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# A feature-based method for tire pattern reverse modeling

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ABSTRACT

In order to efficiently and effectively convert the tire point cloud to the 3D CAD model, a feature-based reverse modeling method reflecting the design intent of pattern structure is proposed in this paper. The concrete research contents are as follows. Firstly, the 3D scan line point cloud is transformed into the 2D point cloud mapping matrix based on range image. Secondly, the segmentation of the tread point cloud is completed with tread data and groove data separated. Thirdly, the top surface, bottom surface, and pattern boundary information is extracted from the segmented mapping matrix. And then the clustering of transversal patterns is carried out by calculating the similarity in order to repair pattern boundary and reduce human interactions. Finally, on the basis of the extracted parameters of pattern design feature, a semantic feature modeling method orienting at 3D tread pattern model is constructed. On the basis of the above theoretical study, a feature-based reverse modeling system for tire structure design is developed on the CATIA V5 platform by CAA. Test examples show the practicality of the system in tire pattern reverse modeling.

## 1. Introduction

As the only area where the tire contacts with the ground, the tread pattern structure not only affects the tire performances, such as maneuverability, traction, hydroplaning and noise characteristics, but also relates to driving safety and ride comfort [1]. In recent years, with the increasing demand for vehicle performance and the intense competition among tire manufacturers, computer-aided design (CAD), computer-aided engineering (CAE) and reverse engineering (RE) technologies have been widely used in tire industry. By adopting these technologies iteratively, the manufacturers can optimize product design and accelerate product innovation. The CAD tools are used to improve design accuracy and shorten design time, and the CAD data can be also directly imported into CAE or CAM (computer-aided manufacturing) system for optimization analysis and intelligent manufacturing. In contrast, RE is an integrated solution to convert real products or manual models into CAD data [2], including data acquisition, segmentation, surface fitting, etc. Nowadays, RE is widely spread in the manufacturing industry. It is used for the capitalization of information and knowledge that have not been collected yet [3]. The basic process of reverse engineering is shown in Fig. 1:

For most companies, the tasks of model reconstruction from scanned data are usually accomplished by RE software packages, such as Imageware, CopyCAD, Geomagic Studio, etc. And there are also add-in RE modules in many commercial CAD software packages, such as Pro/Engineer and CATIA. These RE softwares or modules usually generate the triangular mesh model via establishing topological relations between adjacent points in point cloud, or further fit it into free-form surfaces.

However, the tire tread pattern is mainly composed of grooves and kerfs with depth values, which may contain a large number of subtle features and bring accessibility problem in data acquisition. Thus, the reverse engineering of tire pattern may not be an easy task. Voisin et al. [4] investigated the image-based method and realized the reconstruction of the tire model. But this is only a copy of the tire shape and does not contain the tire parameter information. Lei et al. [5] built a tire model from tire point cloud by manually extracting the main tread structure parameters and reconstructing a surface model. Li et al. [6] proposed a rapid tire die manufacturing technology based on RE and 3D printing, and created a tire model by data segmentation and surface fitting. The latter two models are obtained by extracting tread structure parameters and pattern boundaries from scanned data, then fitting in units of curved surfaces, and finally trimming and splicing them into grooves' surfaces. In consideration of hundreds of grooves on a tire tread, the modeling process will be tedious and time-consuming. Moreover, the models obtained in the above studies all lack flexibility, which means it is difficult for us to redesign the model.

In order to achieve innovative design based on reconstructed model, more and more researches on RE have been conducted with the primary purpose of exploring the design intent of the original parts. The feature-

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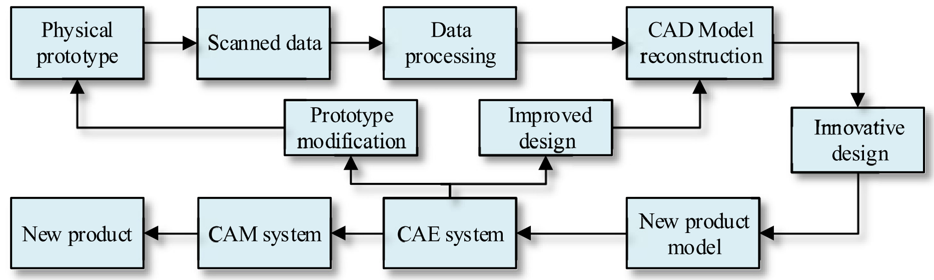


**Fig. 1.** Basic process of reverse engineering.

based reverse modeling method is one of them. Thompson et al. [7] presented a classical geometric features-based RE system which uses manufacturing features as geometric primitives. Also, the resulting models can be directly imported into feature-based CAD systems without losing the semantics and topological information inherent in feature-based representations. In the same way, Sunil and Pande [8] extract sheet metal features in freeform surface CAD models. Data analysis and model generation techniques have been used by Urbanic et al. [9] for reverse engineering rotary components. Kumar [10] proposed that feature-based and constraint-based methods can be characterized as knowledge-based methods. Feature-based models were suitable for manufacturing the mechanical parts with reverse engineering. In order to provide a product's parametric CAD model, Durupt et al. [11] extended the CPM data model and suggested a knowledge-based approach. Based on design intent, general knowledge of the problem, different geometric and dimensional restrictions, and the digitized point cloud, Barbero [12] proposed a method of reverse engineering applied to a particular case of a cam.

Feature-based parametric models include information on semantically meaningful parts (geometric features) with their parameters and a history tree (or a feature tree) representing the sequence of operations for constructing the model [13]. An essential aspect of a feature is that it has a well-defined meaning, or semantics, for a particular life-cycle activity [14]. Compared with the triangular mesh model or freeform surface model, the feature model, which is the result of feature modeling, contains a more simplified amount of data. In addition, it can also be redesigned from the original part. The necessary prerequisite for the feature-based reverse modeling method on is to parameterize the target object and build the semantic model base. Then, the relevant parameters can be extracted from the scanned data and the CAD model is built according to the feature modeling process.

The parameterization of a tire pattern can greatly improve the practical efficiency of 3D modeling. However, most published researches on the tire pattern parameters usually focus on the relations with the driving performance rather than on how to quickly generate a 3D geometric model. Tire parameterization is substantially to implement an effective and reasonable classification of the tread pattern as well as an encapsulation of modeling process and related parameters. Jung et al. [15] adopted a hierarchical fuzzy matching classifier (HFPMC) algorithm and applied it to tire pattern recognition to achieve effective classification. Chu et al. [16] developed a parameterized design system for tire mold production and established a detailed tire groove classification scheme. Hao et al. [17] designed a variety of groove design scheme to implement the intelligent design of tire digital model on CATIA platform. All of the above studies have classified tire patterns in their own way, but the degree of parameterization varies and may not necessarily be applied to the reverse modeling process.

Built on the above research, this paper proposes a new reverse modeling method of tire pattern, combining with the knowledge of data mining and semantic features modeling. At the beginning, through summarizing the pattern structure of a large number of passenger radial tires and referring to the existing tire pattern design process, the concept of tire pattern semantic unit is defined, which is the minimum design unit for tire pattern feature model. After that, the scanned point cloud data are transformed into a point cloud mapping matrix to facilitate the extraction of the pattern features. At last, with researches on the related technologies such as data segmentation and feature extraction in RE, a tire dedicated design system that can identify the key parameters of a tire pattern structure is developed on CATIA/CAA platform to reconstruct the 3D pattern model efficiently. The steps of reconstruction are shown in Fig. 2.

## 2. The structural parameters and tread pattern semantics

### 2.1. Structural parameters of pattern

The *top surface, bottom surface* and *grooves*, which are the main components of the tire pattern structure, are of direct impacts on tire

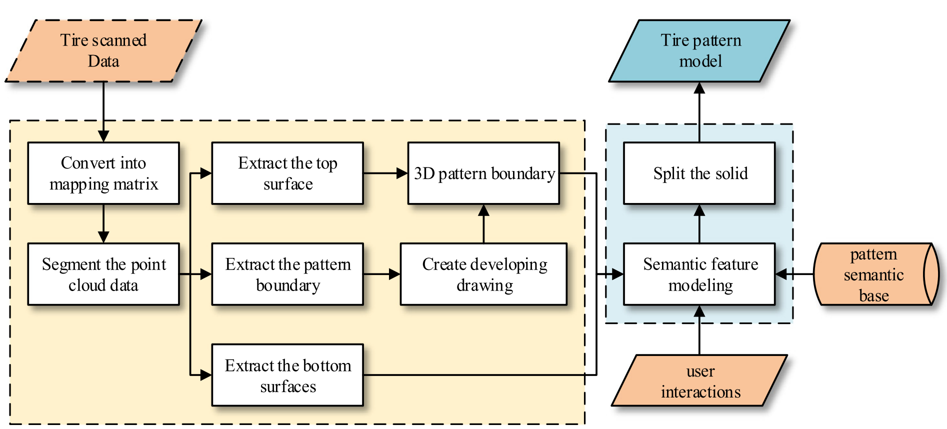


**Fig. 2.** The tire model reconstruction process.