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Feature-based 'design for manufacture' of mechanical parts with sculptured surfaces.

PhD Thesis

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Abstract

This thesis studies the optimization of design and manufacture (machining) of parts consisting of sculptured surfaces, their form being a positive or negative volume, i.e. the original or the cavity mold, respectively, as typically used in the plastics forging and casting industry.

According to state-of-the-art technology, to design complex surfaces is a time consuming procedure when it has to begin from scratch. Usually NURBS or Bezier surfaces are used which must meet size, slope and curvature constraints. Generally, it is not possible to use predefined--parameterized parts as 'building blocks' with specific function in the model, which would accelerate the design process. Moreover, the inherent difficulty of parts with sculptured surfaces when constructed though cutting processes cannot be forecast or evaluated with a view to making appropriate decisions about the relevant geometric features in the design phase. Even if manufacturabiity evaluation of such items was possible, selection of corresponding values by the user for the geometric characteristics, which determine not only the form of the workpiece but also the terms and the manufacturing process, would not be optimum. This is because the selection process, according to current state-of-the-art, would not be supported by any theory and/or its application, but it is based only on designer experience and intent.

This thesis studies and proposes solutions to the above three distinct and complementary issues.

First, extending the concept of morphological characteristics (features) is proposed by analogy to detailed analytical-classical surfaces to sculptured surfaces. In order for this transition to be meaningful, the 'solid' nature of the morphological characteristics is retained and it should not change to the ‘surface’ nature. Morphological features are defined based on their functionality in the product, e.g. 'slot', 'tang', 'head' in the case of a hammer that was used as a case study throughout the thesis. Each of these characteristics is defined based on parametric wireframe models that include constraints. According to this approach, existing CAD technology is being exploited, which adopts the concepts of parameterization and constraints and is fully implemented for curves, but not for surfaces or solids. Each morphological feature is ultimately created as a solid with the standard Boolean and other solid modeling operators (extrude, loft, revolve, etc.) in a CAD system. The result is a product designed so that its form can be easily changed by changing the values of the parameters.

Secondly, the thesis proposes creation of an decision making system concerning CNC machining issues for parts with sculptured surfaces. These decisions refer to roughing and finishing tool diameter selection and the necessity or not of the use of a semi-finishing process. The factors associated with these decisions are the volume of material to be removed, the complexity of the surface to be created, the maximum curvature and the relative importance of machining time in comparison to surface quality, i.e. the remaining material after machining. Moreover, for each of

the three machining phases, i.e. roughing, semi-finishing and finishing, several parameters that define machining strategy are decisive, e.g. vertical stepdown value, horizontal overlap value etc, and their values enable the given time-quality balance to be obtained or to be approximated as close as possible. Given the inherent approximate nature of these decisions, the decision system was implemented as a fuzzy system and leads the user to the choice of machining strategy. It also allows the user to practice with different options, thus gaining experience about the interaction between morphological and manufacturing parameters.

Thirdly, the thesis proposes the creation of neural meta-models linking the parameters of morphological features with functional characteristics and characteristics of its manufacturing process as well. Neural networks were trained with a number of workpiece variations that were created by changing its morphological characteristic values. In generating training examples the decision making tool was applied concerning machining strategy and the computational capabilities of the CAD modeling environment were employed, as well. Thus, neural networks replace both the decision making tool and the CAD environment, which is why they are characterized as meta-models. Next, the calculated parameters were used in the objective function of a standard genetic algorithm which aimed at finding the best values of the model morphological characteristics based on functionality and manufacturing criteria. Examples of such criteria are the distance between the model’s center of mass and a characteristic axis, the roughing or the finishing tool diameters etc. The relative importance of the criteria is defined by the user using weights. Due to this method being as accurate as the neural meta-models, special software to define the optimal architecture was used, in order to obtain acceptably accurate meta-models.

The results of the thesis are directly applicable to the design and construction of mechanical parts with sculptured surfaces and especially molds.

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