An unambiguous expression method of the surface texture

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Abstract The current specification and verification of surface texture in international standards are considered to be too theoretical, complex and over-elaborate for industry. A functional approach that completely expresses the complicated surface texture knowledge for designers and engineers is often non-existent on the shop floor. Based on Geometrical Product Specification (GPS) philosophy, this paper proposes an unambiguous expression schema of surface texture. The surface texture knowledge in design, manufacture and measurement is based on the general GPS matrix and structured by a categorical object model. Explicit specification and verification processes and the mapping between them are presented. The ultimate goal is to improve the collaboration and bridge the knowledge gap between design, manufacture and measurement of surface texture to reduce product development lead time and improve product quality and performance.

Keywords: Surface texture; Specification; Verification; Geometrical Product Specification (GPS); Categorical object model

1. Introduction

In the development of the surface texture expression, more than 100 profile parameters and 40 areal parameters have been defined. The specification of surface texture is getting more and more complicated as shown in figure 1. There is a large amount of surface texture specification and verification data with associated information regarding function requirements, manufacturing process and measurement that needs to be expressed, transferred, stored or analysed. As more data is being collected, there is a need for sharing data and associated information effectively, to eliminate redundancy in data collection and analysis. However, formats currently being used do not convey all the required information of the component, for example, the SDF data format only covers the representation of measured discrete data points with some header information. In 2001, S.H. Bui of NIST applied Java and internet technology to develop an internet based surface texture analysis and information system [1]. B. Muralikrishnan proposed the specification of a common XML language for expressing surface texture metrology data with related process and functional data in 2002 [2]. Other national measurement institutes have also attempted to establish reference software for profile surface texture analysis [3, 4]. Unfortunately, none of these achieved a complete and unambiguous expression of the surface texture for a connection between design, manufacture and measurement.

Although the specification should be designed in sufficient detail that any uncertainty is negligible in comparison with the function requirements, it must be recognized that this may not be always practicable. The design may be incomplete because the definition of the surface texture parameter is ambiguous in some situations. Or it may imply conditions that can never be fully met and whose imperfect realization is difficult to take into account. Currently, so-called "complete" and "unambiguously" expressions are an estimate of the probability of nearness to the best expression that is consistent with presently available knowledge. In addition, the extent of integrity is correlated to function and cost requirements, and extra integrity beyond these requirements is unnecessary and costly. It is important to find a way to satisfy the requirements by omitting other detail offset specifications.

In order to make a clear expression of surface texture for designers and engineers, an unambiguous expression schema of surface texture is proposed. Based on Geometrical Product Specification (GPS) principles, the surface texture knowledge in design, manufacture and measurement is based on the general GPS matrix [5] and structured by a categorical object model [6]. The ultimate goal is to improve the collaboration and bridge the knowledge gap between design, manufacture and measurement in surface texture to reduce product development lead time and improve product quality and performance.

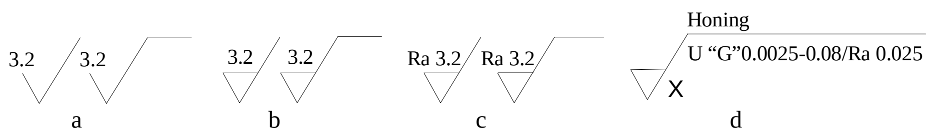

Figure 1 Different versions of the surface texture symbol used in the drawing. a. the 1955 version, high specification uncertainty. b. the 1965 version , up to 300% specification uncertainty. c. the 1991 version, up to 30% specification uncertainty [7]. d. the ISO 1302: 2002 version [8], low specification uncertainty

2 Surface texture specification and verification in the next generation GPS

There have been perceived gaps and contradictions in the "chain" of standards that dealt with dimensional and geometric tolerance specifications and their verifications using metrological instruments, systems and procedures [9]. The rapidly expanding CAD/CAM/CAQ marketplace placed a high premium on mathematical formalism so that reliable and compact software can be developed to support computerized application in these areas. From the summer of 1996, ISO/TC 213 has been working towards harmonizing previous standardized practices in specification and related verification, known as Geometrical Product Specification (GPS). Armed with the experience gained thus far, ISO/TC 213 published its vision for the next generation GPS. The objective of the next generation GPS is to provide engineering tools for economic management of variability in products and processes. Based on metrology and uncertainty, the next generation GPS ensures product function through unambiguous, explicit and complete specifications for design, manufacture and verification of product geometric characteristics.

Figure 2 shows the schematic diagram of the general GPS matrix model in surface texture [5]. In the GPS matrix model, the concept of chain links refers to a specified geometrical characteristic. Chain links 1-3 describe the requirements for specification and verification is defined in chain links 4-6, see [5] for details. The reference to the complementary GPS Matrix considers the items relating to manufacture.

Chain link number		1	2	3	4	5	6
Geometrical characteristic of feature		Product documentation indication-Codification	Definition of tolerances - Theoretical definition and values	Definitions for actual feature - characteristic or parameter	Assessment of the deviations of the workpiece - Comparison with tolerance limits	Measurement equipment requirements	Calibration requirements - Measurements standards
Profile	Roughness	ISO 1302	ISO 4287, 11562,12085, 13565-1,13565-2, 13565-3	ISO 4287, 11562, 12085, 13565-2	ISO 4288,12085	ISO 3274, 11562	ISO 5436, 12179
	Waviness	ISO 1302	ISO 4287,11562, 12085	ISO 11562, 12085	ISO 4288, 12085	ISO 3274, 11562	ISO 5436, 12179
	Primary	ISO 1302	ISO 4287,11562	ISO 4288		ISO 3274, 11562	
Areal		ISO 25178-1(D)	ISO 25178-2(D)	ISO 25178-3(D)		ISO 25178-6 (D),25178-601(D), 25178-602(D), 25178-603(D), 25178-604(D)	ISO 25178-7(D) 25178-701(D) 25178-702(D) 25178-703(D)

D: ISO draft standard in progress

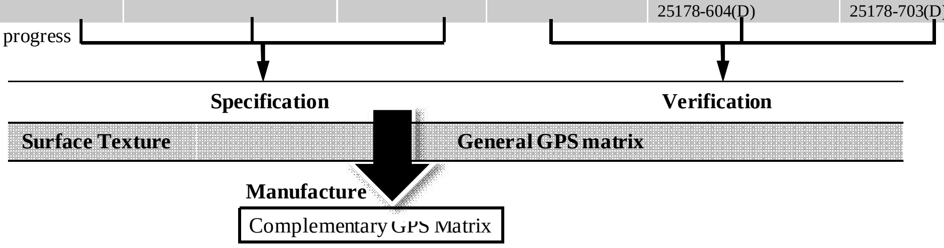

Figure 2 Scheme of general GPS matrix model in surface texture

According to the general GPS matrix, the expression of surface texture can incorporate two processes: specification and verification processes. The surface texture specification process is the design step where the field of permissible deviations of a set of control elements of surface texture is stated, accommodating the required functional performance of the workpiece. ISO 1302:2002 version (see figure 1d) gives 10 different control elements which include profile parameter, limit value, filter type, transmission band, evaluation length, comparison rule, manufacture process and surface texture lay. The purpose of the specification process is to establish those control elements associated with the design requirements of parts and their functional surfaces commensurate with production capabilities for the use of design and engineering drawings. The surface texture verification process takes place after the specification process. It assists manufacturing and inspection areas in the interpretation of drawing information and method of assessment, and explains to them the terms, symbols and values shown on drawings. It defines how surface texture specification data will be interpreted, and how a metrologist determines whether the surface of a workpiece conforms to the specification.

As shown in figure 2, profile surface specification includes the first three chain links. The last three chain links are belong to the verification process. Between chain links 3 and 4 are the comparison rules. According to ISO 4288:1996 [10], there are two comparison rules: the 16%-rule and the max-rule. The default comparison rule in ISO and ASME is the 16%-rule, but in a few company standards it is the max-rule. The comparison rule in the verification process determines whether the workpiece is accepted or rejected according to measurement results. Used as one of ten control elements in specification, the comparison rule must be specified in the specification process to reduce the specification uncertainty. In this paper, the comparison rule is also an essential tool for the mapping between the specification and verification processes.

3 Unambiguous expressions of specification and verification in surface texture

3.1 Knowledge modeling - categorical object model

The categorical object model in this paper is based on category theory and uses categorical object structures to identify and model the knowledge structures of surface texture. Category theory is a general mathematical theory that deals in an abstract way with mathematical structures and relationships between them [11]. It can provide a good unifying tool, with a high-level of abstraction, to unify different types of models from different modeling mechanisms into a single category model. Arrows and objects are two fundamental concepts in category theory. The convenience of category theory to describe complex relationships between different objects was first used for structured entities in surface texture by Yan Wang in her doctoral dissertation in 2008 [6]. A general surface texture object-relationship data model based on category theory was proposed. This idea set a precedent for a mathematical theory to express complex surface texture knowledge. However, her thesis established a basic framework rather than a complete and unambiguous expression. This paper emphasises the unambiguous expression of surface texture, inherits the categorical object model to structure a complete specification and verification for surface texture.

3.2 Categorical object model for specification and verification

In this project, a categorical object model is used to achieve the surface texture knowledge structure model. As shown in figure 3, a high-level abstract diagram of the categorical object model for profile surface texture specification has been presented. The rectangles (I#, Ca#...) in the figure are categorical objects representing characteristic features in profile specification. The dashed arrows ***Ri*** ($1 \leq i < 20$, the relationships label numbers in the figure are no more than 20) represent the complicated relationships between different categorical objects. The relationships between different elements in the same categorical object are presented by dashed line arrows with label s_i. The solid line arrows ***Fi*** show the direction of the inheritance.

At the left side of figure 3, the <u>Input</u> categorical object includes the elements which the designers need to input for completing the specification. The <u>Callout</u> categorical object is the most important part for a surface texture specification design which will be shown in the engineering drawing. A specific example of surface texture specification according to ISO 1302:2002 is shown in figure 1d. The <u>Callout</u> object is composed of 10 control elements. These elements belong to four categorical objects which are the chain links 1-3 in the general GPS matrix respectively and the <u>Comparison</u> object. The <u>Codification</u> object belongs to the chain link No.1 which will determine the indication of the callout. The <u>ToleranceDefinition</u> object belongs to the chain link No.2 which is the definition of surface texture parameters and value. The <u>FeatureCharacteristic</u> object is chain link No.3 and is composed of three different feature operations which are Partition, Extraction and Filtration. The <u>Comparison</u> object is determined by the ***comparison_rule*** in the <u>Callout</u> object and it will be an essential tool for the mapping between the specification and theverification processes.

As a high-level abstract diagram, relationships between two different objects are simplified by label ***Ri***. A single ***Ri*** may expresses two or more relationships. These relationships can be regarded as refinements of categorical modeling. Figure 4 gives an example of the categorical modeling diagram of the relationship ***R5***. c_5 demonstrates the relationship between the ToleranceDefinition and the Filtration objects. It stores all the possible relations and extra information between objects of TD# and F#. The expression "*determine_filter_type*×*transmission_band::prameter_type*×*prameter_name…*" is the name and type of the determination procedures. The notations $\pi_1 c_5$ and $\pi_2 c_5$ are projections of c_5 into the initial objects of TD# and F# respectively, while $\lambda_1 c_5$ and $\lambda_2 c_5$ are represented as arrows injecting the initial instance objects into the pool of instances of this constraint relationship. There are two different refinements of the c_5. Refinement 1 expresses that the combination of *parameter_type*, *parameter_value* and *parameter_ name* in the ToleranceDefinition object determines *transmission_band* in the Filtration object. Refinement 2 presents the *filter_type* in the Filtration object is determined by *parameter_type* in the ToleranceDefinition object. s_1, s_2 and s_3 are the internal relationships between the four elements of the ToleranceDefinition object. For example, the s_1 means *parameter_name* RSm belongs to profile spacing parameters in *parameter_type*. The s_2 shows *parameter_name* RSm has related *parameter_value* range such as 0.013-4μm. The s_3 indicates *parameter_name* RSm has related *parameter_definition*. Table 1 gives three examples of these relationships. Here, transmission band of the Gaussian filter for profile spacing parameter RSm with value 0.04 μm is 0.0025(λs)-0.08mm (λc); transmission band of the Gaussian filter for profile amplitude parameter Ra with value 0. 8 μm is 0.0025(λs)-0.8mm (λc); transmission band of the Motif filter for motif roughness parameter R with value 1.6 μm is 0.008 (λs)-0.5mm (A, see ISO 12085:1998 [12]).

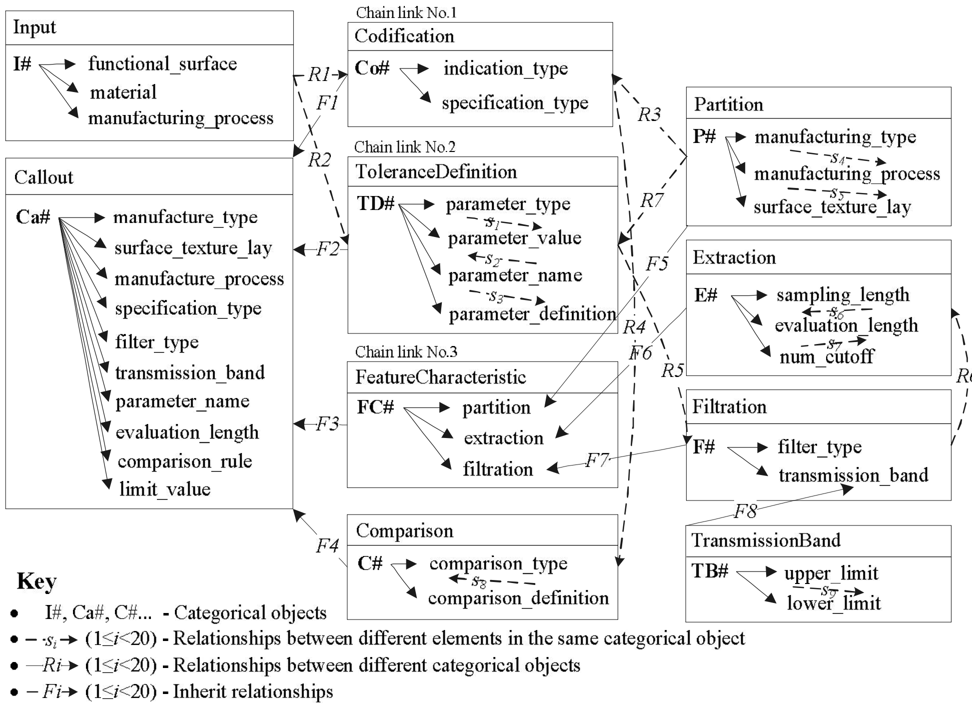

Figure 3 The categorical object model diagram for surface texture specification (high-level abstract diagram)

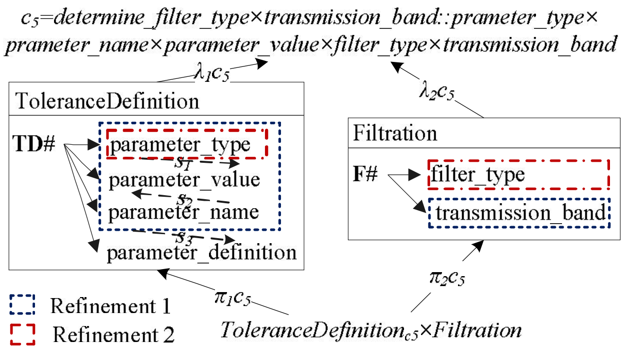

Figure 4 Determination procedures of filter type and transmission band (relationship *R5*)

ToleranceDefinition				Filtration	
parameter_type	*parameter_name*	*parameter_value*	*parameter_definition*	*filter_type*	*transmission_band*
Profile spacing parameters	RSm	0.04μm	Mean value of the profile element widths within a sampling length	Gaussian filter	0.0025-0.08mm (λs – λc)
Profile amplitude parameters	Ra	0.8μm	Arithmetical mean deviation of the assessed profile	Gaussian filter	0.0025-0.8mm (λs – λc)
Motif roughness parameter	R	1.6μm	Mean depth of roughness motifs	Motif filter	0.008-0.5mm (λs – A)

Table 1 Examples of relationships between <u>ToleranceDefinition</u> and <u>Filtration</u> objects

In this paper, according to the general GPS matrix, profile surface verification includes measurand's specifications, the chain links 4-6 characteristic of the features and measurement result. Similarly, a high-level abstract diagram of the categorical object model for profile surface texture verification has been presented as shown in figure 5. The internal relationships of categorical objects are presented by dashed line arrows with label v_i. The <u>MeasurandSpecification</u> categorical object is determined by the specifications process. It interprets the specification and explains to manufacturing engineers and metrologist the terms, symbols and values shown on engineering drawings. It includes <u>ToleranceSpecification</u>, <u>Partition</u>, <u>Extraction</u>, <u>Filtration</u> and <u>Comparison</u> (chain link 4) objects which are the major parts of specification. The <u>MeasurandSpecification</u> object determines the <u>MeasurmentEquipment</u> and <u>CalibrationRequirement</u> objects. Finally, the <u>MeasurementResult</u> is generated according to the <u>Comparison</u> object. As an example, the *comparison_definition* and *comparison_type* determine the *comparison_process* in the <u>Comparison</u> object, the *limit_value* in the <u>ToleranceSpecification</u> object and *comparison_process* in the <u>Comparison</u> object determine the *measurement_No.* in the <u>Partition</u> object which is a part of the <u>MeasurandSpecification</u> object.

Figure 6 gives an example of the categorical modeling diagram of the relationship *R14*. c_{14} is the relationship between the <u>ToleranceDefinition</u> and the <u>MeasurementEquipment</u> objects. There is only one refinement. Refinement 1 expresses that the combination of *limit_value* and *parameter_name* in the <u>ToleranceDefinition</u> object determine *instrument_type*, *tip_radius* and *smapling_spacing* in the <u>MeasurementEquipment</u> object. v_1 and v_2 are the internal relationships between three elements of the <u>ToleranceDefinition</u> object. v_8 and v_9 are the internal relationships between three elements of the <u>MeasurementEquipment</u> object. For example, v_8 means only the stylus instrument type can choose *tip_radius*. The v_9 shows the value of *tip_radius* can determine the resolution of the instrument. Table 2 gives two examples of these relationships. Here, parameter Ra with limit value 0.8μm can determine instrument type suggesting stylus, Focus and SEM types, tip radius of 5 μm and sampling spacing of 0.5 μm; parameter Ra with limit value 0.08μm can determine instrument type suggesting stylus, Focus and SEM types, tip radius of 2 μm and sampling spacing of 0.5 μm.

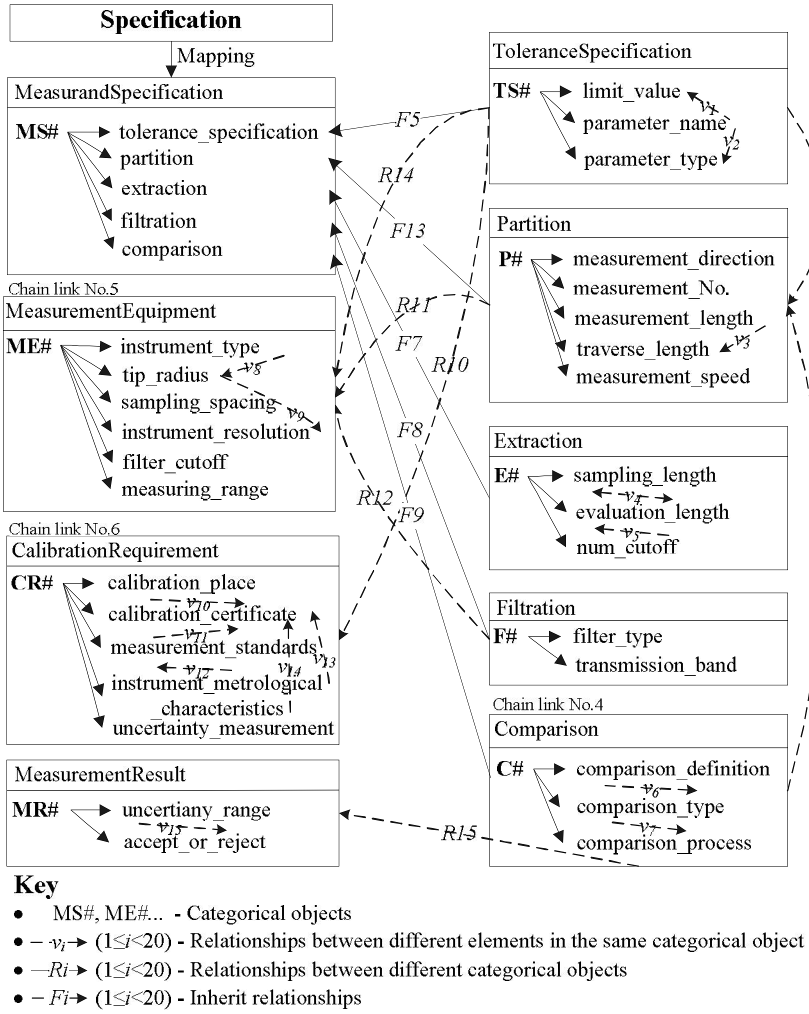

Figure 5 The categorical object model diagram for surface texture verification (high-level abstract diagram)

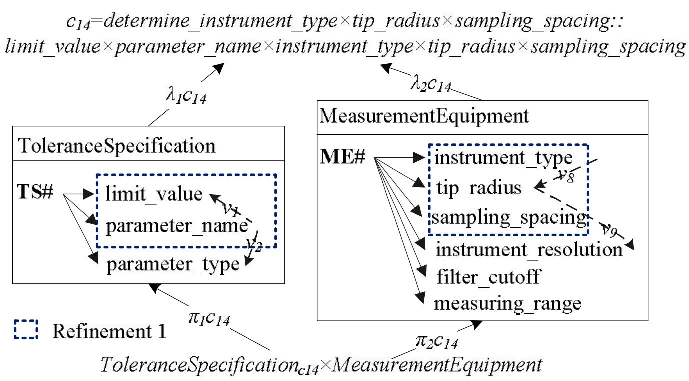

Figure 6 Determination procedures of instrument type, tip radius and sampling spacing (relationship *R14*)

ToleranceDefinition			MeasurementEquipment		
parameter_type	*parameter_name*	*limit_value*	*instrument_type*	*tip_radius*	*sampling_spacing*
Profile amplitude parameters	Ra	0.8μm	Stylus,Focus,SEM	5μm	0.5μm
Profile amplitude parameters	Ra	0.08μm	Stylus,Focus,SEM	2μm	0.5μm

Table 2 Examples of relationships between the ToleranceDefinition and MeasurementEquipment objects

4 Conclusions

In this paper, the categorical object model of specification and verification structured an unambiguous expression schema of surface texture. The basic philosophies of GPS are the key to connect specification and verification of surface texture. This paper concentrates on profile surface texture because the areal surface texture standards are still in progress. The whole structure is suitable for areal surface texture and will be developed in future work. Meanwhile, as the uncertainty concepts are still under development, we cannot give a quantitative specification or measurement uncertainty for a specified surface texture specification or verification. What we can do to satisfy the requirements is to detail the specification as far as possible consistent with presently available knowledge (especially up-to-date ISO standards).

This work is a foundation to bridge the collaboration gap between design, manufacture and measurement in surface texture to reduce product development lead time and improve product quality and performance, thus providing a more timely and profitable solution for industry. The next step is to develop an infrastructure which can integrate CAx (computer-aided technologies) systems for designers and engineers involved in the manufacturing supply chain, including small and medium enterprises (SMEs) and institutes.

Acknowledgements This work was supported by China Scholarship Council and University of Huddersfield Scholarship. The authors would like to thank Mr. David Brook for his kind help in this paper.

References

[1] S.H. Bui, V. Gopalan, J. Raja, An internet based surface texture information system, International Journal of Machine Tools and Manufacture. 41(2001) 2171-2177.

[2] B. Muralikrishnan, J. Raja, A proposal for a common language for sharing surface texture data, Proceeding of the ASPE 2002. (2002) 434-437.

[3] L. Jung, B. Spranger, R. Krüger-Sehm, M. Krystek, Reference software for roughness analysis - features and results, Proc. XI. Int. Coll. on Surfaces part 2, Chemnitz (2004) 164-170.

[4] T. Li, R.K. Leach, L. Jung, X. Jiang, L.A. Blunt, Comparison of Type F2 Software Measurement Standards for Surface Texture, NPL Report ENG 16, National Physical Laboratory, 2009.

[5] International Organization for Standardization, ISO 14638:1995 Geometrical Product Specification (GPS) – Masterplan. 1995.

[6] Y. Wang, A Knowledge-based Intelligent System for Surface Texture (VirtualSurf) in Department of Computing & Engineering, The University of Huddersfield, Huddersfield, 2008, pp.232.

[7] P. Bennich, H.S. Nielen, An Overview of GPS, A Cost Saving Tool, http://www.ifgps.com/, 2005.

[8] International Organization for Standardizations, ISO 1302:2002 Geometrical Product Specification (GPS) – Indication of surface texture in technical product documentation. 2002.

[9] P. Bennich, Chains of Standards – A New Concept in GPS Standards, The American Society of Mechanical Engineers - Manufacturing Review. 7(1994) 29-38.

[10] International Organization for Standardizations, ISO 4288:1996 Geometrical Product Specification (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture. 1996.

[11] M. Barr, C.Wells, Category Theory for Computing Science, Prentice Hall, London, 1996.

[12] International Organization for Standardizations, ISO 12085:1998 Geometrical Product Specification (GPS) – Surface texture – Profile method – Motif parameters. 2001.