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Geometrical product specifications (GPS) — Filtration —

Part 32:
Robust profile filters: Spline filters

Technical Report

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Spécification géométrique des produits (GPS) — Filtrage —

Partie 32: Filtres de profil robustes: Filtres splines

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Field Code Changed

This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This ~~Technical Report~~document cancels and replaces ~~the previous edition (~~ISO/TS 16610-32:2009~~)~~, which has been technically revised ~~and converted to a Technical Report to retain the information~~.

The main changes ~~compared to the previous edition~~ are as follows:

— ~~—~~conversion to a Technical Report;

— inclusion of spline filtration for non-uniform sampling points;

— ~~—~~addition of a generalized filter equation with a revision of the equation of the robust spline filter harmonizing the statistical estimator with that of ISO 16610-31;

— ~~—~~inclusion of a termination criterion of the iterations for the robust, therefore ~~non-linear~~nonlinear, filter;

— ~~—~~addition of specifications of the tension parameter.

A list of all parts in the ISO 16610 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document ~~is a Technical Report which~~ develops the terminology and concepts for spline filters. Spline filters have the advantage of being implementable for non-uniform sampling positions and for closed profiles. An example of application of spline filters is given in Annex A~~Annex A.~~

Robust filters are tolerant against outliers. Spline filters offer one method for form removal.

For more detailed information of the relation of this document to the filtration matrix and the ISO GPS standards, see Annex B~~Annex B~~ and Annex C~~Annex C.~~

Geometrical product specifications (GPS) — Filtration —

Part 32:
Robust profile filters: Spline filters

1 Scope

This document provides information on a generalized version of the linear spline filter for uniform and non-uniform sampling and the robust spline filters for surface profiles. It supplements ISO 16610-22, ISO 16610-30 and ISO 16610-31.

This document provides information on how to apply the robust estimation to the spline filter as specified in ISO 16610-22, as well as its generalized form for non-uniform sampling. The weight function chosen for the M-estimator is the Tukey biweight influence function as specified in ISO 16610-31.

2 Normative references

~~The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.~~

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain ~~terminological~~terminology databases for use in standardization at the following addresses:

— ~~—~~ISO Online browsing platform: available at https://www.iso.org/obp~~http://www.iso.org/obp~~

— ~~—~~IEC Electropedia: available at https://www.electropedia.org/~~http://www.electropedia.org/~~

3.1
robust filter
filter that is insensitive against specific phenomena in the input data

Note 1 to entry: A robust filter is a filter that delivers output data with robustness.

Note 2 to entry: Robust filters are ~~non-linear~~nonlinear filters.

[SOURCE: ISO~~/TS~~ 16610-31:2016, 3.1, modified ~~— Note 1~~ — Definition revised and notes to entry ~~and Note 2 to entry have been~~ added.]

3.2
spline
linear combination of piecewise polynomials, with a smooth fit between the pieces

[SOURCE: ISO 16610-22:2015, 3.1~~]~~, modified — Note 1 to entry removed.]

3.3
spline filter
linear filter based on *splines* (3.2~~(3.2)~~)

Note 1 to entry: An example of spline filter application is given in Annex AAnnex A. .

3.4
robust spline filter
robust filter (3.1(3.1)) based on *splines* (3.2(3.2))

3.5
uniform sampling
sampling of data points at equidistant positions, i.e. with the width of spacing intervals between neighboringneighbouring probing points being constant

3.6
non-uniform sampling
sampling of data points with non-equidistant spacing points

3.7
robust statistical estimator
rule that indicates how to calculate an estimate based on sample data from a population that is insensitive against specific phenomena in the input data

Note 1 to entry: An example forof specific phenomena is significant deviation of the distribution of the input data (amplitude distribution in the case of surface profiles) from a Gaussian distribution mostly in the form of long tails.

3.8
M-estimator
robust statistical estimator (3.7(3.7),) which uses an influence function, i.e. a function which is asymmetric and scale invariant, to weight points according to their signed distance from the reference line

[SOURCE: ISO 16610-30:2015, 3.5], modified — Definition revised.]

3.9
Tukey's biweight influence function
influence function which supresses specific phenomena in the input data *x* anddata*x*and is defined by:

$$\psi(x) = \begin{cases} x\left(1-\left(\frac{x}{c}\right)^2\right)^2 & \text{for } |x| \le c \\ 0 & \text{for } |x| > c \end{cases}$$

$$\psi(x) = \begin{cases} x\,(1-(\frac{x}{c})^2)^2 & \text{for } |x| \le c \\ 0 & \text{for } |x| > c \end{cases}$$

where c is a scale parameter

4 Spline filter for uniform and non-uniform sampling

4.1 General

The following low-pass filter equation for spline profile filters is based on cubic splines with a regularization parameter depending on the nesting index, which complies with the cut-off wavelength in the case of linear filters, for the smoothness of the resultant waviness profile (low-passed signal) and a tension parameter influencing the slope of the transfer function.

4.2 Filter equation for cubic spline filter

4.2.1 General

The filter equation is given in Formula (1)~~by Formula (1):~~

$$w = (V + \beta \alpha^2 P + (1 - \beta) \alpha^4 Q)^{-1} V z \quad (1)$$

where

~~() z~~ is the n-dimensional column vector of input data, e.g. the primary profile of n sampling points;

~~w = (V β α (1 β) ε~~

w is the column vector of output data, e.g. the waviness profile or smoothed profile;

V is the unity matrix in the case of the linear filter and the weighting matrix in the case of the robust filter;

P and Q are the matrices for the discretized differentiation;

β is the tension parameter (see also 4.2.3);

α is the parameter (see 4.2.2) depending on the smoothness, the nesting index (cut-off wavelength in the case of linear filters) of the spline.

Formula (1)~~where~~

~~z is the n dimensional column vector of input data, e.g. the primary profile of n sampling points;~~

~~w is the column vector of output data, e.g. the waviness profile or smoothed profile;~~

~~V is the unity matrix in case of the linear filter and the weighting matrix in case of the robust filter;~~

~~P and Q are the matrices for the discretized differentiation;is the tension parameter (see also 4.2.3);~~

~~α is the parameter (see 4.2.2) depending on the smoothness, the nesting index (cut-off wavelength in case of linear filters) of the spline.~~

~~Formula (1)~~ is obtained by minimization of the objective (cost) ~~function J as~~function/as indicated in Formula (2)~~Formula :~~

$$\min_w J \quad (2)$$

~~$$\min_w J \quad (2)$$~~

with the objective function defined in Formula (3)~~Formula (3):~~

~~$$J = (z - w)^T V (z - w) + \beta \alpha^2 w^T P w + (1 - \beta) \alpha^4 w^T Q w \quad (3)$$~~

$$J = (z - w)^T V (z - w) + \beta \alpha^2 w^T P w + (1 - \beta) \alpha^4 w^T Q w \quad (3)$$

where$Q = P^T P$.

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