Utilizing Assembly Features for determination of Grasping Skill in Assembly System

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Abstract— In this paper, a proposed method to support adaptability of assembly systems in grasping operation is introduced. The method exploits the assembly features of a product to determine the required grasping skill in the assembly system. The required technical parameters of the "grasping" skill are proposed to be determined by extracting assembly features from a CAD assembly model. Assembly features are any information, geometrical, non-geometrical and functional, that is significant to assembly operations. Based on this definition a new set of manipulating (moving and orienting) features are derived such as gripping features. A comprehensive analysis of these features is conducted through a feature- based model derived from product topology. This analysis is illustrated by a four – part assembly example. A literature survey for assembly features is conducted.

I. Introduction

Mechanical products rarely consist of a single part. Cost efficient moving and joining of parts in assembly systems are fundamental challenges in realizing a product. According to [1] assembly costs of industrial products correspond to more than 30 per cent of total industrial product costs. Hence, Assembly process plays a very important role in the overall product realization.

The grasping operation is one of the basic assembly operations in assembly systems. To realize grasping, grippers are widely used in automated assembly systems. According to [2], "Grippers can be the most design-intensive components of an assembly system". Most industrial grippers can be only used for a very limited range of products [3]. To add more adaptability to assembly systems, general-purpose grippers are developed to enable grasping for a wider range of products.

In this paper, a proposed method to support adaptability of assembly systems in grasping operation is proposed. The method utilizes assembly features of a product to determine the required *grasping* skill. Skills describe functional capabilities of assembly resources, which are hardware or software entities involved in process execution [5]. A particular functional capability is associated with a skill concept name, such as *grasping* skill. Skills have parameters, which represent the technical properties and constraints of resources. For the *grasping* skill, parameters such as "number of fingers", "maximum and minimum opening range" and "grasping force" determine the range and constraints of the skill. In the proposed method, the required technical parameters of the *grasping* skill are determined based on assembly features extracted from a CAD assembly model.

A feature, in this context, is a carrier of product information, which may aid design or communication between design and manufacturing, or between other engineering tasks [4]. Features include both geometric information and functional characteristics (shape, type, tolerance and material) of the product data [12]. Assembly features are defined as "features with significance for assembly processes" [3], they can improve the link between product design and production system [13] by facilitating the knowledge transfer between product design information and process planning taking into consideration the continuous changes of manufacturing resources capabilities over time [14].

This paper is organized as follows: section two gives a background about using skills to represent production resources in adaptive systems. Section three includes analysis and representation of assembly features. In this section a proposed representation model of extracted assembly features is described by a case-study example. Section four includes a proposed method for defining gripping features for a part in an assembly. A method to determine the "number of fingers" as a parameter of a grasping skill is illustrated in this section. Section five draws conclusions and gives an outlook for future research.

II. RELATED WORKS

The Skill concept was first used to fill the gap between processes and equipment in the ontology of the EUPASS project. In this project's ontology the skills were divided into basic skills and complex skills. The basic skills are the most fundamental skills, whereas the complex skills are combinations of more simple skills [15]. These ideas were based on [16], in which a multi-agent-based control architecture for a shop floor system (CoBaSa) which supports fast re-engineering and plug and play capabilities was presented. The ontology is used to identify which basic skills are necessary to provide complex skills [17].

SIARAS3 project [18], [19], [20] proposed two approaches for skills: a top-down (AI, artificial intelligence,) approach and a bottom-up (engineering of components and programming of individual tasks) approach. Ontologies have been used to store skills and their relations, which are used for automatic reconfiguration of production systems. ROSETTA4 project [21], [22], [23] defined robotic skills in a production system. Huckaby and Christensen [24] proposed a taxonomy for assembly tasks. They defined the required skills necessary to accomplish an assembly task.

Other authors use a similar approach but exchange the term skill with capability. Smale and Ratchev [9] proposed a capability-based approach for multiple assembly system reconfigurations. Their work comprises a reconfiguration methodology, by providing a means to compare the product requirement with the existing resource capabilities, supported by capability model and capability taxonomy. Järvenpää [25] proposed an approach for capability modeling where capabilities are functionalities of resources that have parameters, which present the technical properties and constraints of resources. Also capabilities can be combined in a dynamic fashion to accomplish combined capabilities. Combined capabilities are combinations of other capabilities, usually formed by a combination of devices, such as a robot and a gripper.

III. ASSEMBLY FEATURES: ANALYSIS AND REPRESENTATION

Assembly features are divided into mating (connection) features (such as final position, insertion path/point, tolerances), handling features, (characteristics that give the location/ orientation of an assembly component such that it can be safely handled by a gripper during assembly) [3], and form features. The latter are ''A set of geometric entities (surfaces, edges, and vertices) together with specifications of the bounding relationship between them and which have engineering/functional implications and/or provide assembly aid, such as a center line of a hole, on an object'' [6], [7]. In other words, form features are geometrical mating entities, which include mating features. Figure 1 illustrates the definition of assembly features.

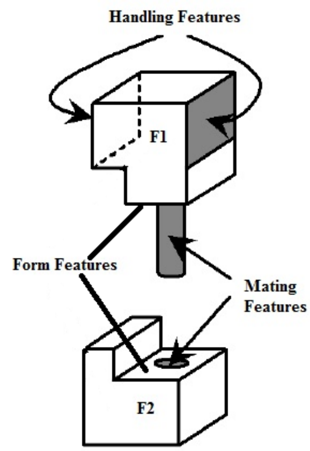

Figure 1. *Assembly features, modified from [8].*

The aim of assembly feature analysis is to deduce assembly information from a product design such that it can be connected to the required assembly processes and capabilities in the production system. According to Smale & Ratchev [9] the basic core of assembly processes are "Moving Part x" and "Joining Parts x and y". A process has to be added to this basic core after "Moving Part x" and before "Joining Parts x and y", and that is "Orienting Part x". Based on this reasoning, handling, mating and form features of a product have to be defined, represented and extracted to enable allocation of manipulation (moving and orientation) features, which are a set of process features include all the functional, geometrical information and constraints significant for allocating moving and orienting processes and skills required to assemble a product. Figure 2 illustrates extraction and derivation of process features.

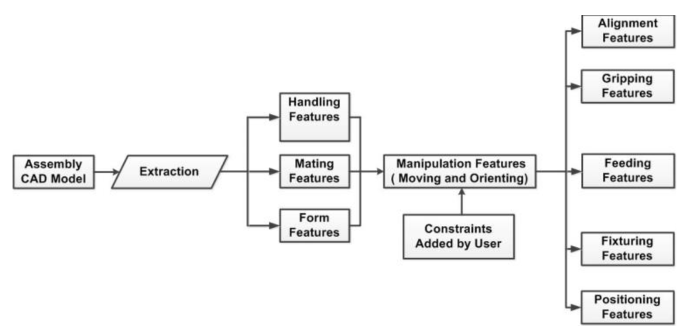

Figure 2. *Extraction and derivation of manipulating features*

Handling features of a component constitute a generic form of assembly information (independent of the actual position and orientation of the component within an assembly), from which information about feeding, fixturing and grasping can be retrieved [3]. Handling features are generic for some assembly components, such as the base component (the component upon which all remaining assembly operations are carried out). For the assembly components, handling features are needed in order to derive fixturing, feeding and gripping features, while mating and form features are mainly used for orienting, positioning and alignment assembly processes. Figure 3 shows a case-study assembly product example consists from four parts, while

Figure 4 illustrates a proposed feature-based model for the case-study example. In this figure, assembly and manipulation process features for each part in the assembly product design are specified.

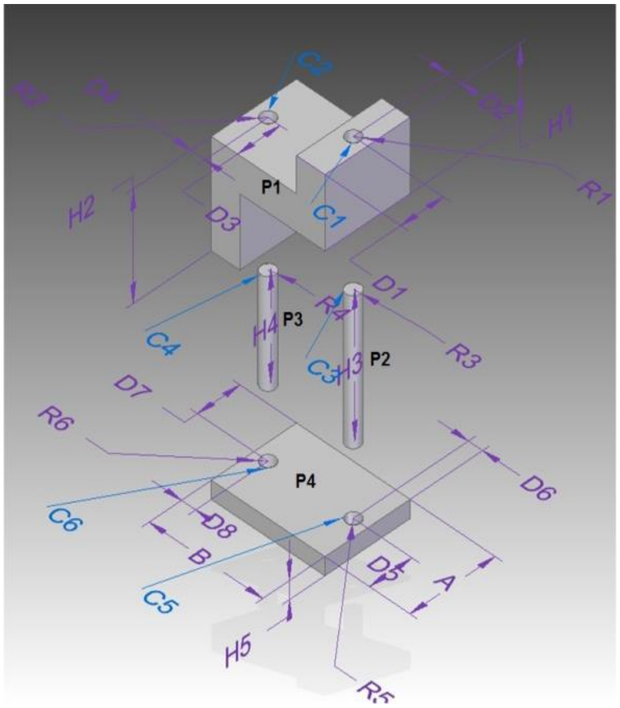

Figure 3. *Four-part assembly design case-study example.*

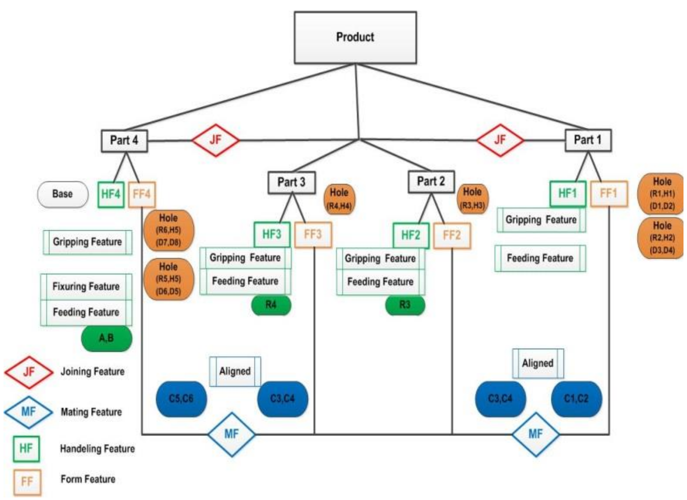

Figure 4. *Feature-based model for the four- part case study example.*

In Figure 3, the dimensions of the parts (P1-P4) are specified, with P4 as a base for the assembly. The radius of each hole (R1-R6), the center (C1-C6) and the exact locations of all holes are specified (e.g. hole with radius R1, center C1 is specified with (D1, D2) dimensions from both edges of P1 and with H1 as depth of the hole). So hole one can be described as (R1, H1), (D1, D2), and all the other holes are described in the same way. In Figure 4, for each part, first a handling and form features are specified, mating features are specified between different form features in different parts, while joining features are specified between different parts. Manipulation process features are specified under the specified handling features for each part. For example P2 and P3 have handling features that are expressed as a gripping and feeding features specified by the radius of each cylinder (R3, R4). Mating features for P2 and P3 are characterized by hole centers (C3, C4) with a mutual aligned relation between (C1, C2) in P1 and (C5, C6) in P4. For P4 (base) a fixturing, feeding and gripping features are specified with (A, B) dimensions for the first two features, while internal gripping can be used through (C5, C6) since the two holes are simple holes. Gripping and feeding features for P1 will be specified in more details in next section.

Specifying manipulation features for different parts in an assembly is a dynamic process, each part should be checked if it is a base part or not, then it should be checked if it is fed part or not and finally checked for grasping. The manipulation processes will be performed after checking for the available required skills. This can be illustrated as a flowchart in Figure 5.

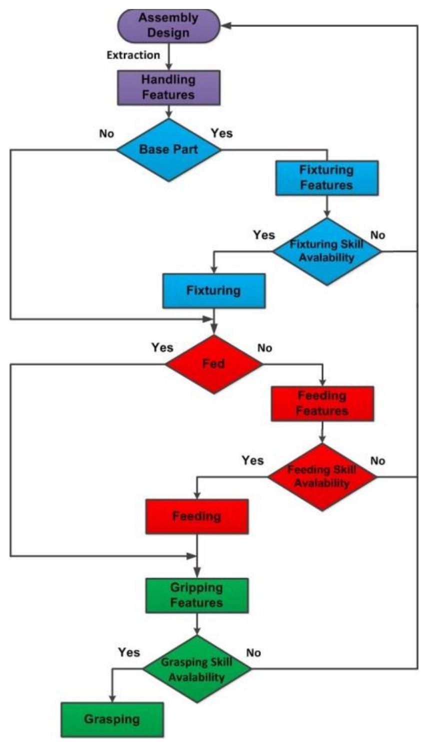

Figure 5. *Flowchart for specifying manipulation features for a part in an assembly*

In Figure 5, after specifying the related features, the availability of the related skill should be checked by matching the manipulating features with the parameters of the available skill, if the skill is available, the related process will be achieved; otherwise the part should be redesigned for a new set of handling features compatible with the available skills. An example for matching feeding and fixturing features with the required skills is illustrated in Figure 6.

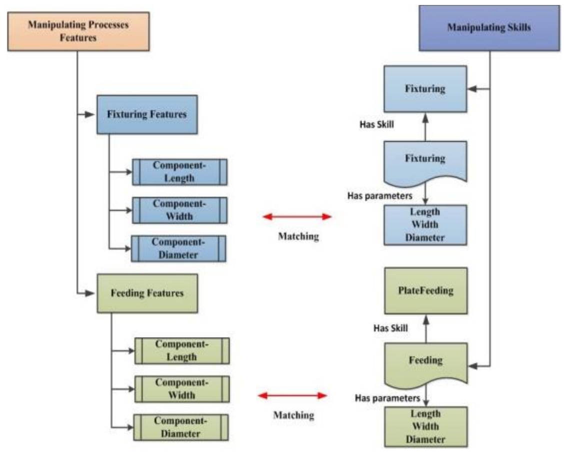

Figure 6. *Mapping fixturing and feeding features to the related skills capabilities.*

The application of a skill on a part in an assembly will generate a sequence of tasks with ordering constraints (e.g. task A must follow directly after task B) [5]. The execution of theses ordering tasks will achieve the required process. Figure 7 illustrates the sequence of tasks required to perform assembly processes (AP) for the case-study example in Figure 3.

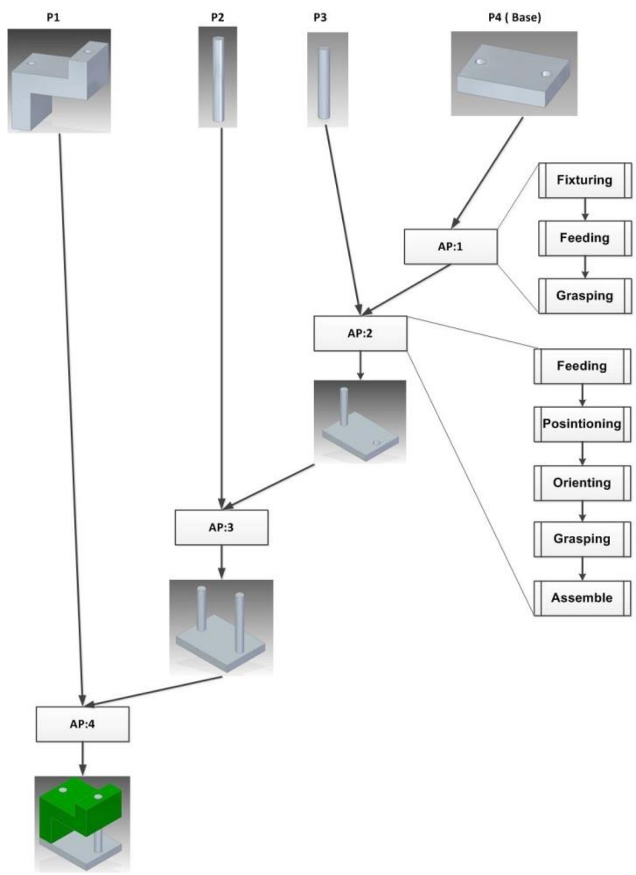

Figure 7. *Assembly graph for the case-study example*

In Figure 7, four assembly processes (AP1-4) are required to assemble the case-study example. AP1, applied for P4, consists of three tasks includes fixturing as P4 is the base part. AP 2-4 consists from the same tasks starting by feeding and ending by assembling (joining) the next part.

IV. GRASP PLANING FOR ASSEMBLY

Grasp planning is the process of planning the collision-free motion of the gripper fingers around an object to obtain a stable configuration for manipulating the part [11]. Gripping features can be used as an intermediate stage to integrate part design and grasp planning. As any process features, gripping features include geometrical, functional information and constrains. One of the geometrical information included in gripping features is gripping planes, which are spatially opposing faces with face normal that diverge away (anti-parallel) [8]. These planes are not included in any joining, fixturing and feeding assembly processes.

Gripping planes include grasping areas, areas that guarantee a good balance between forces and torque, where grasping process will take place. These areas include finger domains, which are collision-free motion contact Points that are reachable by the gripper fingers. Figure 8 illustrates this procedure of grasp planning from gripping features until the determination of finger domains where actual grips will take place.

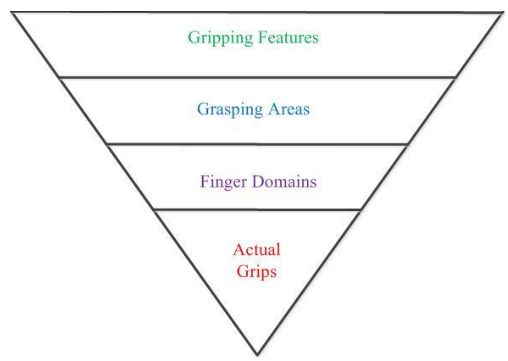

Figure 8. *Grasp planning procedure based on gripping features*

Gripping and feeding features for P1 in Figure 3 is illustrated in Figure 9 below.

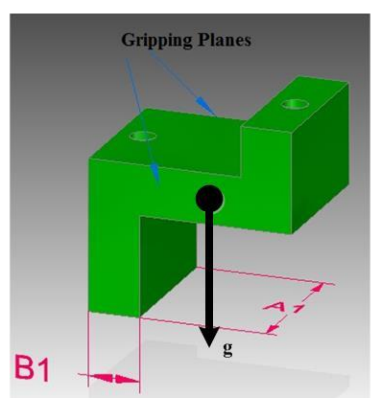

Figure 9. *Gripping and feeding features for P1*

In Figure 9, the indicated gripping planes are not included in any joining processes and they do not contain any mating entities. To determine grasping areas, center of mass for a part should be taken in to consideration in order to achieve a balance (equilibrium) and stability between the weight of the component and the forces exerted by the fingers. Feeding features for P1 are (B1, A1).

The finger domains can be used to determine the gripper fingers required to grasp a part. Different types of grippers are used in grasping process and can be defined as a *grasping skill*, such as finger, magnetic, pincer and vacuum grippers. Figure 10 illustrates the selection of the required gripper based on the determined finger domains.

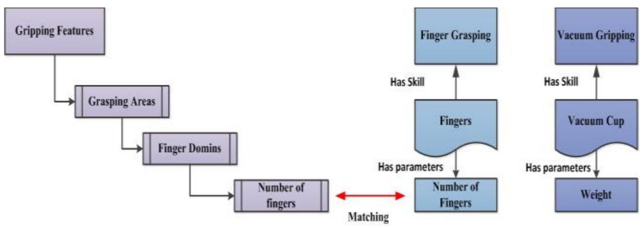

Figure 10. *Mapping grasping features to grasping skill.*

If the number of finger domains in the gripping feature matches the number of the fingers in the resource skill, this skill can be used; otherwise a new constraint (ex. weight) has to be entered by the user (Figure 2), which will be used to match a parameter (weight, grasp force) in a new skill (e.g. vacuum cup in Figure 8).

V. CONCLUSION

In this paper, an attempt to increase adaptability of assembly system based on product design aspect is introduced. For grasping operation adaptability of assembly system is a shared task between product design and assembly system. Adaptability of assembly system can be increased by using general-purpose grippers and can be accelerated by utilizing assembly features to determine grasping areas for different parts in an assembly. In the future planes, extracting gripping features from a CAD model by using programming algorithms is essential for automating the proposed procedure of determining the required fingers for a gripper. One of the suggested ways to achieve this is to use Solid edge API visual basic programming to extract and determine gripping features for an assembly.

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