Knowledge-Based Application of Liaison for Variant Design

Shantanu Das, Abinash Swain

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Shantanu Kumar Das[1,*], Abinash Kumar Swain[2]

Indian Institute of Technology, Dept. of Mechanical & Industrial Engineering, Roorkee, India

[1]E-mail: shantanuds0206@gmail.com

[2]E-mail: swainfme@iitr.ac.in

Shantanu.abinash@springernature.com

Abstract. This paper proposes the use of liaison to develop a knowledge based system for variant design application to assist and guide designers at earlier stage of product development. A knowledge based framework has been proposed to support the joining process selection during variant design, where liaison act as an interface. Various liaison knowledge is represented in a complete and systematic manner. These liaison knowledge includes various geometric and non-geometric information. A user interface has been developed. A query engine is built and used to enable reasoning the joining process based on the requirement of a variant product. An industrial case study of two variants of automobile front bumper is provided in order to illustrate and validate the proposed knowledge based framework.

Keywords: Variant design, Liaison, Ontology, Knowledge based framework

1 Introduction

Diversified customer requirement and growing competition in the global market demands manufacturer to provide an increased variety of product. In order to fulfill this increased demand of higher variety of products [1] in the shortest possible time with lower tooling cost, industries are under tremendous pressure in current times. In addition, manufacturers are providing great efforts to shorten the product development cycle to enable new models or variants of an existing product to be brought out more quickly, more often and with lower tooling costs. The use of a higher variety of product led to the development of complex manufacturing and assembly system. As a result the new design or variant design calls for a major change in the assembly process or sequence where possible, which is very much expensive to handle. In particular, in the context of variants, it is important that changes in the design either avoid or minimize the need to change or modify the assembly line. For variant design, the changes in the design refer the change in existing component's dimension, change in material type, or form of the component. In order to address the above change there are changes in the assembly joint or liaison. In this paper, liaison is defined as a structured collection of various geometric and non-geometric information of parts in an assembly that is associated with one or more assembly process. As design is a knowledge intensive work which takes 20% of the designer's time in searching and analyzing various past information [2], it is required to develop a knowledge based framework which can capture, store, share and reuse the knowledge across various domains. In this paper, a knowledge based framework using liaison is developed in order to reduce product development life cycle for the variant design. Various geometric attributes of assembly components are considered along with some non-geometric attributes for systematic representation various design knowledge. This systematic representation of various knowledge is required in order to maintain various knowledge in proper format so that it can be interpreted and retrieved easily by a computer system.

Various authors represented liaison for collaborative product development [3], assembly sequence planning [4], concurrent evolution of product model with the process model [5] and maintaining associativity between product model and process model [5]. Another important field is a variant design where liaisons are required for concurrent evolution of design of product family and the corresponding assembly system. The prime motivation for this interest is to reduce the design and manufacturing cycle time by identifying the infeasibility and inconsistency in the existing assembly process in the early stages of product variant design. In order to address above, a knowledge based framework developed for selection of assembly joining process for variant design application at the early stage of product development. This knowledge base is providing the required information for joining process selection during the variant design.

The rest of the paper is structured as follows. Section 2 discusses various literatures related to the proposed work. A knowledge based framework developed in Section 3 for joining process selection which includes representation of liaison, selection of liaison knowledge for variant design. In Section 4 an industrial case study of two variants of automobile front bumper is provided in order to illustrate and validate the proposed knowledge based framework. The paper concludes with the discussion of the contributions and its various future applications.

2 State of the art

In this section various literatures related to liaison to support variant design and knowledge based application of liaison are reviewed.

2.1 Liaison used for Variant Design

In the recent decades, variant design has attracted more researchers. Many literatures related to liaison based variant design are discussed in this section. Luh et al. [6] stored hierarchical component interaction information in a QDSM (quantified design structure matrix) and defined it as a liaison, which is applied for variant design solution in a product family. Bryan et al. [7] combined precedence diagram of all product variants of a product family and defined this information as liaison. Further, these information are used for the calculation of assembly time for each instance of base modules and differentiating modules in a product family of office chairs. ElMaraghy & AlGeddawy

[8] addressed about a product variant design model which satisfy various customer's needs in a market. Further, different dependency matrices and liaison graphs are extracted along with the component's architectural constraints in order to identify the best modular product family design. AlGeddawy & ElMaraghy [9] differentiated various products into variants in a product family based on commonality and differentiation between parts and component for the development of a reactive platform design model. Based on various attributes like materials for various components, possible modularity, possible integration, moving components, etc., different liaison graphs have been developed to identify the adjacency of component and to assist in the cladistics analysis to develop a reactive platform design.

2.2 Knowledge based application of liaison

In this section, various literatures restraining to the knowledge based application of many liaison information are discussed. L'Eglise et al. [10] developed a multicriteria decision aid method which helps the designer to choose the suitable joining process for each electro-mechanical product at the early stage of product realization. Various attributes like joint geometry, joint properties, production, materials and process have been included in the knowledge base for the development of a multicriteria decision aid method. Zha et al. [11] developed a knowledge based framework by considering functional, hierarchical relationship between the assembly components for assembly orientated design and assembly sequence planning. Kim et al. [12] introduced assembly design formalism which captured the knowledge related to assembly joining relationship comprising of joint features, mating feature, assembly engineering relation, spatial relationship specification and assembly features which is enhanced using ontologies for collaborative assembly information sharing framework by using OWL & SWRL. Lohse et al. [13] considered different liaisons (i.e. contact liaison, form fit liaison, tight fit liaison, screw fit liaison) in order to develop a product and assembly process domain ontology framework for deciding various assembling operations. Zha & Sriram [14] presented a knowledge based framework which captures, represents and manages product family design knowledge and helps in product variant assessment.

Kim et al. [4] developed a knowledge based framework in which various knowledge related to joining process like riveting, adhesive bonding, fastener, welding, metal stitching, soldering, brazing, spot welding, etc. are described in mereotopological manner. This mathematical description and the Semantic Web Rule Language (SWRL) helps in representing the difference of similar looking joints and also helps in defining the assembly design terms and their correlations. Further, it is used for collaborative assembly design where various knowledge related to joining process is captured using ontology and retrieved, shared & reused across different environment. Demoly et al. [15] developed a mathematical description of product relationship based on mereotopology at different abstraction levels in order to have a greater understanding of product definition and assembly and they have presented the description by ontological implementation using OWL DL and SWRL. Mas et al. [16] proposed a knowledge based application for aircraft assembly line design using assembly joint and its process information along with some jigs, tools and human resource knowledge. However this knowledge based system only considered the assembly process information of liaison without considering other aspects of knowledge related to design, production and functional requirement for selection of liaison and its possible joining processes.

In summary most of the representations of liaison available in the literature have only considered the mating and the hierarchical relationship in an assembly without considering the actual process required for mating. Further, research related to non-geometric liaison information associated with variant design are scarce in the literature. Hence based on the extensive literature review, it is concluded that the various knowledge based system available in the literature are not capable to provide a clear picture for use the liaison for variant design applications at the early stages of product realization.

3 Knowledge based framework for selection of joining process

A knowledge based framework for the selection of joining process in variant design is shown in Fig. 1. It consist of five basic units: customer requirement for variant product, user interface, knowledge base, multiple criteria decision making & query engine.

Various steps for creating the knowledge based system are defined below in detail.

Customer requirement for variant product: Based on the customer requirement like reducing the cost of the product or making the product to be lightweight, the designer has to change material type, joint design type etc. These design inputs are submitted to the user interface module and changed according to the requirement for variant product.

User interface: The user interface module provides an interface for selection of various design knowledge based on the requirement for a variant product. These design knowledge is submitted to a query engine for reasoning about the process. The query results are collected in the multiple criteria decision making module. The designer takes expert advice and if there is any change in the design knowledge, then it is submitted to the user interface module.

Knowledge base: In the knowledge base module various geometric and non-geometric design knowledge are represented in a complete and systematic manner. When a query is fired by the designer, these knowledge is loaded into the query engine and help in retrieving the joining process.

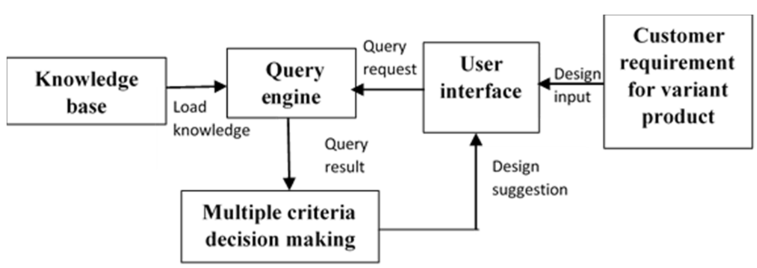

Fig. 1. Knowledge based framework for selection of joining process in variant design

Multiple criteria decision making: The query results from the query engine are collected in a multiple criteria decision making module and the designer takes the expert advice for analyzing the results. If there is any design suggestion, then it is submitted to the user interface module for further reasoning purpose.
Query engine: When a query is fired from the user interface module, the query engine loaded requires knowledge to be retrieved from the knowledge base module. By the use of this knowledge, it enables reasoning about the joining process and also transfers the query result to the multiple criteria decision making module.

Due to variant design, following types of changes are observed, which need to be tackled for the development of knowledge based system for selection of joining process.

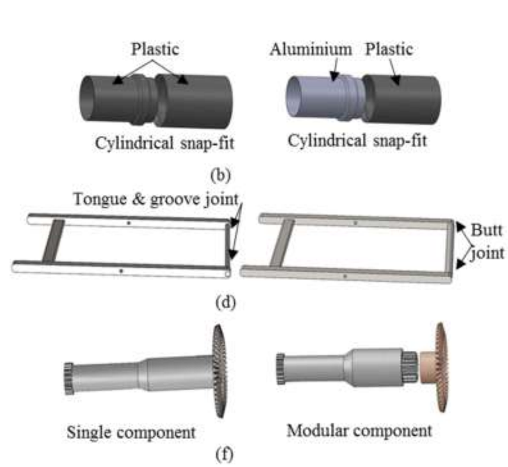

Fig. 2. (a) Change in joint design type (b) Change in material without change in joint design type (c) Change in material with change in joint design type (d) Change in component's dimension with change in joint design type (e) Change in component's dimension without change in joint design type (f) Change in product architecture

Due to change in the form of component the joint design type is changed as shown in Fig. 2(a). The change in the component modifies the joint design type due to the rigidness of material. If one of the component is plastic in nature, then it can be assembled by the cylindrical snap-fit joint as shown in Fig. 2(b). When the material of a component changes, then there is a change in liaison type because of the rigidness of material it can't be assembled by cylindrical snap-fit joint. It can be fixed by some other joints like screwed joint or welded joint as shown in Fig. 2(c). Due to the dimension constraint, the joint design type is changed by modifying the diameter of the component as shown in Fig. 2(d). This is an example of scalable variant design where the length of the A2 component changes without change in liaison type as shown in Fig. 2(e). The bevel gear having single component is converted into a modular architecture in order to change the material for reducing the weight of the shaft of the part without losing the strength of the teeth. This is a variant design for a lighter product by changing the design from integral to the modular architecture as shown in Fig. 2(f).

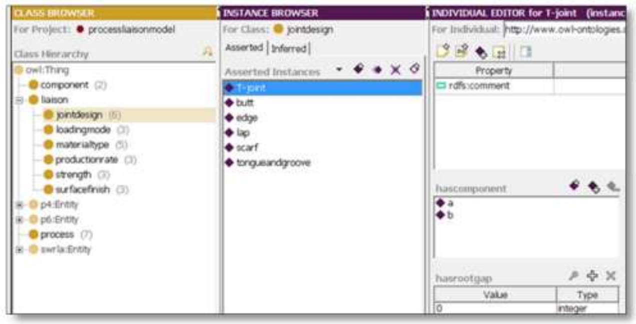

Fig. 3. An instance of assembly joint design and its process parameters

3.1 Development of liaison knowledge based system using ontology

In this paper various geometric attributes and non-geometric attributes of liaison are represented using Protégé [3.3.5] which is an open-source ontology framework for building knowledge based acquisition tool developed at Stanford University. Various liaison attributes and their values of root gap, material type, thickness, production rate, loading mode, strength, surface finish etc. are stored for development of a knowledge database as shown in Fig.3. Also, various interrelationships between the joining process and different liaison attributes are made for the development of knowledge based system. Earlier Swain et al. [5] extracted various joint designs like lap, butt, etc. and used these for process selection by considering only the geometric attributes of liaison. In this paper various geometric attributes along with non-geometric attributes are considered for selection of joining process based on the requirement for a variant product.

A user interface has been developed and is shown in Fig. 4. The designers have to scrutinize various liaison knowledge for the selection of the process according to the design, functional and production requirement of a variant product. For example, when the joint design type is changed from butt to tongue and groove to fulfill the customer requirement, then designer changes the values of "hasjointdesign" attributes in the user interface and reasons about the joining process using the query engine. In this way the designer can change various values of attributes according to the need of the design and can retrieve the joining process using query engine.

A variant design application of developed knowledge based system is defined in a framework as represented in Fig. 5. In this framework, designer first develops the CAD model for variant product and extracts various liaison knowledge using API programming. This variant liaison knowledge is compared with the existing liaison database for determining the modified liaisons and other related information using data mining methods like text mining, clustering and similarity analysis algorithms etc. Hence, using this process a modified liaison database is developed and compared with the existing liaison database. For existing liaison, the assembly joining process has been already available in the previous liaison database. In the case of modified liaison the assembly joining process is chosen by reasoning using the developed knowledge based framework. Hence this framework helps in reducing the product development life cycle of a variant product by eliminating the assembly process planning time for existing liaison.

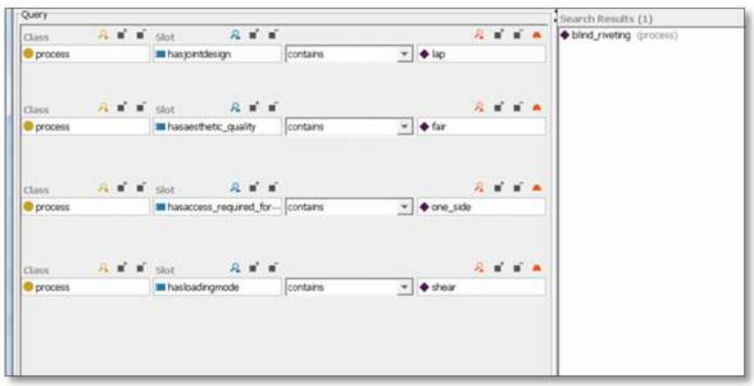

Fig. 4. A user interface for the selection of attributes in joining process selection

4 Industrial case study

An industrial case study of two variants of front bumper in automobile are used as example to illustrate and validate the above knowledge based framework. In this paper, two front bumpers from Toyota and Mitsubishi [18] are taken as a variant product for the validation of the proposed framework. In the variant design of bumper, joint design types between components are changed due to the change in form of components or mixing and matching of components. There is a chance of changing the assembly joining process and needs proper verification for obtaining the modified liaison and its joining process.

In the Mitsubishi-triton-front-bumper there are 4 types of joint designs namely lap joint, tongue & groove joint, corner joint and press-fit joint. The lap joint is present between components namely Frontsideface-3ton (A) and Bumper link 3ton-1(C), and Frontsideface-3ton (A) and Bumper link 3ton-2(D). There are 3 tongue and groove joints which are present between components namely Fog lamp bracket3ton-1(B) and Fog lamp triton-1(E), Fog lamp bracket3ton-2(F) and Fog lamp triton-2(H), and Grill hilux-1(I) and Frontsideface-3ton (A). The corner joint is available between the components namely Fog lamp bracket3ton-1(B) and Frontsideface-3ton (A), Fog lamp bracket3ton-2(F) and Frontsideface-3ton (A), and Bracket roller-1(G) and Frontsideface-3ton (A). There are two press-fit joints present between components namely Fog lamp bracket3ton-1(B) & Fog lamp triton-1(E), and Fog lamp bracket3ton-2(F) & Fog lamp triton-2(H). In the Toyota-fj-cruiser-front-bumper there are 4 types of joint designs namely lap joint, tongue and groove joint, corner joint and press-fit joint. The lap joint is present between components namely Frontsideface-3ton (A) and Bumper link 3ton-1(C), Frontsideface-3ton (A) and Bumper link 3ton-2(D), Bracket roller-1(G) and Frontsideface-3ton (A), Fog lamp bracket3ton-2(F) and Fog lamp triton-2(H), and Fog lamp bracket3ton-1(B) and Fog lamp triton-1(E). There is one tongue & groove joint which is present between components namely Grill hilux-1(I) and Frontsideface-3ton (A). The corner joint is available between components namely Fog lamp bracket3ton-1(B) and Frontsideface-3ton (A), and Fog lamp bracket3ton-2(F) and Frontsideface-3ton (A). There are 2 press-fit joints present between components namely Fog lamp bracket3ton-1(B) and Fog lamp triton-1(E), and Fog lamp bracket3ton-2(F) and Fog lamp triton-2(H).

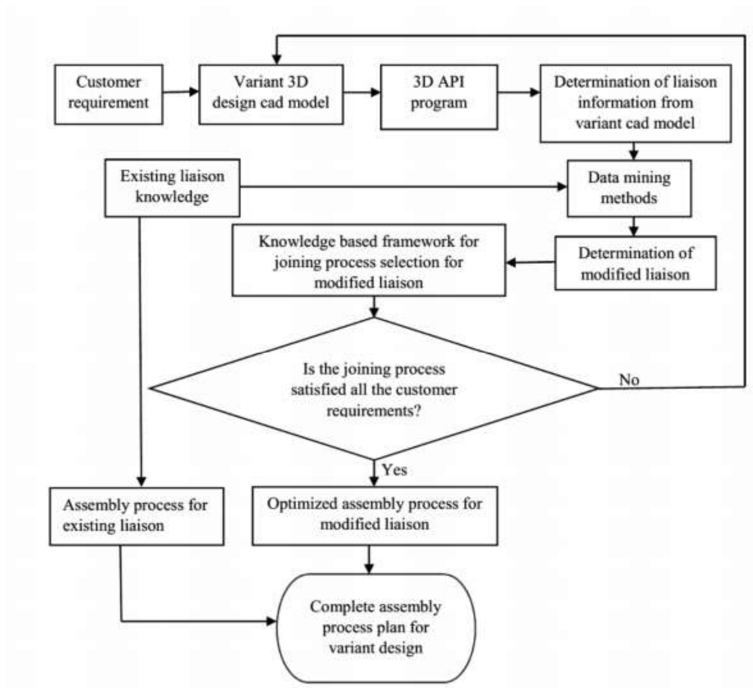

Fig. 5. A framework for variant design application

Due to the variant design there is a change in the form of assembly components as shown in Fig. 6 and Fig. 7. Due to this, there is a change in the assembly joint design (modified liaison) available between the assembly components and its joining process. At this stage, the knowledge based framework of liaison will helps in deciding the suitable joining process for a particular joint design by optimizing the several attributes during the selection of processes.

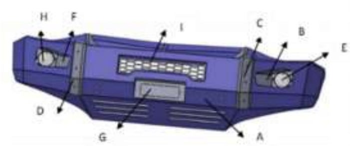

Fig. 6. Mitsubishi-triton-front-bumper

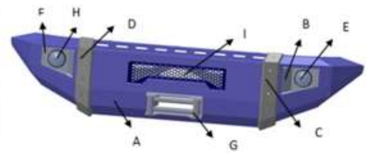

Fig. 7. Toyota-fj-cruiser-front-bumper

Table 1. Change in liaisons during variant design

Involved components		Existing liaisons	Modified liaisons
Bracket roller-1(G)	Frontsideface-3ton(A)	Corner-joint	Lap joint
Fog lamp bracket3ton-2(F)	Fog lamp triton-2(H)	2-Tongue and groove joint,1 press fit	1-press-fit & 4-lap-joint

In this industrial case study, the modified liaison found between components of two variants of the front bumper are shown in Table 1. Due to this change in liaisons, there will be a change in the assembly joining process. This can be tackled by the above knowledge based framework by changing the value of required attributes in the user interface according to the requirement of a variant product. Also, by submitting these values to the query engine and executing this will generate a suitable joining process which reduce the process planning time of modified liaison. So this knowledge based framework will help in reducing the product development life cycle time for a variant product.

5 Conclusion & future work

In this paper, a knowledge based framework of liaison is developed for the selection of suitable joining process for variant design application. In the knowledge based system various geometric attributes and non-geometric attributes of liaison are represented systematically using ontology. A user interface is developed and a query reasoning engine is implemented for retrieving the suitable processes according to the requirements for a variant product. An industrial case study of two variants of automobile front bumper are used in order to illustrate and validate the proposed knowledge based framework. The knowledge based framework can be extended to resolve the challenges related to the concurrent evolution of product family and its assembly system.

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