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ISO STANDARDS FOR GEOMETRICAL FILTERS

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Abstract: For the past four years, a group of international experts in the International Organization for Standardization (ISO) has been working on a series of standards for geometrical filters. This effort was motivated by an urgent need in industry to define the terms, concepts, and techniques involved in reducing raw data collected by measurements for proper interpretation while inspecting manufactured parts to verify whether they meet their tolerance specifications. This paper describes the efforts of this ISO group and what has been accomplished thus far.
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1 INTRODUCTION

An important application of metrology in industry arises while inspecting geometrical attributes of manufactured objects to verify whether they satisfy tolerances specified during the product development phase. Realizing the close relationship between the problem of product geometry specifications and their verification, the International Organization for Standardization (ISO) appointed a technical committee ISO/TC 213 in the Summer of 1996, combining these two areas. This committee is charged with the task of “standardization in the field of geometrical product specifications (GPS), i.e., macro- and micro-geometry specifications covering dimensional and geometrical tolerancing, surface properties and the related verification principles, measuring equipment and calibration requirements including the uncertainty of dimensional and geometrical measurements” [1].

A technical subgroup of TC 213 is the Advisory Group ISO/TC 213/AG 9 that deals with "GPS Extraction Techniques". It is charged with defining the basic concepts and recommending practical techniques for filtering geometrical information collected during measurements. This paper describes the efforts in ISO/TC 213/AG 9 towards issuing a series of international standard documents that define and describe such filters in detail.

We begin with a brief introduction to the role of geometrical filters in GPS in Section 2. This is followed in Section 3 by a description of how linear filters are defined. Section 4 describes how morphological filters are defined. Section 5 offers a summary and some concluding remarks.

2 ROLE OF GEOMETRICAL FILTERS IN GPS

The notion of geometrical filters has been found to be useful not just for metrology and industrial inspection (referred to as geometrical product verification), but for the entire GPS field. This is due to the fact that the designer, who is engaged in geometrical product specification, must also have a model of non-ideal surfaces that bound the model of a manufactured part. The notion of geometrical filters enables one to take a unified view of what the designer has in mind while specifying tolerances, and what the inspector does while examining a real work-piece.

Intuitively, a *real* surface is the set of infinite number of points that separate a work-piece from its surrounding. Given any physical work-piece, it is, of course, impossible to come up with a computable mathematical representation of this set; we need some additional information about the resolution at which the real surface is perceived. There are at least two known ways to characterize this resolution - one is a *mechanical* real surface and the other is an *electro-magnetic* real surface. A mechanical surface is the set of all points on a real surface that a spherical probe of finite radius r can touch. An electro-magnetic real surface is the set of all reflection points on a real surface by electro-magnetic radiation with a specified wavelength λ. In both cases, we have a *nesting parameter* - radius r in the case of mechanical real surface and wavelength λ in the case of electro-magnetic real surface. The nesting arises from the fact that a real surface obtained with a smaller value for the nesting parameter contains more information than the one obtained with a larger value for the parameter. Theoretically, a mathematical model that approximates the real surface can be obtained within any measure of closeness by choosing the nesting parameter very close to zero.

A real surface corresponding to a specified nesting parameter is then partitioned into *real integral features*. These features still contain infinite number of points. During actual inspection, however, we sample only a finite number of points on these features. These are called *extracted* integral features. It turns out that sampling alone is insufficient to extract a feature; it should be accompanied by some smoothing to remove noise and unwanted details from the measured data. Therefore, techniques for extracting information on real integral features involve both sampling and some filtration.

ISO/TS 16610-1 [4] rigorously defines the terminology used in the above loose description of the basic concepts. ISO/TC 213/AG 9 has identified two types of geometrical filters - linear filters and morphological filters - which are the most commonly used filters in industry, and therefore it is appropriate to standardize them. These filters can operate on profiles as well as surfaces.

3 LINEAR FILTERS

Linear filters are the most commonly used geometrical filters in metrology. Gaussian filter is a prime example of linear filters, where the weighting function is the standard Gaussian function. Mathematically, linear filters are based on the theory of linear operators. Intuitively, linear filters replace every point on a profile or surface by a weighted average of points in its neighborhood. Different linear filters differ in the way they do this weighted averaging. Spline filters and spline wavelet filters are special cases of linear filters. They have made their appearance in recent times in technical literature and have attracted industrial attention because of their flexibility and increased capability. Technical information on linear filters considered by ISO can be found in [2].

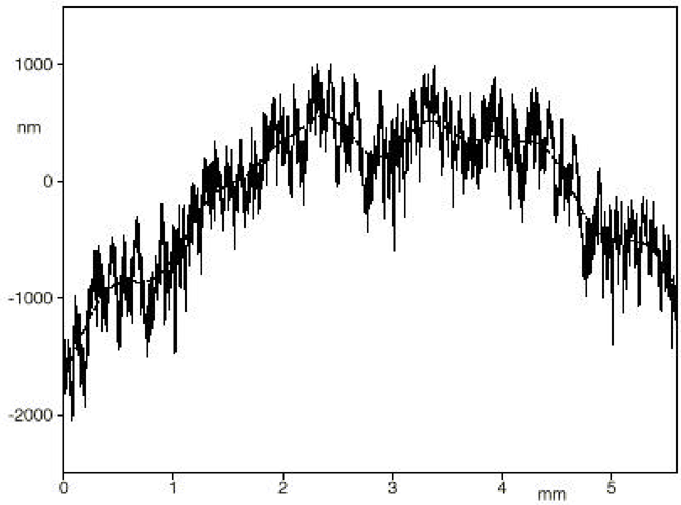

Figure 1. Output from a Gaussian filter superposed on unfiltered input profile.

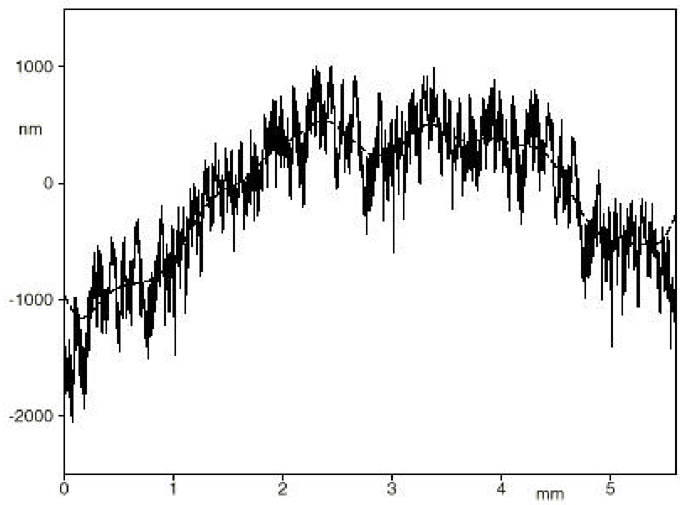

Figure 2. Output of a cubic spline filter superposed on unfiltered input profile.

Figure 1 gives an illustration of a Gaussian filter. Note how the high frequency variations are smoothed out by the filter. Figure 2 illustrates the working of a spline filter on the same input data. Filters using spline wavelets are showing promise for inspecting work-pieces for conformance to specification as well as for diagnostics of manufacturing processes that produced the work-pieces in the first place. Technically speaking, spline wavelets provide a rigorous multi-resolution analysis of the measured data - a fact that is becoming increasingly important in computer aided metrological data acquisition and analysis.

Of all linear filters, Guassian filters are the most well known. Their lesser known but more promising cousins - spline filters and spline wavelet filters - are introduced for the first time in ISO metrology documents. ISO/TS 16610-2 [5] deals with basic concepts of linear profile filters. The case of surfaces will be handled in ISO/TS 16610-9 [12]. Splines filters are covered in ISO/TS 16610-3 [6]; robust spline filters will be described in ISO/TS 16610-8 [11]. Spline wavelet filters are addressed in ISO/TS 16610-4 [7].

4 MORPHOLOGICAL FILTERS

Morphological filters are mathematically well defined operations that are rooted in Minkowski sums. Such filters can be defined for both profiles and surfaces. Morphological filters are particularly attractive for metrology applications where surfaces are scanned using a tactile probe having a specially shaped tip. Intuitively, morphological filters operate by sweeping the input geometric object using a second geometric (structuring) element. Technical information on morphological filters considered by ISO can be found in [3].

It was recognized by ISO/TC 213 that a morphological operation - called *erosion* - can be used to define a mechanical surface when information about the surface is gathered by collecting data on the locus of centers of a spherical ball that is rolled on the real surface. To illustrate this idea, Figure 3 shows an upper curve that is the locus of a 50 µm radius disk rolled over a profile. The mechanical surface is the lower curve obtained mathematically from the upper curve by the morphological operation of erosion.

It was also recognized by ISO/TC 213 that several envelope filters used in metrology data processing are special cases of morphological filters. Figure 4 shows how an envelope filter using a 50 µm radius disk operates on an input data. This envelope filter was implemented as a morphological filter called the *closing filter*. Note how this fills "valleys" while preserving the "peaks". A similar morphological filter called the *opening filter* knocks out the peaks and preserves the valleys. When applied in alternating sequence, these two filters can be used to selectively eliminate features of any given "size" from the input data. Figure 5 illustrates how an alternating sequence filter operates at different scales on an input data.

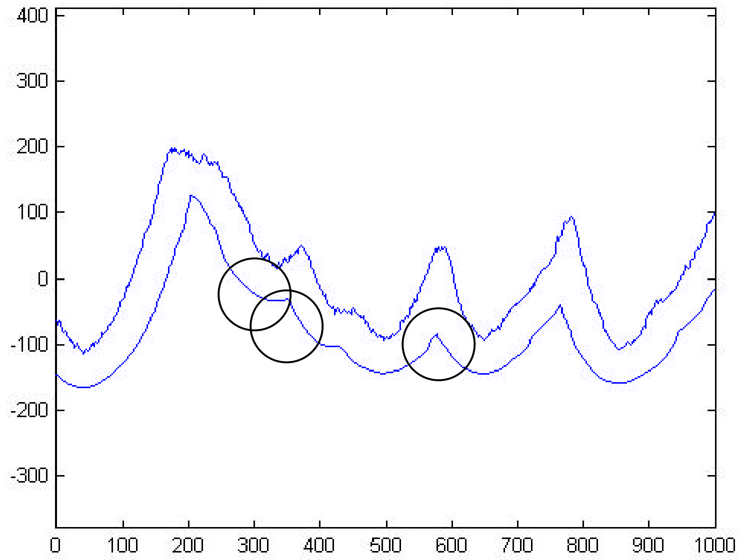

Figure 3. Output of a morphological operation (erosion) shown as a lower curve. The input is the upper curve. The lower curve is the mechanical surface corresponding to a 50 µm radius disk, shown in three distinct places.

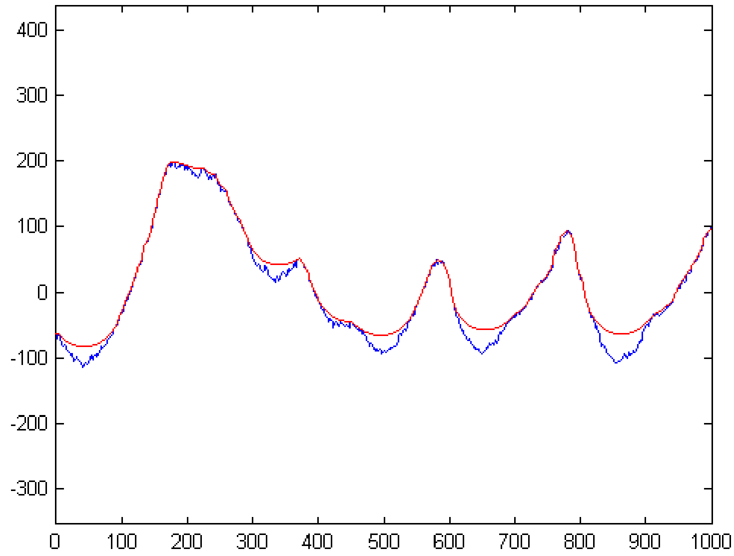

Figure 4. Output of an envelope filter, implemented as a morphological filter called closing filter, is shown as the upper curve. The input to the filter is the lower curve.

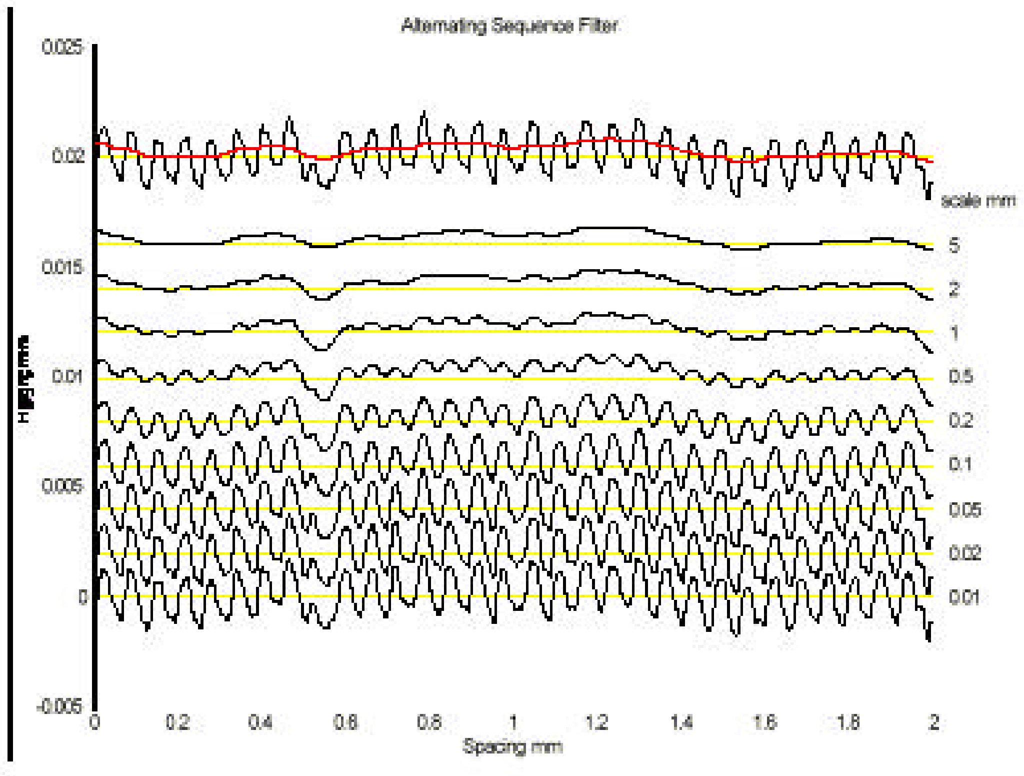

Figure 5. Operating the alternating sequence filter at increasing scale, features varying in size from small to large can be progressively removed from the input data.

ISO/TS 16610-5 [8] describes the basic idea behind morphological operations and how they can be used to define morphological filters. ISO/TS 16610-6 [9] describes how to compute discrete morphological filters. ISO/TS 16610-7 [10] deals with scale space techniques that use morphological filters in alternating sequence.

5 SUMMARY AND CONCLUDING REMARKS

We presented an integrated view of nine documents in the proposed ISO/TS 16610 series of standards. This is the first time that many of the geometrical filters, both old and new, will be presented under a unified framework by ISO. Our intention is to issue them quickly as technical specification so that industry can start using them immediately. This will enable us to evaluate their industrial utility and we hope that in an evolved form they will be issued as official ISO standards at a later date.

In addition to providing the usual standardized definitions of terminology, basic concepts and recommended practices, these ISO documents contain actual code in MATLAB and C that implement these filters in informative annexes. The inclusion of actual code in these documents proves their efficient implementability and provides an open source environment for a computational metrology toolbox. This departure from tradition is intended to hasten the industrial adoption of the newer filters.

6 ACKNOWLEDGMENT AND A DISCLAIMER

We gratefully acknowledge the help and support of numerous colleagues in our national and international standards bodies. However, opinions expressed in this paper are our own and do not represent the official position of ISO or any of its member bodies.

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[10] ISO/TS 16610-7, Geometrical Product Specifications (GPS) - Data extraction techniques by sampling and filtration - Part 7: Morphological scale space techniques. (Under preparation)
[11] ISO/TS 16610-8, Geometrical Product Specifications (GPS) - Data extraction techniques by sampling and filtration - Part 8: Robust spline filters. (Under preparation)
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