

Design and implementation of an integrated surface texture information system for design, manufacture and measurement[☆]



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HIGHLIGHTS

- We developed a surface texture information system.
- Profile and areal surface texture modules each with five components is constructed.
- Category theory based knowledge representation mechanism is devised.
- We developed a platform to integrate the information system with CAx systems.

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ABSTRACT

The optimized design and reliable measurement of surface texture are essential to guarantee the functional performance of a geometric product. Current support tools are however often limited in functionality, integrity and efficiency. In this paper, an integrated surface texture information system for design, manufacture and measurement, called “CatSurf”, has been designed and developed, which aims to facilitate rapid and flexible manufacturing requirements. A category theory based knowledge acquisition and knowledge representation mechanism has been devised to retrieve and organize knowledge from various Geometrical Product Specifications (GPS) documents in surface texture. Two modules (for profile and areal surface texture) each with five components are developed in the CatSurf. It also focuses on integrating the surface texture information into a Computer-aided Technology (CAx) framework. Two test cases demonstrate design process of specifications for the profile and areal surface texture in AutoCAD and SolidWorks environments respectively.

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1. Introduction

The trend in global manufacturing, along with the emergence of computer-aided technologies (CAx), urges a rigorous and systematic common language to characterize geometrical products throughout the product supply chain. An international technical language, called Geometrical Product Specifications and Verification (GPS), has created a synergy for design, manufacture and measurement. It uses rigorous mathematical definitions of geometric specifications mapped to verification, and is intended to save design modification and manufacture time and to reduce scrap material in manufacture and measurement cost [1,2]. Comprehensive implementations of the GPS-language globally, will promote future

manufacturing moving to a knowledge driven economic environment, where design, manufacture and measurement are integrated into a single engineering process that enables ‘right first time’ every time fabrication of customized products [3]. Such evolutions will force product technical specification and verification to be much more precise and with a clearer implementation methodology.

Over the last decades, continuing efforts have been directed toward understanding fundamental concepts and models in the GPS system, as well as developing optimized tolerance models and applications for the system. However as yet the GPS is largely a document based system which covers several kinds of geometric characteristics (such as size, distance, form, surface texture, etc.) and its implementation is viewed as highly complex, requiring high levels of understanding.

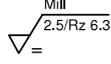
The implementations of some geometric characteristics were hindered. One example is surface texture, one of the most complicated geometrical specification and verification systems in GPS.

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Table 1
Status of specification design status for profile surface texture (PST) in commercial CAD systems.

Commercial CAD/CAM/CAE systems		Surface texture specification design	PST standards	Indications	Database support
			Versions		
Autodesk	AutoCAD	None	None	None	None
	AutoCAD mechanical	Surface texture symbol tool	A simplified version from ISO 1302:2002		None
Dassault Systemes	CATIA	Roughness symbol tool	ISO 1302 1965 version		None
	SolidWorks	Surface finish symbol menu	A simplified version from ISO 1302:2002		None
PTC	Pro/Engineer (PTC Creo)	Surface finish tool menu	ISO 1302 1965 version		None
Siemens	NX (Unigraphics)	Surface finish symbol tool	ASME Y14.36M-1996		None

It is relevant for the whole surface manufacture chain from design through manufacture and qualification, and plays a significant role in determining the functional performances of a workpiece, e.g. friction, wear and lubrication. In recent years, the characterization of surface texture has experienced a paradigm shift moving from profile measurement to areal measurement thanks to the rapid development of advanced measurement instruments and information technology [4,5]. Surface design, manufacturing and metrology are however disconnected, becoming a very complicated and ambiguous system, especially since the necessary skills/expertise are often not available in global supply-chains, SMEs and multi-country manufacturing.

One of the essential reasons for this disconnect is the complexity of surface texture knowledge in GPS. Currently, there are 29 GPS published standards for profile and areal surface texture, a set of new standards, including ISO 25178 series, are being issued. Those paper-based documents which contain a wealth of information under the GPS matrix structure have been recognized as being too complicated to be comprehended and implemented without an effective implementation methodology. To tackle this issue it requires a deeper understanding of the underlying reasons that can be summarized in five aspects:

1. *Limitations in existing surface texture information systems.* It has been found that majority of surface texture information systems were developed either for design support [6,7] or measurement support [8–13] only, until a so-called “VirtualSurf” project was undertaken by Wang [14] and Xu [15] to develop a knowledge-based system for the design and measurement of profile surface texture (PST). A preliminary framework of the VirtualSurf system has been proposed. However, it has not been developed as a comprehensive functional system for practical implementation. For example, the ‘Function’ part of the system was a ‘function performance report’ rather than having practical correlation with specification. Moreover, a comprehensive surface texture system with the support of AST is required due to the high functional demand of surface texture in industry, and with the rapid development of areal characterization and standards publication.
2. *Integration problems between surface texture information systems and CAx systems.* Current practice in manufacturing still relies on design based on traditional standards, which utilize a symbolic language, this being driven by the limitations of CAD/CAM/CAE multi-platform software suites including CATIA, AutoCAD, Pro/Engineer (PTC Creo), SolidWorks and NX, see Table 1. All roughness symbol tools in the CAD systems are requiring manual input of all the symbol elements without any assistance, such that they have no support to help CAD users choosing the appropriate elements and to prevent them generating a wrong roughness symbol.

3. *Restrictions of existing data representation methods for surface texture.* It was discovered by Wang, Xu and Lu [14–16] that traditional data models such as relational and object-oriented models had limitations to efficiently support complex data structures and to reflect the complicated relationships among engineered artefacts and surface texture GPS standards. The VirtualSurf system utilized category theory to develop an object-based modelling mechanism, since category theory is an alternative to the foundations of mathematics and can represent any mathematical object very efficiently (more efficient than set theory). It has been proved that the devised categorical DBMS (database management system) has been proved to be on an average 10 times faster than an analogue MySQL product when processing a query operation, as well as an average 1/3 memory cost of traditional relational DBMS when containing more than 500k data in memory [15]. This formalism, however, has still thrown up some issues. One of the essential problems is the rigorous application of category theory. The major definitions of category theory, are based on the categories, objects and arrows in/between them. The object-based categorical model [14,15] was focused on the objects rather than categories and relationships between categories. It significantly limited the effectiveness of category theory in dealing with complex relationships. A more rigorous categorical model is required to completely utilize the advantages of category theory.
4. *Limited correlation between function and surface texture specification.* The number of applications in which surface texture is involved is so large and diverse that a systematic approach has been difficult. There is an urgent need of function support tools to ensure the functionality of the assigned specification.
5. *Knowledge gap between specification and verification.* Some of the definitions in the surface texture standards still leave a room for several different interpretations [17,18]. Misunderstanding caused by the ambiguities and imperfections can result in significant information loss between specification and verification, especially when there are vast quantities of information for exchange. Currently there is also lack of support tools to help metrologists for measurement strategy, imprecise interpretation of specification can produce unmatched verification [19]. Assigning unambiguous specifications and mapping them rigorously with verification are essential tools to bridge the gap.

These issues highlight the necessity of a comprehensive implementation of surface texture in design, manufacture and measurement. The development of support systems and integrating them with CAx is one of the most efficient ways to allow partners collaborating effectively in creating innovative products [20]. The proposed work is to develop a surface texture information system to bridge

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