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Geometrical product specifications (GPS) — Filtration —

Part 32: **Robust profile filters: Spline filters**

Spécification géométrique des produits (GPS) — Filtrage —

Partie 32: Filtres de profil robustes: Filtres splines

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information.

The committee responsible for this document is ISO/TC 213, *Dimensional and geometrical product specifications and verification.*

This first edition of ISO 16610-32 cancels and replaces ISO/TS 16610-32:2009, which constitutes a minor revision.

ISO 16610 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Filtration*:

— *Part 1: Overview and basic concepts*

— *Part 20: Linear profile filters: Basic concepts*

— *Part 21: Linear profile filters: Gaussian filters*

— *Part 22: Linear profile filters: Spline filters* [Technical Specification]

— *Part 28: Profile filters: End effects* [Technical Specification]

— *Part 29: Linear profile filters: Spline wavelets*

— *Part 30: Robust profile filters: Basic concepts* [Technical Specification]

— *Part 31: Robust profile filters: Gaussian regression filters* [Technical Specification]

— *Part 32: Robust profile filters: Spline filters*

— *Part 40: Morphological profile filters: Basic concepts* [Technical Specification]

— *Part 41: Morphological profile filters: Disk and horizontal line-segment filters* [Technical Specification]

— *Part 49: Morphological profile filters: Scale space techniques* [Technical Specification]

— *Part 60: Linear areal filters: Basic concepts*

— *Part 61: Linear areal filters: Gaussian filters*

— *Part 85: Morphological areal filters: Segmentation*

The following parts are planned:

— *Part 26: Linear profile filters: Filtration on nominally orthogonal grid planar data sets*

— *Part 27: Linear profile filters: Filtration on nominally orthogonal grid cylindrical data sets*

— *Part 42: Morphological profile filters: Motif filters*

— *Part 69: Linear areal filters: Spline wavelets*

— *Part 70: Robust areal filters: Basic concepts*

— *Part 71: Robust areal filters: Gaussian regression filters*

— *Part 72: Robust areal filters: Spline filters*

— *Part 80: Morphological areal filters: Basic concepts*

— *Part 81: Morphological areal filters: Sphere and horizontal planar segment filters*

— *Part 82: Morphological areal filters: Motif filters*

— *Part 89: Morphological areal filters: Scale space techniques*

See Annex B for relationships with other filtration documents.

Introduction

This part of ISO 16610 is a geometrical product specification (GPS) standard and is to be regarded as a global GPS standard (see ISO 14638). It influences the chain links C and F of all chains of standards.

The ISO/GPS Matrix model given in ISO 14638 gives an overview of the ISO/GPS system of which this part of ISO 16610 is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this part of ISO 16610 and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this part of ISO 16610, unless otherwise indicated.

For more detailed information of the relation of this part of ISO 16610 to the GPS matrix model, see Annex C.

This part of ISO 16610 develops the terminology and concepts of robust spline filters. The robust spline filter has the advantage over a conventional phase correct filter that the edges of the measured profile are still usable. This is important especially in the case of form filtering. Moreover, the robust spline filter is tolerant against outliers.

Geometrical product specifications (GPS) — Filtration —

Part 32:
Robust profile filters: Spline filters

1 Scope

This part of ISO 16610 specifies the characteristics of robust spline filters for surface profiles.

It specifies in particular how to separate the long and short wave content of a surface profile.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4287, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Terms, definitions and surface texture parameters*

ISO 16610–1:2015, *Geometrical product specifications (GPS) — Filtration — Part 1: Overview and basic concepts*

ISO 16610–22, *Geometrical product specifications (GPS) — Filtration — Part 22: Linear profile filters: Spline filters*

ISO 16610–30, *Geometrical product specifications (GPS) — Filtration — Part 30: Robust profile filters: Basic concepts*

ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99, ISO 4287, ISO 16610-1:2015, ISO 16610-22, ISO 16610-30, and the following apply.

3.1
robust spline filter
robust filter based on splines

Note 1 to entry: The result of the low-pass filtering (the mean line) is a spline.

Note 2 to entry: The degree of the spline is equal to the degree of the polynomial of highest degree used, e.g. a cubic spline is made of cubic polynomials.

Note 3 to entry: Robust spline filters are nonlinear filters.

4 Robust spline filters

4.1 Weighting function

The weighting function of a robust spline filter does not exist because this filter is nonlinear.

4.2 Filter formulae

4.2.1 General

Filter formulae for robust spline filters may be constructed for any degree, but only those based on cubic splines are given here.

4.2.2 Filter formula of the robust spline filter for open profiles

The filter formula is given by Formula (1):

$$2\alpha^2\left[\beta P+(1-\beta)\alpha^2 Q\right]w=\mathrm{sgn}(z-w) \tag{1}$$

with the matrix given in Formula (2):

$$P=\begin{pmatrix} 1 & -1 & & & & & \\ -1 & 2 & -1 & & & & \\ & -1 & 2 & -1 & & & \\ & & \ddots & \ddots & \ddots & & \\ & & -1 & 2 & -1 & & \\ & & & -1 & 2 & -1 & \\ & & & & -1 & 1 & \end{pmatrix} \quad Q=\begin{pmatrix} 1 & -2 & 1 & & & & \\ -2 & 5 & -4 & 1 & & & \\ 1 & -4 & 6 & -4 & 1 & & \\ & \ddots & \ddots & \ddots & \ddots & \ddots & \\ & & 1 & -4 & 6 & -4 & 1 \\ & & & 1 & -4 & 5 & -2 \\ & & & & 1 & -2 & 1 \end{pmatrix} \tag{2}$$

with n rows and n columns and the parameters given in Formula (3):

$$\alpha=\frac{1}{2\sin\frac{\pi\Delta x}{\lambda_c}} \quad \text{and} \quad 0 \text{u} \beta \text{u} 1 \tag{3}$$

where

n is the number of measured values of the profile;

z is the vector of dimension n of the profile values before filtering;

w is the vector of dimension n of this profile's values in the reference line;

λ_c is the limiting wavelength of the profile filter;

Δx is the sampling interval.

$$\mathrm{sgn}(t)=\begin{cases}+1 & \text{if } t \text{ w } 0\\ -1 & \text{if } t<0\end{cases}$$

NOTE 1 The vector w gives the profile values of the long wave component (reference line). The short wave component, r, can be obtained by the difference vector $r = z - w$, i.e. by subtracting the mean line values obtained by the filtering process from the measured profile values.

NOTE 2 The β value of 0,625 242… gets the spline filter as close as possible to the Gaussian filter.

NOTE 3 Examples for the application of the robust spline filter and the Gaussian filter are given in Annex A.

4.2.3 Filter formula of the robust spline filter for closed profiles

The filter formula is given by Formula (4):

$$2\alpha^2\left[\beta\tilde{P}+(1-\beta)\alpha^2\tilde{Q}\right]\tilde{w}=\operatorname{sgn}(\tilde{z}-\tilde{w}) \tag{4}$$

with the matrix given by Formula (5):

$$\tilde{P}=\begin{pmatrix} 2 & -1 & & & & & -1 \\ -1 & 2 & -1 & & & & \\ & -1 & 2 & -1 & & & \\ & & \ddots & \ddots & \ddots & & \\ & & & -1 & 2 & -1 & \\ & & & & -1 & 2 & -1 \\ -1 & & & & & -1 & 2 \end{pmatrix} \quad \tilde{Q}=\begin{pmatrix} 6 & -4 & 1 & & & 1 & -4 \\ -4 & 6 & -4 & 1 & & & 1 \\ 1 & -4 & 6 & -4 & 1 & & \\ & \ddots & \ddots & \ddots & \ddots & \ddots & \\ & & 1 & -4 & 6 & -4 & 1 \\ 1 & & & 1 & -4 & 6 & -4 \\ -4 & 1 & & & 1 & -4 & 6 \end{pmatrix} \tag{5}$$

with n rows and n columns and the parameters given in Formula (6):

$$\alpha=\frac{1}{2\sin\frac{\pi\Delta x}{\lambda_c}} \quad \text{and} \quad 0 \le \beta \le 1 \tag{6}$$

where

- n is the number of measured values of the profile;
- $\tilde{z}$ is the vector of dimension n of the profile values before filtering;
- $\tilde{w}$ is the vector of dimension n of this profile's values in the mean line;
- λ_c is the limiting wavelength of the profile filter;
- Δx is the sampling interval.

NOTE The vector $\tilde{z}$ gives the profile values of the long wave component (mean line). The short wave component, $\tilde{r}$, can be obtained by the difference vector $\tilde{r}=\tilde{z}-\tilde{w}$, i.e. by subtracting the mean line values obtained by the filtering process from the measured profile values.

4.3 Transmission characteristic

The transmission characteristic of a robust spline filter does not exist because this filter is nonlinear, i.e. no weighting function exists.

NOTE The transmission characteristic of a linear filter is given as the Fourier transformation of the weighting function. This is not possible with nonlinear filters.

5 Recommendations

5.1 Nesting index (cut-off value λ_c)

It is recommended that the nesting index (the cut-off value λ_c) be chosen from a logarithmic series (constant ratio) of values. Experience has shown that a constant ratio of around the square root of 10 between successive scale values is optimal. The nesting index should be chosen from the following series of values:

... 2,5 µm; 8 µm; 25 µm; 80 µm; 250 µm; 0,8 mm; 2,5 mm; 8 mm; 25 mm; ..