Spatial Filtering of Surface Profile Data

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Explanation of Filtering

A highway can be considered a surface with filter components corresponding to hills and valleys or speed bumps. This type of road with these various topographies is shown in Figure 1.

One road has a large, slow rolling hill, which because it is very smooth (1A), may be acceptable for high speed travel. An alternate road has a constant series of speed bumps that are a few feet tall with 20 feet between bumps. This road would obviously be unacceptable for high speed travel (1B). The third road has a large slow rolling hill with the same speed bumps on the surface, which is also unacceptable for high speed travel (1C). The speed bumps in Figure 1B can be considered as short spatial wavelength information and the slow rolling hill as low spatial wavelength. Surface features in general can be separated into various spatial wavelengths, similar to the example shown in Figure 1.

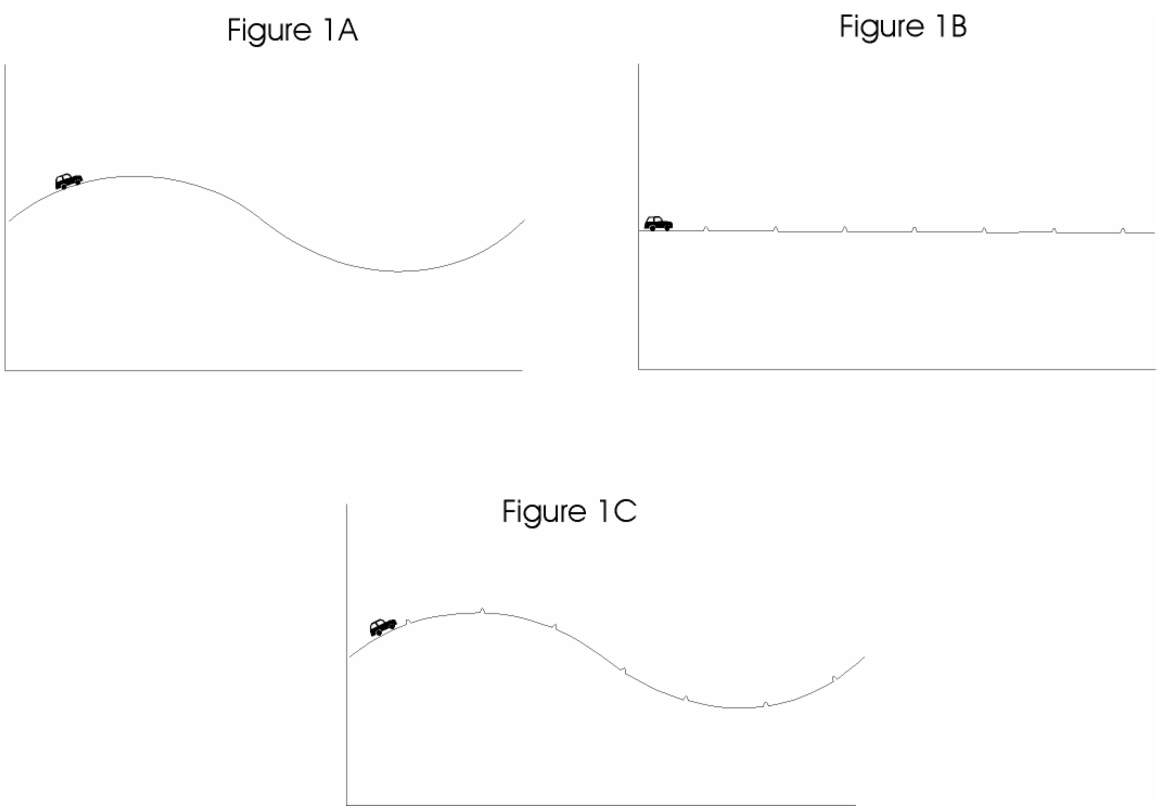

Figure 1

Amplitude and Spatial Wavelengths

The example shown in Figure 1 illustrates the importance of not just the amplitude or height of surface features, but also the amplitude at given intervals or spatial wavelengths. The example shown in Figure 1 shows the importance of considering the spatial wavelengths in addition to the height. The height of the road in Figure 1A is larger than the speed bumps in Figure 1B, yet the road in Figure 1A would obviously represent a better surface for high speed travel.

Filtering in the Spatial Frequency Domains

There are three fundamental, analytical representations for displaying surface features in the Spatial Domain: Total Profile, Roughness and Waviness.

The example of the road surface shown in Figure 1 has these three fundamental representations. The same road surface is shown in Figure 2 in the profile, waviness and roughness representations. The complex road structure shown in Figure 2A would be considered the total profile, including both the speed bumps and the rolling hill. Removing the speed bumps yields the waviness, Figure 2B. Alternatively, removing the hills yields the roughness (2C). The roughness, which shows only the speed bumps, represents the shorter spatial wavelengths. The height of the speed bumps can be calculated in the roughness series shown in Figure 2C. The height of the overall complex road structure in Figure 2A would be primarily due to the rolling hill, which is much taller than the speed bumps.

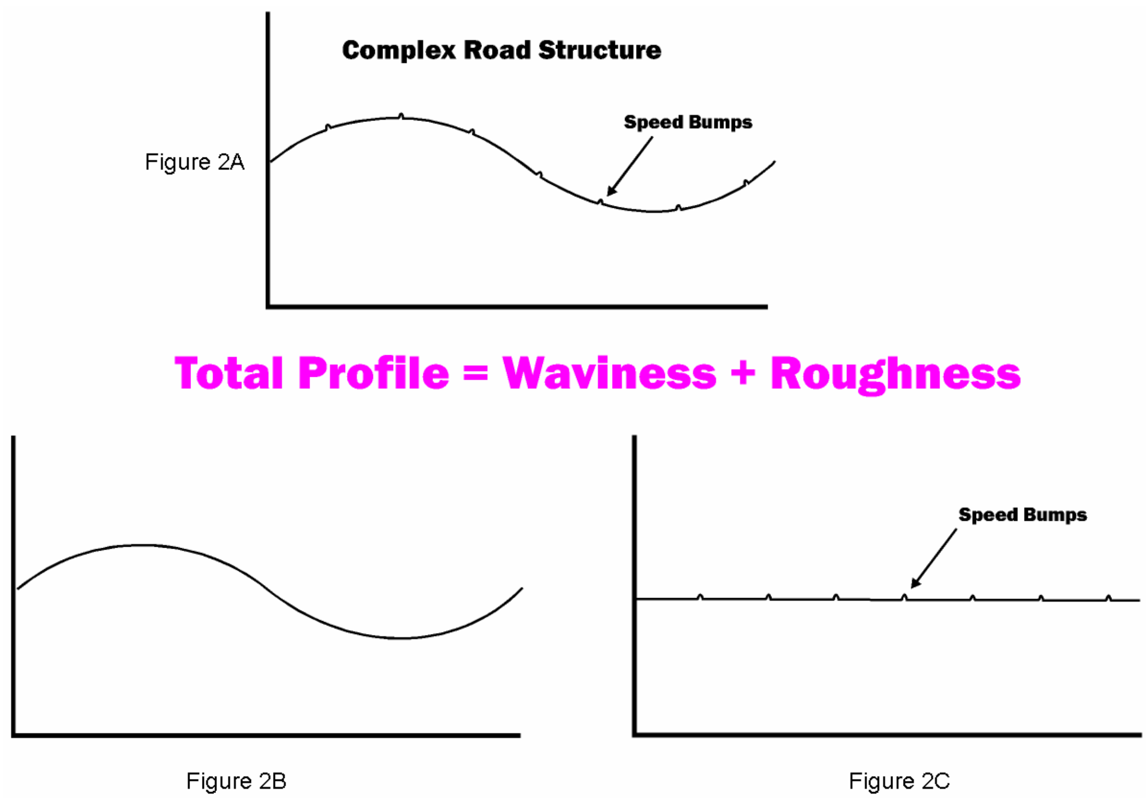

Figure 2

Total Profile

The Total Profile definition is the surface information, which spans the entire bandwidth of the measuring instrument. Depending on the instrument setting, this may be from distances on the order of 1 micrometer in length to tens of millimeters. The Total Profile contains both roughness and waviness information.

Roughness

The Roughness is calculated by subtracting the Waviness from the Total Profile data. The Roughness shows the finer, or shorter spatial wavelength features, of the surface. Typically, roughness parameters are given by “R_{sub}” where *sub* is the appropriate subscript for the parameter. For example, R_a is the average roughness.

Waviness

Calculated from the Total Profile, the waviness represents the longer spatial wavelength features of the surface. Waviness over long distances is typically called form, figure or bow. Typically, Waviness parameters are given by “W_{sub}” where *sub* is the appropriate subscript for the parameter. For example, W_a is the average waviness.

The example shown in Figure 3 shows how this method is applied to surface profile data. First a cutoff filter is selected to separate the roughness from the waviness. The cutoff filter is chosen so that only the small spatial features are evident in the roughness series. The cutoff filter is typically a Gaussian Filter as specified by International Standards (Further information on the International Standards is available from Chapman Instruments.) The cutoff filter is shown schematically in Figure 3B with a specific width as a rectangle. The filter is moved across the profile resulting in the roughness and waviness data. Features smaller than the width of the filter will be incorporated in the roughness data and features wider than the filter width will be incorporated in the waviness data. Increasing the cutoff filter width allows wider features into the “roughness” plot while decreasing the cut-off filter width allows only the narrower features into the roughness data.

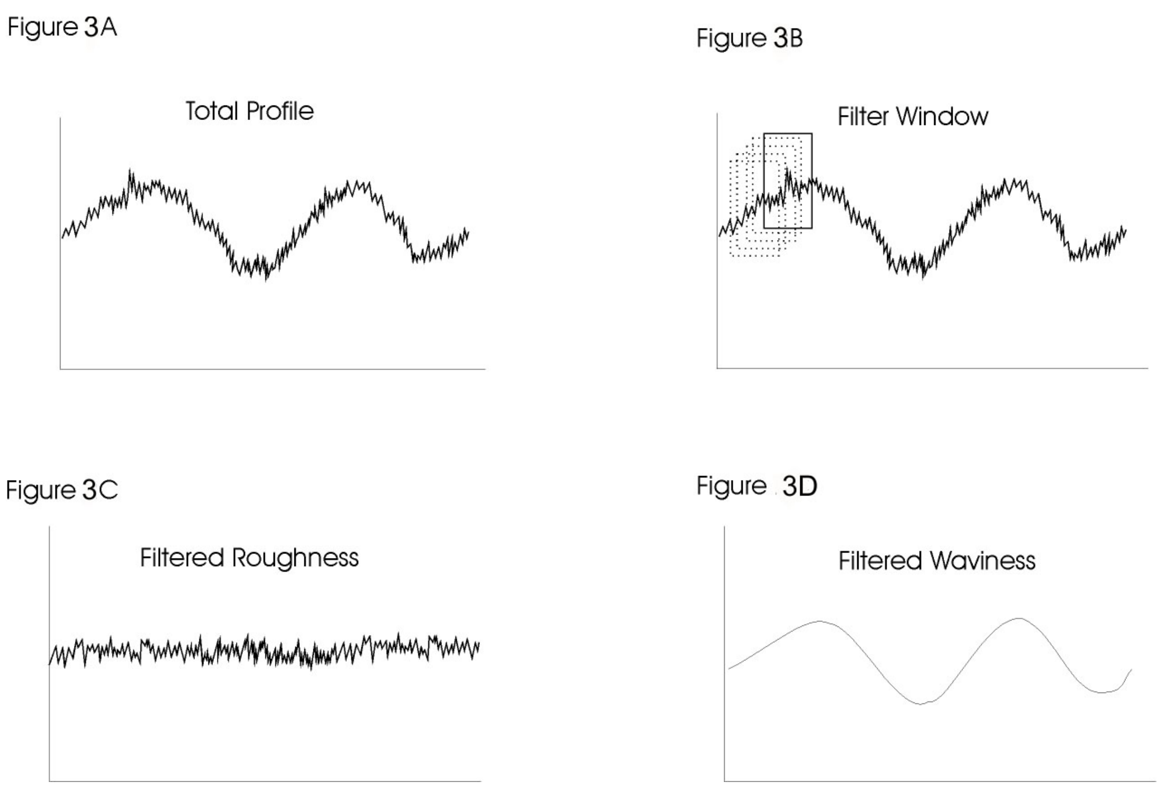

Figure 3

Cutoff Filter Length

The cutoff filter length is a definition used by a United States Standards group to define the filter length for waviness and roughness data. (International Standards use a similar format). In modern profiling instruments, this is a digital filter in the analysis software incorporating a Gaussian Filter. The cutoff filter is used to specify the range of spatial wavelengths (or the spatial frequencies) in the waviness and roughness data. It is important to note that a roughness number, such as R_a and RMS, are meaningless without specifying the cutoff filter used in the roughness calculation.

The concept of a cutoff filter is similar to a high pass filter in electronics. A high pass filter will pass frequencies higher than its cutoff and block lower frequencies. For surface profile data it is useful to describe a high pass filter as passing high spatial frequencies (or short wavelengths). A cutoff filter must be specified for analysis of either the roughness or waviness data.

Recommended Filtering Procedures

It is possible to choose any cutoff filter length. However, there are five standard cutoff filter lengths that are defined by various standard organizations. These five cutoff lengths represent a method to divide the spatial frequency information into different regions. The three organizations have different recommendations for the number of cutoff filter lengths and the corresponding overall evaluation length. The following is the recommendation for three current standards:

- *U.S. standard:* For proper statistics the evaluation length should contain a number of cutoff filter lengths.
- *ISO (International Standard):* The evaluation length should contain one or more cutoff filter lengths.
- *German (DIN) Standard*: The evaluation length is five times the cutoff filter length.

The following table shows an example of five different cutoff filter lengths and a recommended evaluation length using five segments. The table also shows the number of sections for a full 100 mm scan. Our recommendation is to use at least two to five cutoff lengths for a good statistical evaluation. Better statistics of the surface can be obtained by taking a longer scan length with increasing number of filter sections. The five cutoff filter lengths in Table 1 can be used in general to separate different spatial width features in the data.

Table 1 Standard Cutoff Filter Definitions

Cutoff Filter Length (mm)	Scan Length with 5 Cutoff Lengths (mm)	Number of Sections for a 100 mm scan
0.080	0.400	1,250
0.250	1.250	400
0.800	4.000	125
2.500	12.500	40
8.000	40.000	12

Varying Cutoff Filter Lengths

The Chapman profiling instruments offer wide measurement bandwidths. Data for short spatial wavelengths, on the order of a micrometer, can be included in the overall scan length up to 100 mm. This flexibility allows a wide selection of roughness evaluation. User's can select a cutoff filter best suited to there manufacturing process. Chapman's analysis software offers additional flexibility in showing the roughness data with different cutoff filters on the same screen. The Chapman software allows users to add or change the filter without rescanning the surface.

Example use of cutoff filter

An example of the roughness and the corresponding waviness is shown in Figure 4 on the following page. The example shows the surface topography of a computer hard disk. Similar analyses could be made on other types of surfaces. Figure 4A shows the total profile of a 1.25 mm scan. Figures 4B and 4D show the roughness and waviness with a 40 µm filter and Figures 4C and 4E show the same data calculated with a 250 µm filter. The total profile shows fine micro roughness and other wide spatial topographic features; for example, several valleys on the order of 100 µm wide. The roughness data with a 40 µm filter only shows spatial wavelengths less than 40 µm. The small valleys on the order of 100 µm in the total profile have been filtered out. The roughness data with the 250 µm filter includes some of these longer spatial features. The associated waviness data also shows these differences; the waviness with a 40 µm cutoff filter shows more of the small spatial features than the waviness data with a 250 µm filter. Both roughness and waviness plots show a R_a and W_a value, respectively. These are referred to as the roughness average and waviness average, only two of the dozens of user selectable surface parameters, which can be reported with the Chapman software.

This example illustrates how selecting two different cutoff filter lengths for a single measurement can yield information on three key surface features:

- Very fine micro roughness (roughness)
- Periodic features
- Bow or warp of the substrate (waviness)

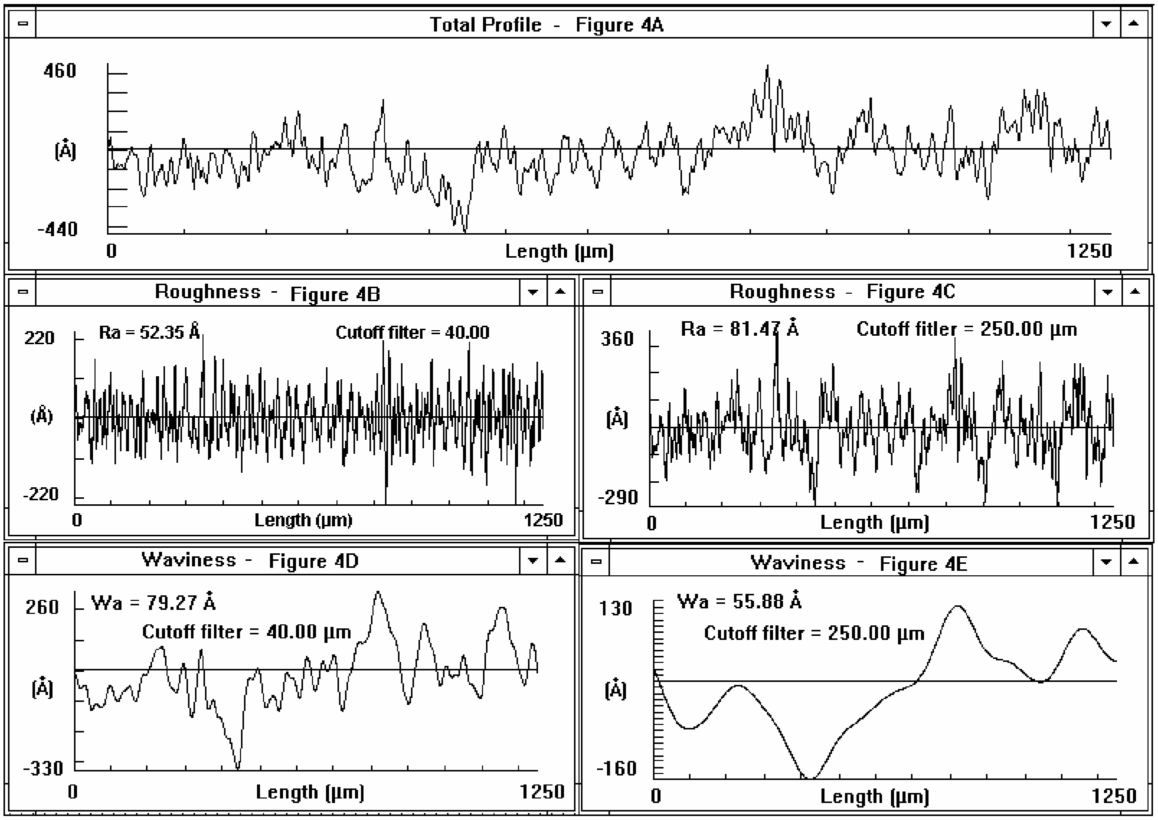
Total Profile - Figure 4A
460
(Å)
-440
0
Length (µm)
1250
Roughness - Figure 4B
220
Ra = 52.35 Å
Cutoff filter = 40.00
(Å)
-220
0
Length (µm)
1250
Roughness - Figure 4C
360
Ra = 81.47 Å
Cutoff fitler = 250.00 µm
(Å)
-290
0
Length (µm)
1250
Waviness - Figure 4D
260
Wa = 79.27 Å
Cutoff filter = 40.00 µm
(Å)
-330
0
Length (µm)
1250
Waviness - Figure 4E
130
Wa = 55.88 Å
Cutoff filter = 250.00 µm
(Å)
-160
0
Length (µm)
1250

Figure 4

For more information on spatial filtering of surface profile data, contact:

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