Precision Engineering 36 (2012) 322–333

Contents lists available at SciVerse ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Knowledge modeling for specifications and verification in areal surface texture

Qunfen Qi, Xiangqian Jiang*, Paul J. Scott

EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, Huddersfield HD1 3DH, UK

ARTICLE INFO

Article history:
Received 13 July 2011
Received in revised form 1 December 2011
Accepted 9 December 2011
Available online 17 December 2011

Keywords:
Areal surface texture
Knowledge modeling
Category theory
Specification
Verification

ABSTRACT

The 25178 series of standards in areal surface texture covers terms and definitions for specification and verification operators and is being developed by work group (WG) 16 in the International Standards Organization (ISO) TC 213. As there are many innovative concepts and definitions included in these standards, it is often considered difficult for mechanical engineers to comprehend and for computing engineers to apply in computing science. This paper presents the utilization of category theory to model sophisticated knowledge in the field of areal surface texture. The ISO 25178 series can be divided into specification and verification series according to the principles of Geometrical Product Specifications (GPS). In the category model, categories and objects are used to represent different knowledge structures; arrows and pullbacks are used to sketch diverse connection between objects; functors are utilized to reveal the structure-preserving mapping between categories in specification and verification. In this paper the function of pullbacks is considered to be a pullback inference mechanism since most of the objects in the model can be determined by different pullbacks. The knowledge model in this paper is the foundation for developing a design and measurement information system in areal surface texture for manufacturing industry.

1. Introduction

With the advance in surfaces assessment, it was found that some of the surface profile parameters (such as Ra and Rz) had very limited value in relating the surface to its functional effectiveness. Had instrument development, in relation to data acquisition and signal processing, proceeded in advance of the subject of surface characterization, the probable development and specification of parameters would have been more logical through areal data collection analysis [1]. It shows that areal surface texture analysis is now essential wherever a complete assessment of the surface is required to enable the selection of the most appropriate surface texture to achieve a required functionality. Conscious of the “parameter rash” [2], the research group of Prof. Stout developed a primary set of areal parameters named “Birmingham 14” parameters [3] in 1993. Later, the European project “SURFSTAND” [4] under the leadership of Huddersfield University improved these parameters by working on the correlation with functional specifications, and prepared the basis for ISO 25178-2 [5] of which the first draft was developed in April 2006. Currently, the ISO 25178 series of areal surface texture standards concerning terms and definitions, specifications and verification operators is being developed by WG 16 in TC 213. It is the first and foremost series of standard providing a redefinition of the foundations of surface texture, and based upon the principle that nature is intrinsically 3D. It is anticipated that future work will extend these new concepts into the domain of 2D profile metric surface analysis, requiring a total revision of all current surface texture standards (ISO 1302, ISO 4287, ISO 4288, ISO 115652, ISO 12085, ISO 13565 series, etc.). Many innovative concepts are introduced in the ISO 25178 series of documents. Table 1 shows all areal surface texture standards in the general GPS matrix [6]. Heretofore, ISO 25178 part 1 [7] defines the indication of areal surface texture as shown in Fig. 1; part 2 defines the terms, definitions and surface texture parameters which include field and feature parameters [8]; part 3 [9] defines areal surface texture specifications operators; part 6 series [10–15] define the measurement methods and instruments; part 7 series [16–19] define calibration requirements and software measurement standards. Here, parts 1–3 define the requirements for specifications and parts 6–7 described the characteristics for verification.

In 2010, ISO 25178-6, ISO 25178-601, ISO 25178-602 and ISO 25178-701 became the first four published standards in areal surface texture. According to the schedule of WG16, other standards will be published shortly. Areal surface texture characterization in manufacturing industry will be more widely used. As there are many innovative concepts and definitions involved in this series, it is often considered difficult for mechanical engineers to comprehend and for computing engineers to apply in computing science. Moreover, the level of understanding designers have for specifications knowledge of areal surface texture is still unsatisfactory; and

* Corresponding author. Tel.: +44 1484 473634; fax: +44 1484 472161.
E-mail address: x.jiang@hud.ac.uk (X. Jiang).

0141-6359/$ – see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.precisioneng.2011.12.002

Table 1
Areal surface texture standards in general GPS matrix.

Chain link no.	Geometrical characteristic of feature	Areal surface texture standards
1	Product documentation indication – codification	ISO 25178-1(D)
2	Definition of tolerances – theoretical definition and values	ISO 25178-2(D)
3	Definition for actual feature – characteristic or parameter	ISO 25178-3(D)
4	Assessment of the deviations of the workpiece – comparison with tolerance limits	
5	Measurement equipment requirements	ISO 25178-6, 25178-601, 25178-602, 25178-603(D), 25178-604(D), 25178-605(D)
6	Calibration requirements – measurements standards	ISO 25178-70(D), 25178-71(D), 25178-701, 25178-702(D)

Note: The symbol (D) is standards under development.

there is no effective reference for metrologists to arrange a series of measurement processes for areal surface texture.

The aim is to express specifications and verification knowledge involved in areal surface texture, and help designers and metrologists to utilize areal surface texture characterization effectively. This paper utilizes a graphical category model which is based on category theory to structure the knowledge. The specifications model can generate a complete series of areal surface texture specifications for designers. According to the specified specifications, the verification model can produce series related verification information to guide the measurement procedure and measurement result treatment for metrologists. The knowledge model in this paper is the basis for developing a design and measurement information system in areal surface texture for manufacturing industry.

2. Category theory applided in areal surface texture

2.1. Category theory

Category theory is a branch of mathematics that has been developed over the last 60 years since it has been found that many properties of mathematical system can be unified and simplified by a presentation with diagrams of arrows. It explores the relationships between different kinds of mathematical objects, and ignores unnecessary detail to give general definitions and results. It is a high-level (abstract) and efficacious language that focuses on how things behave rather than on what their internal details are [20,21]. There are three important concepts in category theory which are often used when utilizing it in areal surface texture – categories, pullbacks and functors.

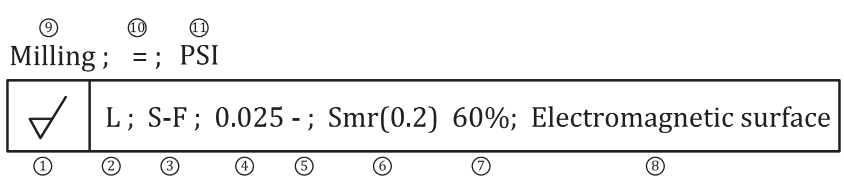
A **category C** consists of a collection of objects A, B, C, . . . and a collection of morphisms or arrows which are the abstraction derived from structure-preserving mappings between objects f: $A \to B$, g: $B \to C$, . . ., that are closed under composition and satisfy the following conditions.

- For each arrow f there are given objects: dom(f), cod(f) called the domain and codomain of f. We write: f: $A \to B$ or $A \xrightarrow{f} B$ to indicate that A = dom(f) and B = cod(f).
- Given arrows f: $A \to B$ and g: $B \to C$, that is, with: cod(f) = dom(g), there is given an arrow: $g \bigcirc f$: A → C, called the composite of f and g.
- For each object A, there is an identity arrow id_A: $A \to A$ satisfying the identity law: for any arrow f: $A \to B$, $id_B \bigcirc f = f$ and $f \bigcirc id_A = f$.

The collection of all morphisms from A to B in category **C** is denoted hom$_{\mathbf{C}}$(A,B) and called the **hom-set** between A and B (the collection of morphisms is not required to be a set). A number of types of morphisms are defined in category theory are monic (monomorphism), epic (epimorphism) and isomorphic. In the category **Set** (objects are sets, morphisms are functions), monic is same as injection (one-to-one function), epic is same as surjection (onto) and isomorphic is same as bijection (one-to-one and onto). Note that a morphism may not be an isomorphism even it is monic and epic.

A **pullback** of the pair of arrows f, g with cod(f) = cod (g) as shown in Fig. 2a is an object P and a pair of arrows p_1 and p_2 as shown in Fig. 2b such that $f \bigcirc p_1 = g \bigcirc p_2$. And if z_1: $Z \to A$ and z_2: $Z \to B$ are such that $f \bigcirc z_1 = g \bigcirc z_2$, then there exists a unique u: $Z \to P$ with $z_1 = p_1 \bigcirc u$ and $z_2 = p_2 \bigcirc u$. The related picture is shown in Fig. 2c. A product of two objects A and B is an object $A \times B$ together with two projection arrows π_1: $A \times B \to A$ and π_2: $A \times B \to B$. Thus, object $A \times B$ and arrows π_1 and π_2 is the pullback of C, and arrows f, g. Consider the diagram in Fig. 2f which e is an equalizer of $f \bigcirc \pi_1$ and $g \bigcirc \pi_2$ and $p_1 = \pi_1 \bigcirc e$, $p_2 = \pi_2 \bigcirc e$. Then E, p_1, p_2 is a pullback of C, f and g.

An arrow between categories is termed a functor if it satisfies some structure-preserving requirements:



① Surface texture graphical symbol
② Type of tolerance upper (U) or lower (L)
③ Type of scale-limited surface
④ Nesting index – S filter
⑤ Nesting index – F operator or L filter
⑥ Areal parameter
⑦ Limit value
⑧ Other non-default(s)
⑨ Manufacturing process
⑩ Surface texture lay
⑪ Other information

Fig. 1. Control elements in indication of areal surface texture requirements on engineering drawings.