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Investigating filter end-effects on profiles having form, in the context of ISO 21920

Faivre A[1], Blateyron F[1]
[1] Digital Surf, Besançon, France

Corresponding author: fblateyron@digitalsurf.fr

Abstract

ISO 21920-2 introduced a change in the order of operations required to obtain the Primary profile. Now, the microroughness S-Filter (with *Nis* nesting index, equivalent to λs) is applied first, before the F-Operation (levelling or form removal), contrary to what was done earlier with ISO 3274. This change implies that a profile with form can be smoothed by a Gaussian filter (the default filter type) which is notoriously not robust against form, leading to end-effects that may affect parameter calculations. This paper compares different methods for managing end-effects, as described in ISO 16610-28, discusses their respective advantages and drawbacks, and introduces a possible alternative way to minimize biases on parameter results.

Keywords: Filtration, end-effects, ISO 21920, S-Filter, F-Operation

1. Introduction

ISO 21920-2 [1] changed the order between S-Filter and F-Operation, so it is now possible to smooth a profile, using a small-scales S-Filter, while the form is present (slope or geometrical form). The problem is that the Gaussian filter does not cope well with form, therefore, the smoothed profile exhibits end-effects when applied on a profile with form, sometimes leading to huge differences, for example in peak-to-valley parameters. This drawback could be a huge obstacle for users wishing to move from ISO 3274 [2] to the new ISO 21920 standard.

Literature on the subject of filter end-effects (also called edge effects) is quite rare. ISO standards describe end-effects management methods (EEM method), but without explaining their advantages or drawbacks. Moreover, users are left with inconsistencies between different documents, such as ISO 16610-21 [3] which recommends the "moment retainment" method for the Gaussian filter, and ISO 16610-22 [4] which includes the "line extension" method in the Spline filter, while ISO 16610-28 [5] proposes a collection of possible methods. Besides, Part 28 does not have an equivalent document for surfaces (that should be Part 68), yet surfaces are also impacted by the same end-effects.

Several authors though have investigated end-effects and have proposed filter variants, sometimes by exploring other types of filters [6, 7, 8, 9]. However, a complete characterization of all the proposed EEM methods does not seem to exist.

This is why, we propose in this paper to explore the impact of each EEM method on a selection of test profiles, in order to recommend good practices. We also propose an alternative method, suitable for surface texture, that minimizes end-effects, in particular of the small scales S-Filter with a *Nis* nesting index.

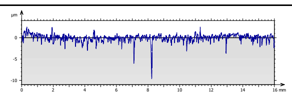
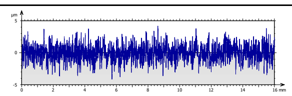
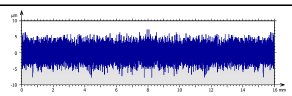
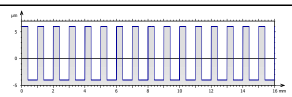
2. Methodology

In order to characterize the impact of each EEM method, a specific experimental workflow is used in the Mountains® software and applied on test profiles.

2.1 Test profiles

This experimental workflow is applied on a bank of profiles, composed of 4 different base texture profiles (see Table 1) superimposed on 7 different form components, 6 of them given in Table 2 plus No Form, which makes a total of 28 test profiles.

Table 1: *texture bases of the test profiles*

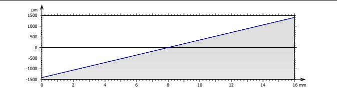
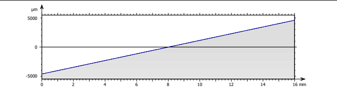
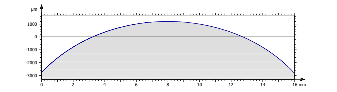
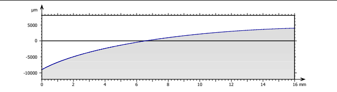
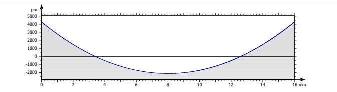
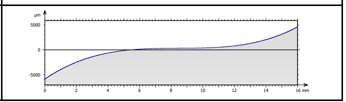
Honing1	
Noise	
Sym Noise	
Square	

Honing1 is a stratified profile measured on a cylinder bore; Noise was created with a random generator using a Gaussian distribution, but where several instances of the same value are possible (which may influence the mean line position), Symmetrical noise has only one instance per value to ensure that the mean line is centred; Square is a rectangular shape periodical profile with a non-symmetrical duty cycle.

Regarding the Form components, there are two inclined line segments, to compare the impact of the amplitude of form, two different arcs, one almost centred and the other taken on the side, each with a different radius, and two polynomial profiles, a parabola and a 3rd-order polynomial.

The resulting test profiles are obtained by summing a texture with a Form component.

Table 2: *Form components*

10° slope	
30° slope	
Arc 10mm	
Arc 20mm	
Parabola	
3rd-order polynomial	

2.2 Workflow

The workflow presented in Figure 1 is designed to allow the assessment of an EEM method by comparing a particular filtered profile with an end-effects management method with the filtered profile without end-effects.

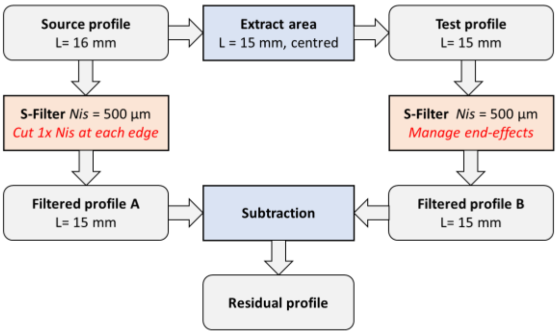


Figure 1: *workflow used to characterize end-effects*

The left side of the workflow produces the *Filtered profile A* where the S-Filter cuts one cut-off at each end. Profile A acts as a reference (that has no end-effects). The right side of the workflow uses one of the EEM method under test, and the residual profile is characterized in amplitude and/or in lateral span. Figure 2 shows an example of residual profile.

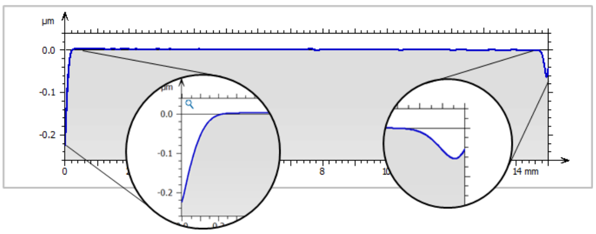


Figure 2: *Example of residual profile showing end-effects*

2.3 End-effect management methods

The study applied the above workflow to various EEM methods, defined in ISO 16610-28, plus the additional suggested method, defined in section 4. Some of the methods extend each end of the profile by a length equal to one cut-off length and others modify the filter equation within the end-effect zone (EEZ).

The tested methods were:

- Zero padding (ZP)
  Extends the profile by adding zeros on both ends.
- Copy last point (LP)
  Extends the profile by copying the first or last point.
- Simple mirror (SM)
  Copies the points of the EEZ by horizontal symmetry.
- Double mirror (DM)
  Copies the points of the EEZ by horizontal and vertical symmetry.
- Slope extension (SE)
  Extends the profile with a LS line calculated in the EEZ.
- Retain moments (RM)
  Modifies the filter equation in the EEZ.

3. Alternative EEM method

Considering that the inversion between the S-Filter and F-Operation is the main cause of troubles, a simple solution is proposed, as shown in Figure 3.

1. A first F-Operation is applied before the S-Filter in order to allow the filtration without end-effects
2. Then the form is put back after the S-Filter to obtain a smoothed profile with the original form
3. Then the specified F-Operation is done

This method minimizes end-effects due to the S-Filter, as it is applied on a profile without form, as before with ISO 3274. However, it stays compatible with the aim of ISO 21920-2 as the final F-Operation is applied on a smoothed profile.

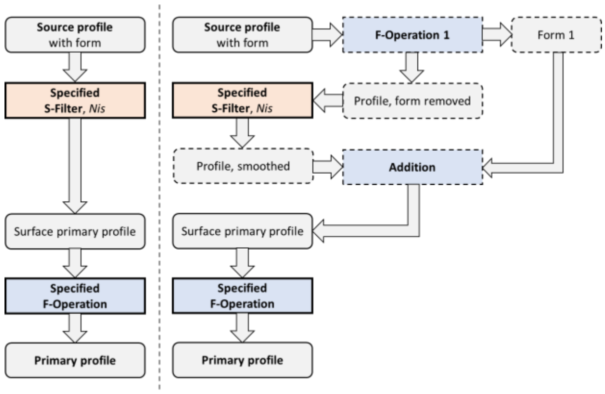


Figure 3: standard workflow to obtain the primary profile (left) and *proposed alternative workflow (right)*

In Figure 3, the alternative EEM method is shown with dotted boxes. It might look trivial but it simply separates the texture and the form, to filter the texture without end-effects, and produce a smoothed version of the source profile. The second F-Operation is applied on the smoothed profile, so the removed form it is slightly different from the first form calculated on the source profile. In this paper, we suggest to call this method *Preliminary Form Removal* (FR).

4. Test results

Test profiles have been characterized using a document that implements the workflow described above, in MountainsMap® version 11.1, using a special function that enables to change the EEM method in the S-Filter. The 28 test profiles have been filtered using one of the 7 EEM methods, to produce 196 results.

In the tables below, the best and worst EEM methods are given for each type of texture, using the 2-letter code provided in 2.3, and the deviation in percentage of the texture amplitude is given.

Table 3: *results on No Form*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,006%)	ZP (5,9%)
Noise	**ZP** (4,1%)	DM (31%)
Sym Noise	**SM** (0,34%)	DM (24%)
Square	**FR** (8%)	RM (35%)

Table 4: *results on 10° slope*

Texture	Best EEM method	Worst EEM method
Honing1	**ES** (1,6%)	ZP (49%)
Noise	**ES** (0,03%)	ZP (49%)
Sym Noise	**ES** (0,002%)	ZP (50%)
Square	**DM** (0,2%)	ZP (49%)

Table 5: *results on 30° slope*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,01%)	ZP (49%)
Noise	**ES** (0,01%)	ZP (48%)
Sym Noise	**ES** (< 0,001%)	ZP (49%)
Square	**FR** (0,05%)	ZP (49%)

Table 6: *results on Arc 10mm*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,04%)	ZP (35%)
Noise	**DM** (0,07%)	ZP (35%)
Sym Noise	**FR** (0,003%)	ZP (35%)
Square	**DM** (0,005%)	ZP (35%)

Table 7: *results on Arc 20mm*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,01%)	ZP (40%)
Noise	**DM** (0,02%)	ZP (49%)
Sym Noise	**FR** (0,001%)	ZP (49%)
Square	**DM** (0,02%)	ZP (49%)

Table 8: *results on Parabola*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,02%)	ZP (92%)
Noise	**RM** (0,04%)	ZP (34%)
Sym Noise	**FR** (0,001%)	ZP (22%)
Square	**DM** (0,04%)	ZP (34%)

Table 9: *results on 3rd order polynomial*

Texture	Best EEM method	Worst EEM method
Honing1	**FR** (0,01%)	ZP (22%)
Noise	**DM** (0,03%)	ZP (47%)
Sym Noise	**FR** (0,001%)	ZP (47%)
Square	**DM** (0,06%)	ZP (46%)

5. Discussion

In order to classify the methods, we calculate a score based on the number of cases where the method is the best minus the number of cases where the method is the worst.

Using this score, we obtain:

1. FR (Form removal): 12 – 0 = 12 points
2. DM (double mirror): 8 – 3 = 5 points
3. ES (Extend slope): 5 – 0 = 5 points

But in some cases, two or three methods provide good results with close percentages. So, in order to take them into account, even though they are not the very best, we also calculated the number of times where the deviation is lower than 1% (so where the EEM method is good) minus the number of times where the deviation is larger than 10% (the method is not very good). Deviations are calculated with respect to the test profile that contains form.

With this second score, we obtain:

1. FR (Form removal): 25 – 1 = 24 points
2. ES (Extend slope): 25 – 2 = 23 points
3. RM (Retain moments): 24 – 2 = 22 points
4. DM (double mirror): 24 – 3 = 21 points

The other methods are clearly behind in terms of score, i.e. of performance (CP: 10 pts; SM: 6 pts; ZP: -25 pts).

However, it is more realistic to calculate deviations with respect to the texture profile without form.

In that case, we obtain the following podium:

1. FR (Form removal)
2. RM (Retain moments)
3. DM (double mirror)
4. ES (Extend slope)

The deviations calculated using this method are always quite high, demonstrating that any EEM method, applied on a profile that has form, introduces errors and that the only harmless solution is to cut ends.

Choosing the Retain moments (RM) method as the default EEM method for the Gaussian filter is sound, as it provides the second lowest deviations. The Extend slope method (ES) implemented by default in the Spline filter is acceptable, but it may not be adequate in case of small cut-offs, as the slope is calculated on a too small EEZ. The Double mirror (DM) is the default method implemented in MountainsMap®, except for the small scales S-Filter which implements the Retain moments. The Double mirror is a good solution for stochastic profiles but less adequate for structured profiles.

The Form removal method (FR) is always the best solution, for any texture and any form. It is an artificial way to come back to the previous workflow where the F-Operation was done prior to the S-Filter. It may be a kind of trick but it confirms that for surface texture applications, it should be the preferred workflow.

6. Conclusion

The change in the order of operations in ISO 21920 created some confusion amongst users. The initial idea was to allow the use of filters and parameters in form deviation applications (such as Contour analysis), but effects on roughness profiles is sometimes significant, especially in presence of slope or form. It is therefore important to either use a small scales filter type that is robust against form, such as a Robust Gaussian filter [11] or to use a proper end-effects management method, or to cut the profile ends to remove the end-effects.

This paper provided hints to understand the properties of each EEM method.

The proposed alternative method (FR) provides a better solution for surface texture applications and is also simple to understand and simple to implement. It solves the problems due to the inversion in the order of operations.

This inversion was not necessarily a good idea for surface texture users, although it opens the scope of filtration to a broader range of applications such as evaluation of form deviation.

It is important to remember that applying a EEM method always introduces a deviation compared to the solution of cutting edges. It was already the case even when the F-Operation was done first, but it is even more true with the new workflow.

The solution could be to separate applications, and recommend to keep the previous workflow (F-Operation then S-Filter) for surface texture applications and have the inverted workflow (S-Filter then F-Operation) for form deviation analysis.

7. Future work

As explained, different EEM methods are included in the Gaussian and Spline filters, in the ISO 16610 series, and in addition, other methods are proposed is Part 28 that could be used and specified. All of these methods are not equivalent and some of them should be avoided. ISO TC213 WG16 should revise these documents in the future to clarify this point and if possible, homogenize a single method for all filters.

Our study focused on profile filters but it would be important to carry on the same study on surfaces to check if the conclusions are consistent or not.

Note on the implementation in Mountains®

All the EEM methods discussed in this paper have been implemented within Mountains® for the purpose of this investigation. However, users do not have access to the selection of the EEM method when applying a filter. The only choice is whether to cut ends or manage end-effects. By default, the Double mirror (DM) is used. Since version 11.1, the Retain moments (RM) is used for the small scales S-Filter when calculating parameters from ISO 21920-2 or when using the S-Filter operator, in order to minimize end-effects discussed in this paper. For other parameters or other filters, the manage end-effects still applies the Double mirror.

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