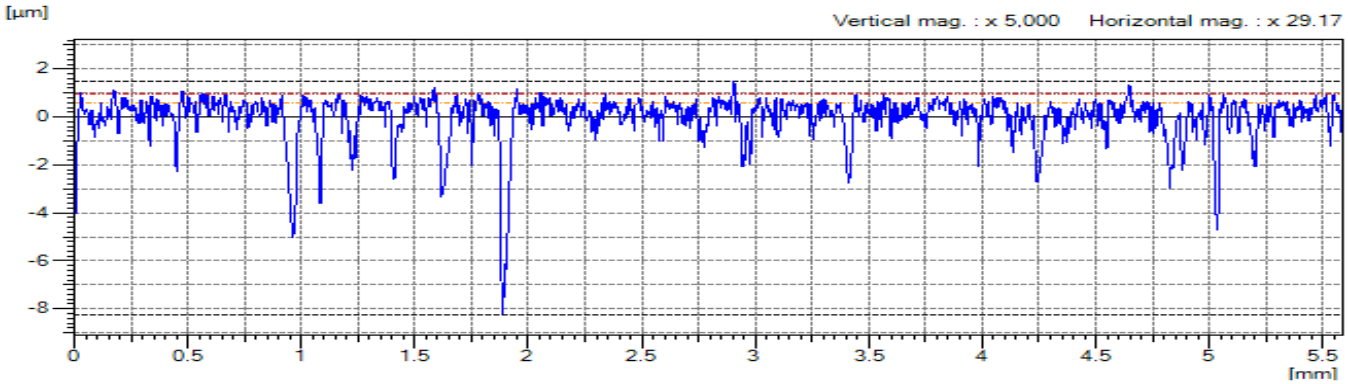


Gaussian R-Profile “Overshoot”

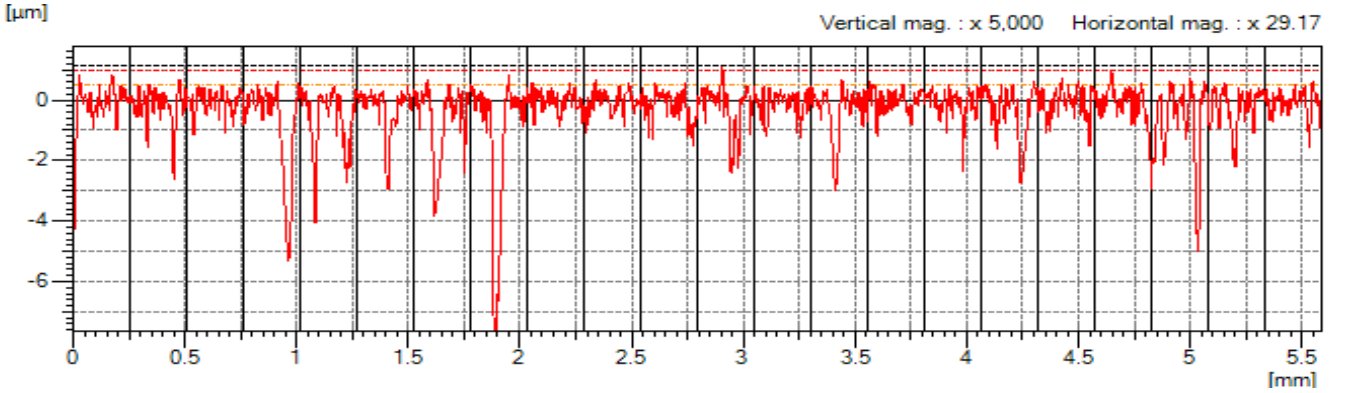


Method Comparison

P Profile



Robust Spline



Number of Points

- A filter needs at least 7 points per wave
- Linear Features (step width)

0.8 λc	2.5 λc	8.0 λc
0.11mm	0.35mm	1.14mm

- Round Features (number)

15 UPR	50 UPR	150 UPR
105pts	350pts	1050pts

- Filtering occurs AFTER outlier elimination
  - Minimums are not enough
  - Use recommended settings from cookbook

Recommended Settings
Round Features

Borehole/shaft diameter	Cutoff wavelength	Probing points per circle, angle range	Contact sensor Stylus tip diameter
<8 mm	15 UPR Gaussian filter	min. 145 for 400°	max. 3 mm
8 to 25 mm	50 UPR Gaussian filter	min. 425 for 380°	max. 3 mm
26 to 80 mm	150 UPR Gaussian filter	min. 1270 for 380°	max. 3 mm
81 to 250 mm	500 UPR Gaussian filter	min. 4250 for 380°	5 mm
>250 mm	1500 UPR Gaussian filter	min. 12700 for 380°	>5 mm

- Cookbook recipe Z100

Recommended Settings
Linear Features Location

Surface size (length)		
<25 mm	λc = 0.8 mm Gaussian filter	Stylus tip diameter: 3 mm Max. scanning speed: 3 mm/s Step width: 0.1 mm
>25 to 80 mm	λc = 0.8 mm Gaussian filter	Stylus tip diameter: 3 mm Max. scanning speed: 5 mm/s Step width: 0.1 mm
>80 to 250 mm	λc = 2.5 mm Gaussian filter	Stylus tip diameter: 3 mm Max. scanning speed: 10 mm/s Step width: 0.31 mm
>250 mm	λc = 8.0 mm Gaussian filter	Stylus tip diameter: 5 mm or more Max. scanning speed: 20 mm/s Step width: 1 mm

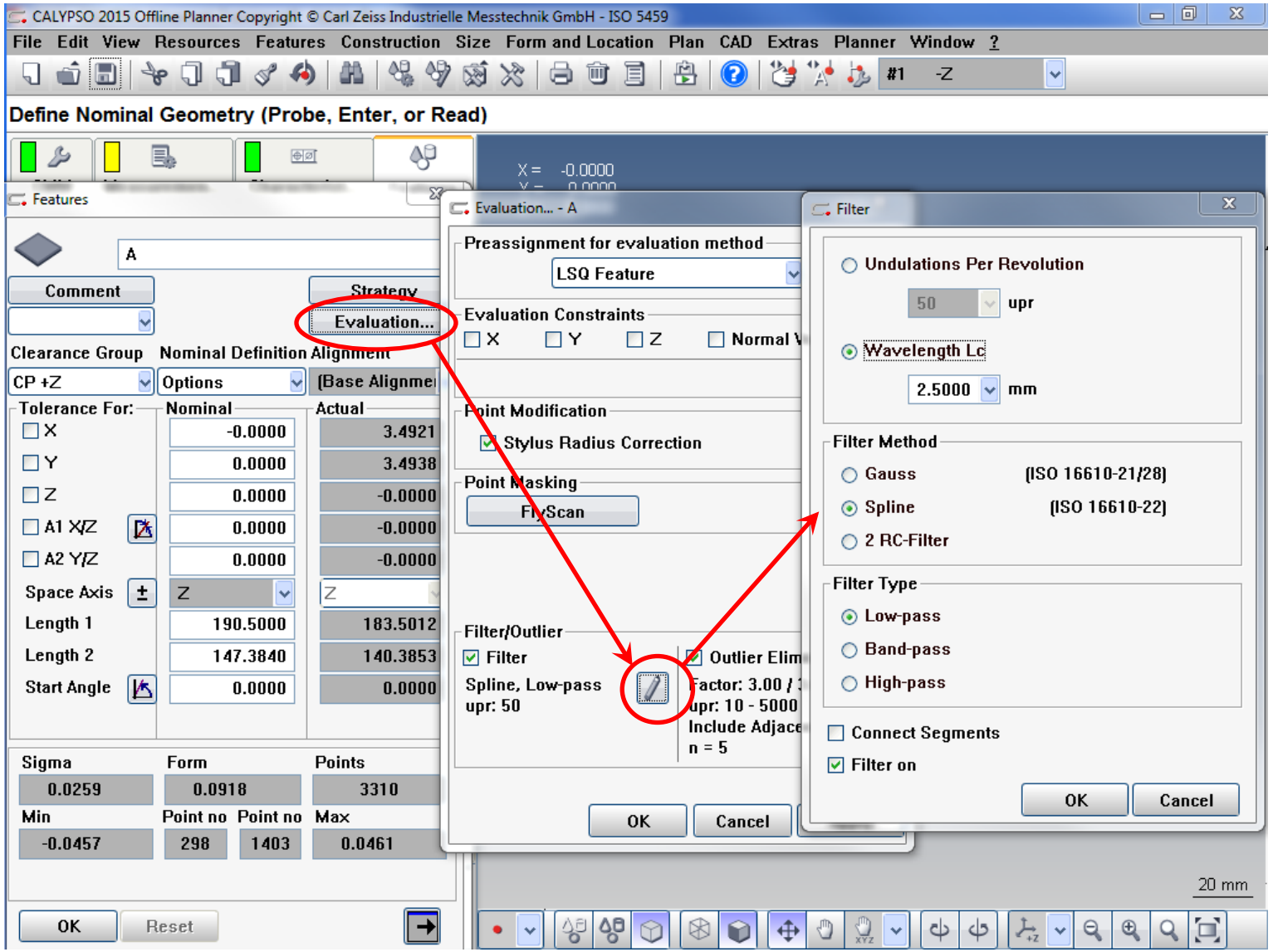
- Cookbook recipe Z400L

Recommended Settings
Linear Features Form

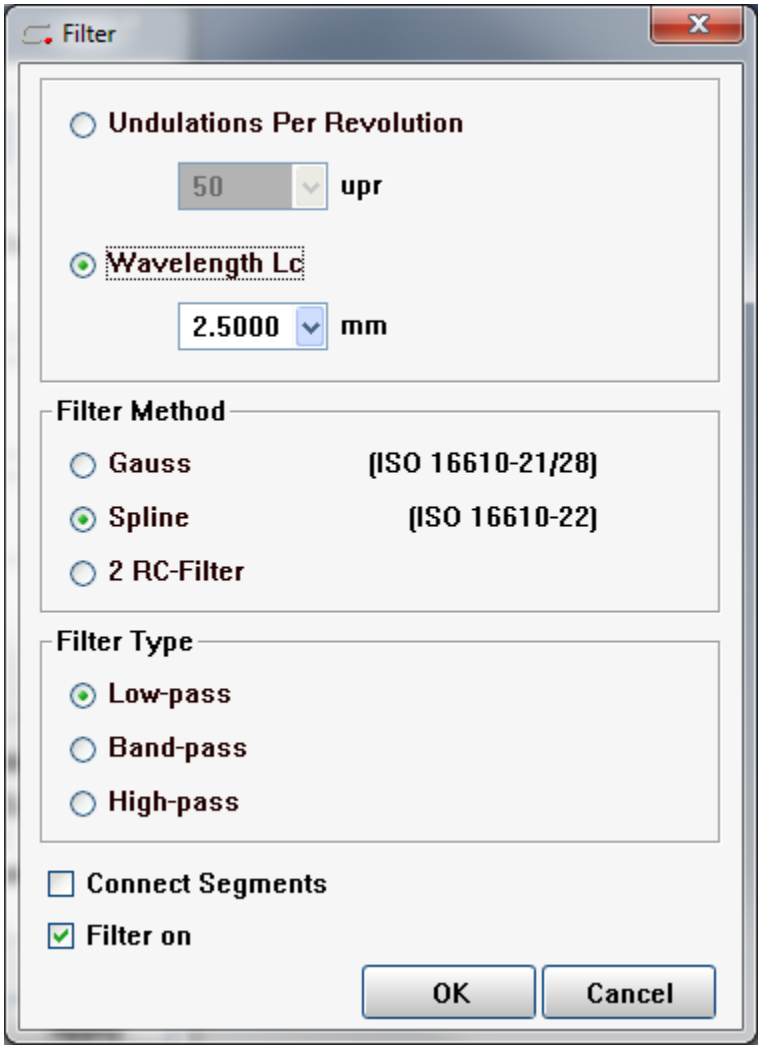
Roughness		
Ra ≤0.025 µm or Rz ≤0.1 µm	λc = 0.25 mm Gaussian filter	Stylus tip diameter: 1 mm Max. scanning speed: 1 mm/s Step width: 0.031 mm
Ra >0.025 µm to 0.4 µm or Rz >0.1 µm to 1.6 µm	λc = 0.8 mm Gaussian filter	Stylus tip diameter: 3 mm Max. scanning speed: 5 mm/s Step width: 0.1 mm
Ra >0.4 µm to 3.2 µm or Rz >1.6 µm to 12.5 µm	λc = 2.5 mm Gaussian filter	Stylus tip diameter: 3 mm Max. scanning speed: 10 mm/s Step width: 0.31 mm
Ra >3.2 µm or Rz ≤12.5 µm	λc = 8.0 mm Gaussian filter	Stylus tip diameter: 5 mm or more Max. scanning speed: 20 mm/s Step width: 1 mm

- Cookbook recipe Z400G

Calypso Settings



Calypso Settings



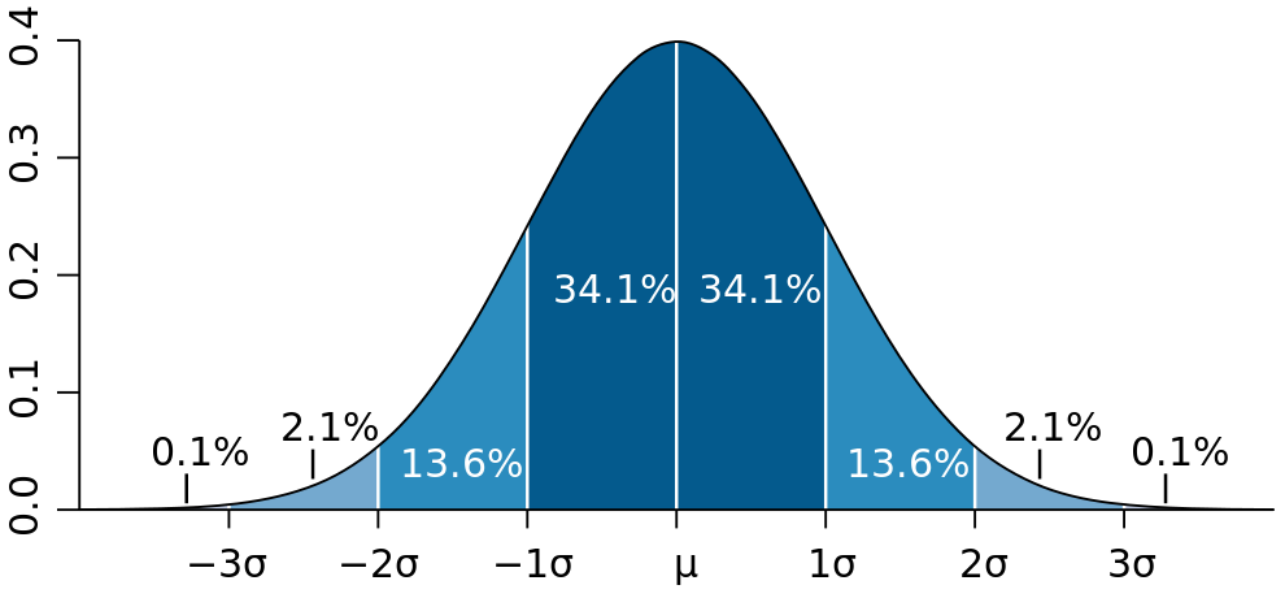
- Feature Settings transfer to characteristics & alignments
- Resources > Save/Load Defaults
  - Applies to Characteristics only

Outlier Elimination

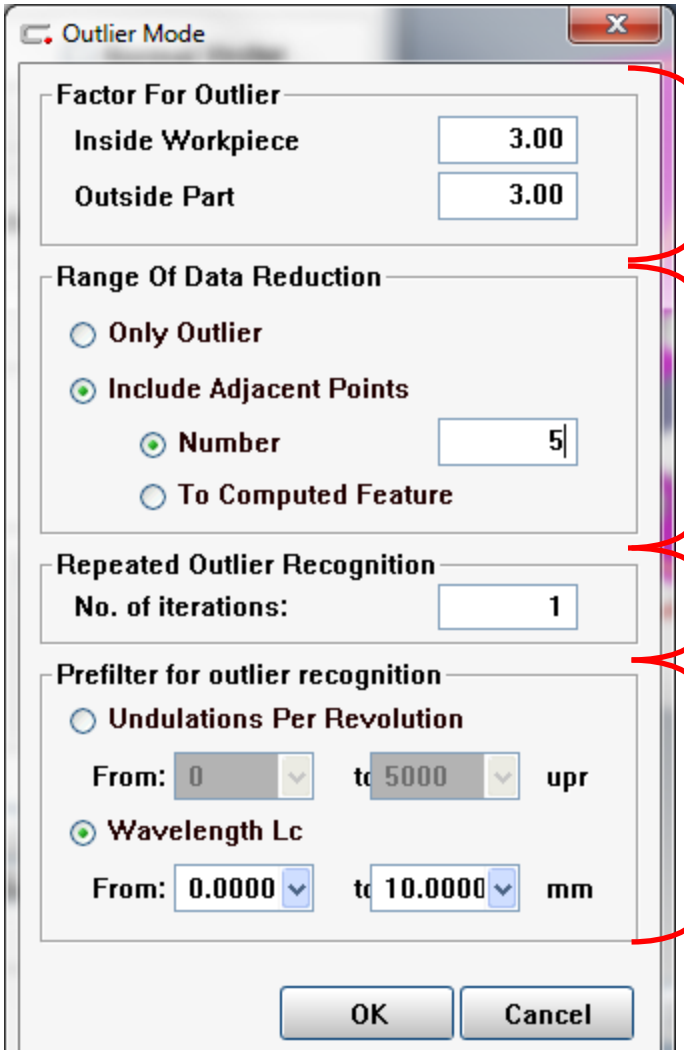
- Used to remove points that we didn't intend to measure (chips, nicks, fuzz, burrs, pores, boogers…)
- Based on the standard deviation (σ or sigma) of the calculated feature
  - Sigma is multiplied by a factor (usually ±3) to determine acceptable limits from feature
  - Any point outside limits is removed
- Example:
  - A feature has a 10µm σ with a factor of ±3
  - Any point > 30µm from the actual feature is removed

Outlier Example

- Standard Deviation is a predictor
  - If the data points follow a normal distribution (bell curve), a certain percentage of data will exist in each range
  - Most thing don't follow a perfect bell curve so there may not be anything at the extremes or there could be lots.
  - As a general rule, don't eliminate more than 5% of points



Outlier Settings



Standard Deviation Factor

Number of point to eliminate

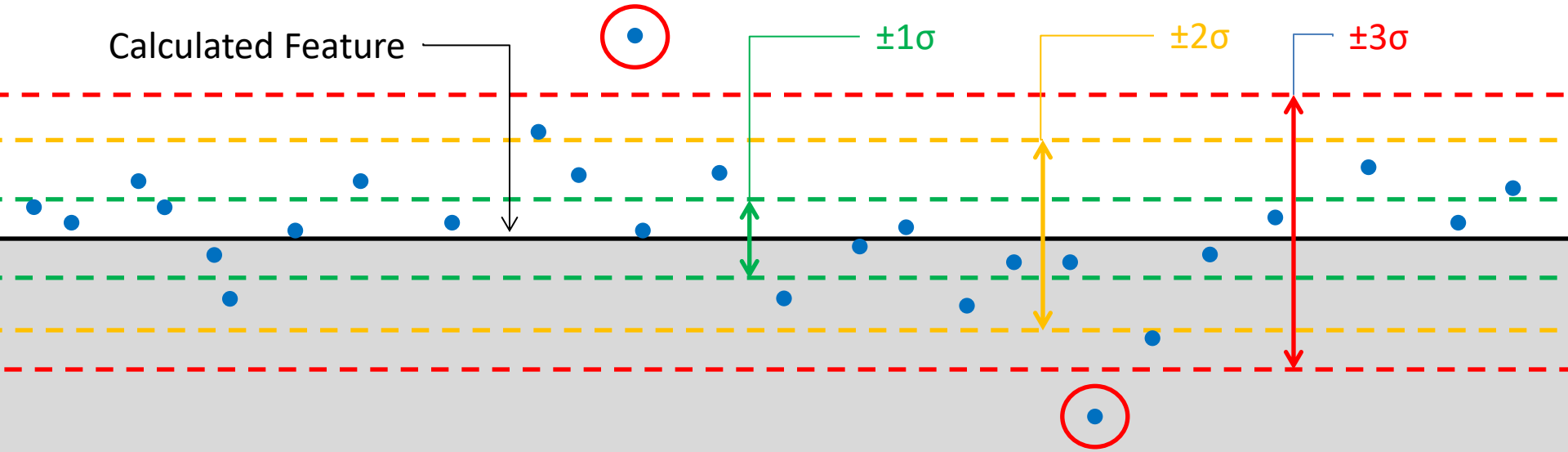
Number of times to find outliers

Prefilter for mean feature

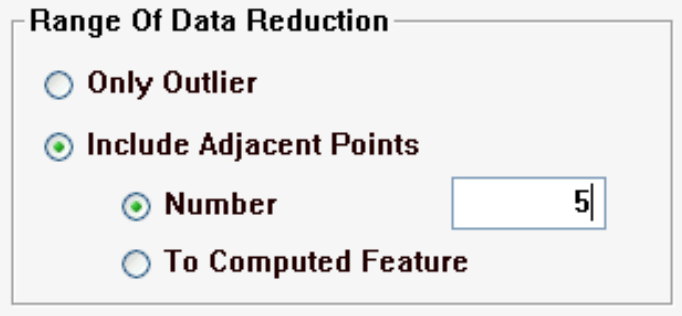
Standard Deviation Factor

- Defines the limits for identifying an outlier
  - Inside Workpiece = Into Material
  - Outside Part = Out of the Material

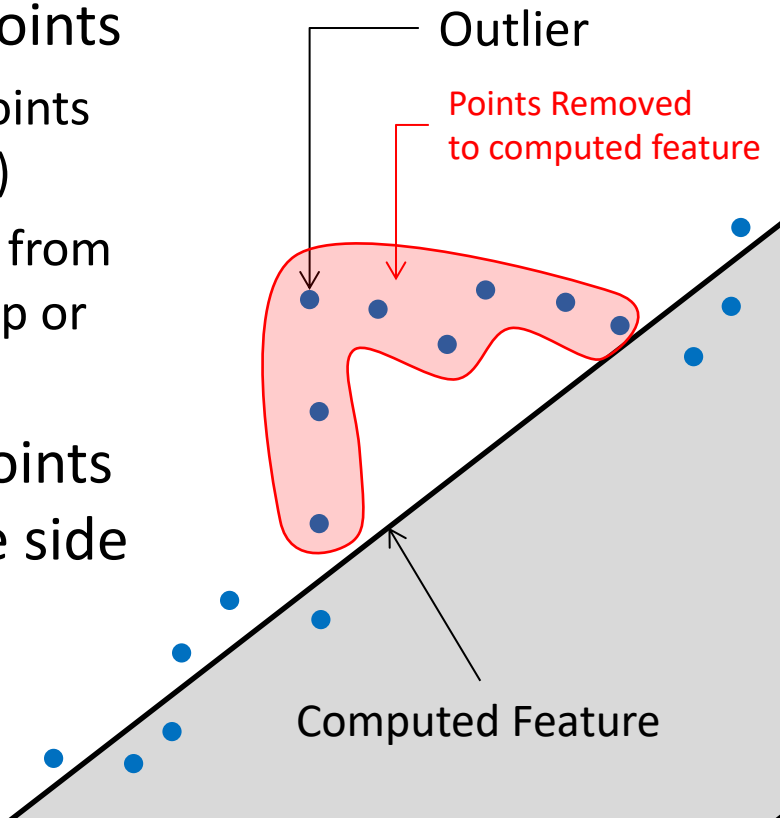
- The factor is the number of standard deviations
  - A smaller number is more aggressive



Number of Points



- When an outlier is found, how many points are removed
- Calypso defaults to Only Outlier
- Cookbook recommends 5 adjacent points
  - For each outlier found, the outlier + 5 points on each side is removed (11 total points)
  - Typically there are points leading to and from the outlier that should not be there…chip or burr
- To computed feature gets rid of all points near the outlier that are on the same side of the calculated feature. Use with extreme caution!

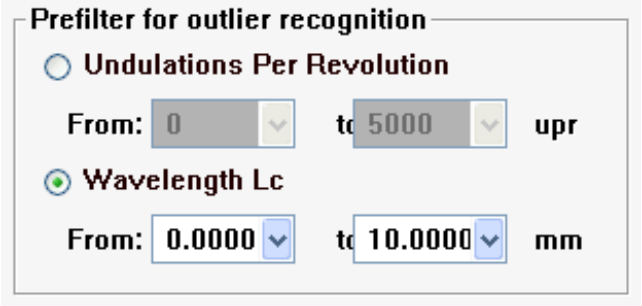


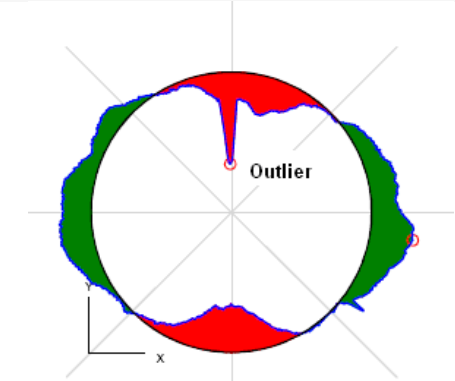
Iterations

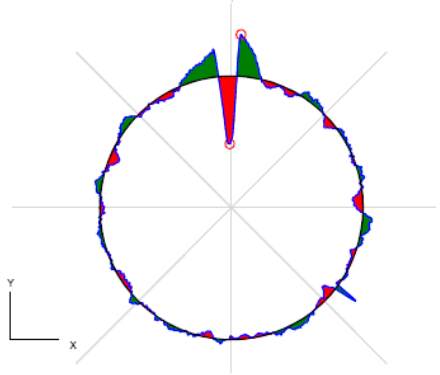
- When the first calculation of the standard deviation occurred, the outliers contributed to the size of the standard deviation
- By removing the outliers the new standard deviation will be smaller & there may be points outside the limit using the new value
- Removing adjacent points makes iterating more than once unnecessary
  - Typically only used if removing only outlier
  - Iterating more than once starts to move into the arena of removing valid data

Prefilter

- Prefilter is used to calculate a computed feature that considers the form of the actual feature
- A Band Pass filter is applied such that the extremely low and high wavelengths are ignored when computing the feature
- Without the prefilter, features with high form deviation may not recognize outliers due to the high standard deviation
  - Oval or lobed circles
  - Concave/Convex planes







Extreme Low Frequency Removed

Summary

- Filtering
  - Used to separate different errors that exist on parts
  - On a CMM we remove High Frequency error (surface finish) so the Low Frequency error (form) can be inspected without extra influence
  - Filtering is done in accordance with accepted ISO standards
- Outlier Elimination
  - Looks for and removes points that should not have been measured
  - Based on standard statistical methods (standard deviation)
- Both require high data density to work properly