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Geometrical product specifications (GPS) — Filtration —

Part 71: Robust areal filters: Gaussian regression filters

Spécification géométrique des produits (GPS) — Filtrage —
Partie 71: Filtres surfaciques robustes: Filtres de régression gaussiens

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Foreword

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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).

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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*.

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

— *Part 1: Overview and basic concepts [Technical Specification]*

— *Part 20: Linear profile filters: Basic concepts [Technical Specification]*

— *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 [Technical Specification]*

— *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 [Technical Specification]*

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

— *Part 85: Areal Morphological: 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 62: Linear areal filters: Spline filters*

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

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

— *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*

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/TR 14638). It influences the chain links 3 and 5 of all chains of standards.

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

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

This part of ISO 16610 specifies the metrological characteristics of robust areal Gaussian regression filters, for the rotationally symmetric filtration of nominal planar surfaces and the filtration of nominal cylindrical surfaces.

The filter is insensitive against specific phenomena in the input data (e.g. spike discontinuities as well as deep valleys and high peaks, etc.). The boundaries of the measured surface are still usable.

Geometrical product specifications (GPS) — Filtration —

Part 71:
Robust areal filters: Gaussian regression filters

1 Scope

This part of ISO 16610 specifies the characteristics of the robust areal Gaussian regression filter for the evaluation of surfaces that may contain spike discontinuities as well as deep valleys and high peaks. It specifies in particular how to separate large scale lateral components and short scale lateral components of a surface.

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

ISO 16610-30:—[1)], *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)*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16610-1, ISO 16610-30, ISO/IEC Guide 99 and ISO/IEC Guide 98-3 and the following apply.

3.1
robust planar filter
non linear areal filter to separate a planar surface with specific phenomena (e.g. spike discontinuities as well as deep valleys and high peaks etc.) into large scale lateral components and short scale lateral components

3.2
robust cylindrical filter
non linear areal filter to separate a cylindrical surface with specific phenomena (e.g. spike discontinuities as well as deep valleys and high peaks etc.) into large scale lateral components and short scale lateral components

1) To be published. (Revision of ISO/TS 16610-30:2009)

3.3
biweight function
asymmetric influence function defined by

$$\psi_{\mathrm{B}}(u,c)=\begin{cases} u\left(1-\left(\frac{u}{c}\right)^2\right)^2 & \text{for} \quad |u|\le c \\ 0 & \text{for} \quad |u|>c \end{cases} \tag{1}$$

where c is the real scale parameter and u is a real number

Note 1 to entry: See ISO 16610-30:—, Figure 4.

3.4
robust areal regression filter
weighted M–estimator based on the areal local complete polynomial modelling of the surface

Note 1 to entry: See ISO 16610-30 for the definition of the weighted M-estimator.

Note 2 to entry: See Annex A for the mathematical definition of the robust areal regression filter.

3.5
robust areal Gaussian regression filter
robust areal regression filter based on the areal Gaussian weighting function, the biweight influence function and a local complete polynomial modelling of the surface with the degree $p=2$ as the default case

Note 1 to entry: to entry:See ISO 16610-61 for the definition of the areal Gaussian weighting function.

Note 2 to entry: to entry:In case of $p=2$, the robust areal Gaussian regression filter follows a complete polynomial up to second degree.

4 Robust planar Gaussian regression filter

4.1 General

Robust planar Gaussian regression filters complying to this document shall conform to sections 4.2 to 4.4.

4.2 Weighting function

The weighting function of the robust planar Gaussian regression filter depends on the surface values (height to the reference surface) and the location of the weighting function on the surface.

4.3 Filter equation

The filter equation is given by

$$w_{ij} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \left(\boldsymbol{X}_{ij}^T \, \boldsymbol{S}_{ij} \, \boldsymbol{X}_{ij} \right)^{-1} \boldsymbol{X}_{ij}^T \, \boldsymbol{S}_{ij} \, \boldsymbol{z}, \quad i = 1,...,m \quad j = 1,...,n \tag{2}$$

with the surface values

$$\boldsymbol{z} = \begin{pmatrix} z_{11} & \cdots & z_{m1} & \cdots & z_{1n} & \cdots & z_{mn} \end{pmatrix}^T \tag{3}$$

The regression function is spanned by the matrix:

$$\boldsymbol{X}_{ij} = \begin{pmatrix} 1 & x_{1i} & y_{1j} & x_{1i}\, y_{1j} & x_{1i}^2 & y_{1j}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{mi} & y_{1j} & x_{mi}\, y_{1j} & x_{mi}^2 & y_{1j}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{1i} & y_{nj} & x_{1i}\, y_{nj} & x_{1i}^2 & y_{nj}^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_{mi} & y_{nj} & x_{mi\ nj} & x_{mi}^2 & y_{nj}^2 \end{pmatrix} \tag{4}$$

where

$$x_{ki} = (k - i)\,\Delta x, \qquad k = 1,...,m \tag{5}$$

and

$$y_{lj} = (l - j)\,\Delta y, \qquad l = 1,...,n \tag{6}$$

The spatial varying weighting function $\boldsymbol{S}_{ij}$ is given by:

$$\boldsymbol{S}_{ij} = \begin{pmatrix} s_{11ij}\,\delta_{11} & 0 & \cdots & & & & 0 \\ 0 & \ddots & & & & & \\ \vdots & & s_{m1ij}\,\delta_{m1} & & & & \\ & & & \ddots & & & \\ & & & & s_{1nij}\,\delta_{1n} & & \vdots \\ & & & & & \ddots & 0 \\ 0 & & & & \cdots & 0 & s_{mnij}\,\delta_{mn} \end{pmatrix} \tag{7}$$

with the Gaussian weighting function:

$$s_{klij} = \frac{1}{\gamma^2 \lambda_c^2} \exp\left(-\frac{\pi}{\gamma^2} \left(\frac{{x_{ki}}^2 + {y_{lj}}^2}{\lambda_c^2} \right) \right) \qquad k = 1,..,m \qquad l = 1,..,n \tag{8}$$

The constant γ is given by:

$$\gamma = \sqrt{\frac{-1 - \mathrm{W}_{-1}\left(-\frac{1}{2e} \right)}{\pi}} \simeq 0{,}7309 \tag{9}$$

with the branch $\mathrm{W}_{-1}(u) < -1$ of the "Lambert W" function [7].

The weights δ_{ij} are derived from the biweight function as follows:

$$\delta_{ij} = \frac{\psi_B\left(z_{ij} - w_{ij}, c\right)}{z_{ij} - w_{ij}}, \qquad i = 1,..,m \qquad j = 1,..,n \tag{10}$$

In the default case, the scale parameter c is given by:

$$c = \frac{3\,\Delta_{MAD}}{\sqrt{2}\ \mathrm{erf}^{-1}\left(\frac{1}{2}\right)} \tag{11}$$

Δ_{MAD} is the median absolute deviation of the residuals $z_{ij} - w_{ij}$, and erf^{-1} is the inverse error function [6].

m number of the surface values in x direction

n number of the surface values in y direction

i index of the surface values in x direction $i = 1,...,m$

j index of the surface values in y direction $j = 1,...,n$

z_{ij} surface values before filtering

w_{ij} filtered surface values

λ_c cut-off wavelength

Δ_x sampling interval in x direction

Δ_y sampling interval in y direction

NOTE 1 See ISO 16610-30 for the definition of Δ_{MAD}.

NOTE 2 w_{ij} gives the surface values of the large scale lateral components. The short scale lateral components r_{ij} can be obtained by the difference vector $r_{ij} = z_{ij} - w_{ij}$.

NOTE 3 The definition for the value c is equivalent to 3σ of a surface with a Gaussian amplitude distribution.

NOTE 4 The number of zeros in Formula (2) is equal to $p(p+3)/2$ (see Annex A).

NOTE 5 The values w_{ij} are generally calculated by iteration starting with $\delta_{ij}^0 = 1$ and updating the weights according to Formula (10). For the calculation of the first updated weights δ_{ij}^1, the default scale parameter c can be increased by a factor of two.

NOTE 6 For surfaces with big pores or peaks at the surface boundaries the robustness can be increased by setting $p = 0$. In this case the nominal form can be eliminated by using the F-operator. The filter equation for $p = 0$ results in:

$$w_{ij} = \frac{\sum_{k=1}^{m}\sum_{l=1}^{n} s_{klij}\,\delta_{kl}\,z_{kl}}{\sum_{k=1}^{m}\sum_{l=1}^{n} s_{klij}\,\delta_{kl}}, \text{ with } \gamma = \sqrt{\frac{\ln 2}{\pi}} \tag{12}$$

4.4 Transmission characteristics

The weighting function of the robust planar Gaussian regression filter depends on the surface values and the location on the surface. Therefore no transmission characteristic can be given.

5 Robust cylindrical Gaussian regression filter

5.1 General

Robust cylindrical Gaussian regression filters complying to this document shall conform to sections 5.2 to 5.4.

5.2 Weighting function

The weighting function of the robust cylindrical Gaussian regression filter depends on the surface values (height to the reference surface) and the location of the weighting function on the surface.