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Parametric design of automotive ball joint based on variable design methodology using knowledge and feature-based computer assisted 3D modelling

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ABSTRACT

Ball joints used in steering system of vehicles have hundreds of different types and configurations. The use of traditional design methods causes loss of time and increases design cost. In this study, a new platform called as "parametric design platform" has been developed for the parametric design of a ball joint using three dimensional (3D) modelling technique to reduce design time and cost. The developed platform can be used for the design of part and assembly using top-down design approach. The major advantage of the proposed system is that the system can parametrically change assembly, part, part material, feature, geometry and dimensions in a programmable environment. This provides a wide range of alternative systematic solutions to design every parts of ball joints. Whereas the current parametric systems, allow changes only in dimensions or parts of assembly in a library. The suggested approach and the platform have been tested to validate ball joint designs. The results demonstrated the practicability and validity of the proposed parametric system.

1. Introduction

Ball Joints (or universal joints) are especially used in steering system of vehicles in automotive industry. Dozens of original equipment manufacturers' (OEMs) brands and hundreds of models are available in the market of the automotive industry. Considering that each model has unique weight, chassis and steering system each of which has at least six ball joints, thousands of different types and configurations of ball joints are available that leads to millions units in the market. Ball joints manufacturers usually deal with many brands and models of each brand for OEMs and aftermarket. The high variety of different ball joint designs should be carried out with minimum time and effort due to high pressures on the cost, competition and ever increasing demands on urgent supplies coming from vehicle manufacturers to ball joint co-designers. This demand can be met more efficiently if the design is carried out using computer assisted parametric design of automotive ball joint based on variable assembly methodology.

Fifty years have passed since Sketchpad, which is the first parametric system invented by Ivan Sutherland in 1963 (Davis, 2013), Aish and Woodbury (2005) say that the hope still remains that parametric modelling will "reduce the time and effort required for change and reuse". In parametric design, geometric shape is modelled by parameters which can be changed by users. In addition, these parameters are associated with a sequence of relationships. When the value of one parameter (e.g., a dimension) is changed, this change is then propagated to the other parameters through these relationships. In modern computer-aided design (CAD) and computer-aided manufacturing (CAM) or computer-aided engineering (CAE) systems such as Pro/Engineer (Pro/E), the relationships among parameters in 3D part models, assembly models, 2D drawing models, computer numerical control (CNC) machining models and finite element analysis models can also be defined (Zhao and Xue, 2010). Multiple tasks of CAD systems can be aggregated by parametric design to eliminate manual CAD disruptions. Repetitive or iterative design works can also be done faster. Therefore, parametric design is an effective and efficient method in saving product design time and cost.

Parametric modelling technology has been adopted in mainstream (CAD) tools used by United States industry and in developed industries. This technology provides designers with tremendous flexibility to explore feasible design alternatives (Chang and Joo, 2006). A large number of parametric design studies have been done on parametric design to reduce design time and cost. However, most of the studies have only focused on single function of a whole system of product such

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as only automatic generation of gating system rather than complete system design for die casting (Wu et al., 2007). It is beneficial to propose a top-down methodology to design assembly, parts, features of parts, geometry of feature and dimensions each individually and as a whole to provide flexibility and explore the feasible alternative. The term "feature", used throughout in this work, refers to a region of a part including geometrical, topological and dimensional properties.

Additionally, the methodology should also support variable design conditions. In order to reach feasible design solution, sometimes it is sufficient to change only one dimension but in some cases it can be achieved rather difficultly and it may lead redesigning of a complete assembly. A part used in an embodiment could not be used in another, a supplementary part could be necessary or a part which have different geometry or material could be better alternative. A methodology, which supports the variation, enhances flexibility of parametric design system.

Current commercially available CAD systems such as Pro/E (Creo), Catia, NX, Rhino-Grasshopper support parametric design. However, these systems need to add functional relations of designed products. The relations stored to solve engineering problems of design are Knowledge-Base. Knowledge base must contain all data required for assembly functions, topologic relations between parts and assembly, constraints, part library, geometries, dimensions, dimensional calculations, materials, and logical statements (rules) of them.

The current parametric 3D CAD software products have extensive parametric 3D modelling capabilities but these products cannot achieve the following;

(1) Dimensions of parts and assembly models can be changed easily, but unfortunately a substantial change in the processes is required one by one and manually. In order to change many dimensions by a single parameter, additional relations (mathematical calculations and expressions) between dimensions must be defined.
(2) Many 3D CAD software products are capable of using non-numerical parameters (string, pop-up list, yes/no, etc.) for parametric programming but these need programming embedded to 3D CAD software products.
(3) The software products support user interface to enter parameters in a single graphically designed page but it can be achieved by either preparing parameters in another readable software i.e. Microsoft-Excel or using parallel (combining) running software products like C programming language but the build of interface is more difficult.
(4) 3D software products automatically demonstrate 2 dimensional (2D) drawing of 3D part or assembly. But the relevant design information that is pertinent to object (part) such as material and heat treatment of parts, paints, coatings, amount and properties of oil etc. must be added to 2D views. This can only be achieved by adding logical algorithms and programming embedded to the software.
(5) Current parametric design methodology controls only dimensions of one set of parts and their features with relation and programming. It is not compatible;
    - for different configurations and variation alternatives of parts and interactions between them in an assembly,
    - for different variant topology and,
    - it does not allow managing all parts and features in different axis or planes.

In this paper, a new 3D design platform for parametric design of automotive ball joints has been proposed based on variable design methodology using knowledge and feature-based computer assisted 3D modelling. It was designed to tackle with the all five of the aforementioned issues of the currently existing 3D software products. It particularly aims at automating the repetitive parametric part design and assembly process for various types of ball joint assemblies (including all alternative parts) in order to reduce the design time and cost. The parametric design of the parts are carried on based on the predefined 3D master model of the assembly, while the parametric assembly modelling, with possible features, is aggregated depending on desired ball joint assembly configuration. The platform allows the combination of different parts and ensure that it does not violate some predefined "rules" and "restrictions", and it can be extended to similar applications. The proposed platform comprises different components and relies on currently existing software products (Pro/E and Microsoft-Excel or C programming language) to facilitate ball joint assembly designing process. Unlike, currently available parametric design systems;

- The newly proposed platform allows automated reconfigurations of the ball joint assembly model by adding and changing for different parts, geometries, materials and design dimensions of 3D CAD parts by a parameter(s).
- In addition, the algorithms of the proposed platform completely fix lowest level of CAD design, and it is compatible for different variant topology.
- It also allows managing all features in different axis or planes.

Briefly, the platform was designed to better meet ever increasing design demands on urgent supplies coming from vehicle manufacturers to OEMs.

The remainder of the paper organized as follows. In Section 2, literature for parametric 3D design of different products including mechanical assemblies was reviewed. Section 3 introduces and compares the algorithm of the suggested parametric design platform with the existing parametric design systems. In Section 4, design characteristics and types of ball joints are explained. Section 5 discusses the implementation of the proposed parametric design algorithm. Section 6 discusses parametric design of a ball joint based on the algorithm. Section 7 gives a case study. Section 8 concludes the paper.

2. Literature review

In recent years, many research works have been carried out about parametric design of different products using 3D modelling to reduce design time and cost. Liu (2011) developed a parameterized mock up design of polycrystalline diamond compact (PDC) bits for drilling operation. More complex parametric design studies focused on parts and their production processes. Chu et al. (2006) used a parametric design system for 3D tyre mould production. A set of geometric algorithms is proposed that first detects undesired groove geometries arising in the design process, and then corrects them automatically. Wu et al. (2007) developed a design system that helps to realize automatic generation of the gating system's geometries for die-casting die by applying parametric design. Mok et al. (2011) developed an effective reuse and retrieval system that can easily register modelled standard parts using a simple graphical user interface (GUI) for automation of mould designs. It consists mainly of three kinds of module; (a) standard part module is helpful for designers to effectively reuse or modify standard parts after registering them using a GUI, (b) parts-list module generates a parts list using either standard and/or non-standard parts, (c) The retrieval-system module allows the effective retrieval and classification of standard parts (Mok et al., 2011). Wu et al. (2012) presented a response surface methodology as the approach for parametric design and process parameter optimization of seamless and traceless bra cup moulding. The proposed methodologies in these studies automate repetitive design works to prevent from manual malfunctions.

Some other groups of studies focused on parametric design of mechanical assemblies. Myung and Han (2001) described the parametric modelling of a machine tool and proposed a framework for parametrically modelling a machine tool assembly based on configuration design method in their study. A design expert system to redesign assemblies of a machine tool has been implemented, because it is claimed that