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Feature modelling for assembly

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Abstract

Feature modelling is now being used quite extensively in the context of manufacturing of parts. It is shown that the use of features in product models, instead of geometric information only, can be very useful in assembly as well.

This is done by showing that the feature concept can be the link between functional modelling and detailed modelling. Conceptual functional models are transformed into detailed models with form and assembly features.

Two types of assembly features are introduced, handling and connection features, and their usability in several assembly planning modules is outlined.

1 Introduction

Feature modelling is a relatively new development in CAD/CAM. In geometric modelling only information about the shape of products is stored, whereas in feature modelling also functional information is included in the product model. This functional information may be the function for the user of some part of the object, but also the way in which some part of the object is manufactured or assembled.

Although the term feature was used with different meanings in the past, it is now more or less agreed upon that a feature is a physical part of an object being mappable to a generic shape and having functional significance. If the form plays a predominant role in a feature, it is often called a form feature. Surveys on feature modelling are given by Shah (1991) and Bronsvoort and Jansen (1993).

Until now the concept of features has been used more frequently for manufacturing processes of parts, rather than for assembly processes of parts into a product. This is somewhat surprising, because assembly is an equally important step in the production process, and features seem to be usable here just as well as in manufacturing.

An attractive way of modelling compete products is functional modelling. The main function of a product is subdivided into functions with more and more details. At the lowest level these functions can be realized using features. Features in the model represent either parts or relations between parts. The latter are represented by assembly features.

In section 2 the concept of an assembly modelling system is described. Section 3 the details about assembly features are given. Section 4 gives an overview of the usefulness of assembly features in assembly planning modules. In section 5 some conclusions are given.

2 Assembly modelling system

Nowadays most modelling systems are only used for the design of single parts. If features are used in these modelling systems, these features contain mostly design significance, and sometimes manufacturing significance.

A problem with these kind of modelling systems is that most features used in a single parts only have a functional meaning in relation with other parts. Parts are not designed on their own, but in relation with other parts, and all these parts together perform some specific high-level function.

Therefore, an ideal modelling system should provide a functional modelling environment. The designer can use this to create a functional hierarchy: at the top a conceptual functional description of the product, and lower in the hierarchy sub functions containing more details. At the lowest level, the detailed level, the sub functions are realized by detailed parts and relations between these parts. An example of a functional hierarchy is shown in figure 1.

To realize such an ideal modelling environment, there must be a functional modeller that can subdivide functions into sub functions, and there must be also modellers for the detailed parts and the relations between them. The latter modellers link abstract functions to detailed form and assembly information. The single parts can be modelled very effectively with current feature modellers. However, these modellers do not have an adequate representation for relations between the parts. There are modellers representing the relations between parts, but these do this on a very low, geometric level. We think that this shortcoming in representing assembly-specific information can be solved by extending the feature modelling concept with assembly features, as is also suggested by Shah and Rogers (1993).

In this paper the emphasis will be on the bottom side of the functional hierarchy, especially assembly feature modelling. Therefore we made a feature modeller to create models of single parts, and to represent the relations between these parts. For example, the single part, shown in figure 2

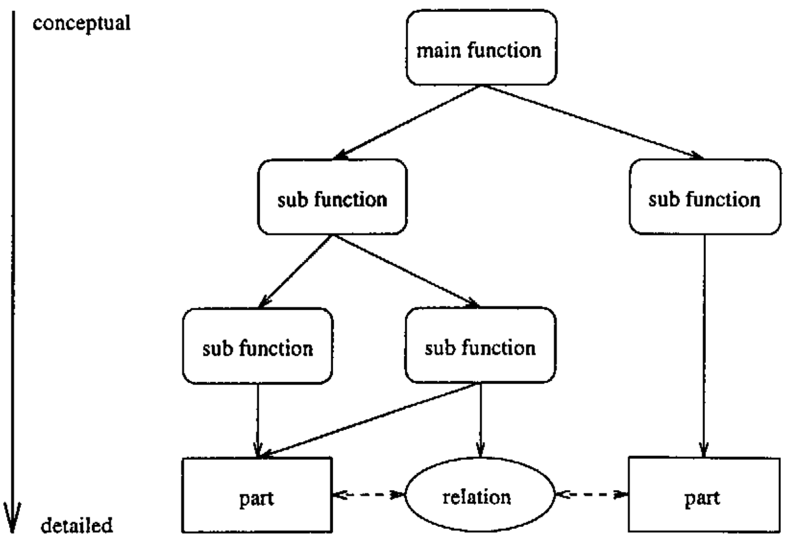

Figure 1: Functional hierarchy

is represented by a feature model given in figure 3. The part is created by combining five form feature instances: block, rib, round hole and two chamfers. The relations between these features specify the positions of the features; these relations can, for example be of type: mating, co-planar and offset.

Figure 2: A single part model

It must be possible to link form features of different part models to specific assembly information. This can be done by creating instances of assembly features. In the next section more details are given on the assembly features, but for now it is enough to know that assembly features represent relations between parts. In figure 4 an assembly feature model is given with instances of assembly features between part models; these features are shown in figure 5. Each assembly feature knows which form features of the parts are involved in the relation, and by giving some parameters the assembly feature also knows how to position the parts relatively to each other.

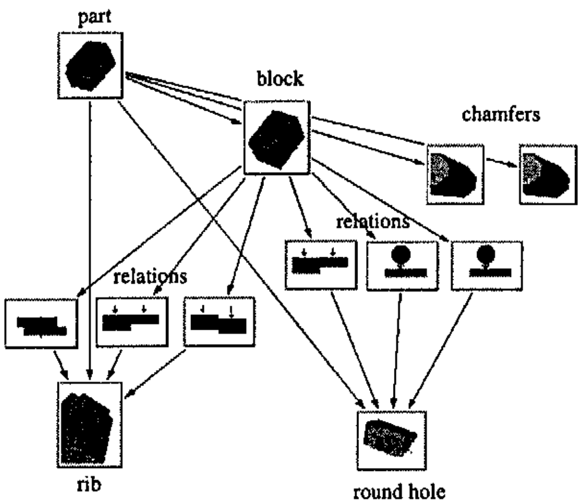

Figure 3: Feature hierarchy

Figure 4: Assembly model

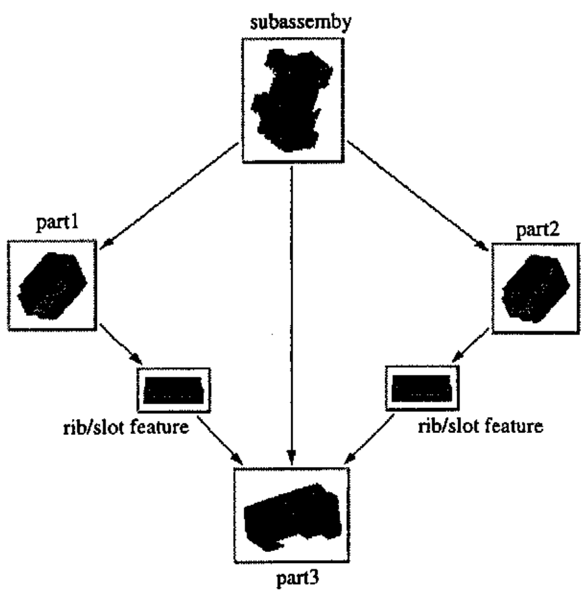

Figure 5: Assembly feature hierarchy

3 Assembly features

Shah and Rogers (1993) define an assembly feature as an association between two form features on different components. This definition can be generalized, because assembly-specific information can be an association between more than two components, or can be specific for one component only. Therefore an *assembly feature* is defined as a feature with significance for assembly processes. We distinguish two types of assembly features: handling features and connection features. *Handling features* represent assembly information specific for one component, whereas *connection features* represent assembly information for connections between components.

First some basic terminology for assembly is given, then the details about handling features and connection features are described.

Basic terminology

In literature many different definitions have been given for terms used in assembly, such as assemble, partial assembly, part, sub-assembly, component and assembly. Our definitions are mainly taken from Boneschanscher (1993).

Assemble is defined as the process of joining components to form a new unit, ie it is the action taking place when a component is joined with the components assembled already. The latter will, from now on, be denoted as the *partial assembly*. The result of the joining process is a connection between the component and the partial assembly. Components can be assembled on partial assemblies. This implies that a component is stable on its own, or can be kept stable with the use of resources. It can be grasped by a gripper or by a human hand, and placed onto the partial assembly. The smallest component is a *part*, which cannot be decomposed into smaller components, and is therefore stable on its own. A partial assembly that is stable and can be used as a component, is called a *sub-assembly*. So a *component* can be a single part or a sub-assembly. An *assembly* can either be a partial assembly, a sub-assembly or a complete product.

Handling features

To assemble a component, it is important to know where and how a gripper can grasp the component. Some areas on the component cannot be grasped, because these are error-sensitive for grasping, or easy to damage, eg thread on a bolt. Contact faces between component and partial assembly are areas that cannot be used for grasping either. These contact faces are, however, dependent on the partial assembly, and thus dependent on the assembly sequence chosen.

A handling feature is a feature containing information about the way it can be grasped independent of any partial assembly, eg specific grip areas or grippers that can be used for grasping. Besides to determine the grip faces, handling features are also used to determine which faces can be used to fix components in fixtures.

Connection features

In a product model for assembly, besides information about individual components, also information about relations between these components in the assembled product has to be stored. This information can be given in the form of a relation graph on component level, where several kinds of mating conditions between components can be distinguished, eg against, fit and screw fit; for an overview on relational models, see Libardi, Dixon and Simmons (1988) or Srikanth and Turner (1990).

For assembly planning, more information about the mating conditions between components is required than only the knowledge that components mate. The mating geometric elements must be specified in, or calculated from, the given relation graph. Sometimes, however, it is very hard to find the geometric elements being responsible for the mating conditions.

Therefore, a relation graph representing relations between components on feature level seems to be more attractive (Ambler and Popplestone 1975, Roy, Banerjee and Liu 1989, Shah and Rogers 1993). Connected features and their mutual relations are called a connection feature. Mating conditions between geometric elements can be derived more easily from these connection features than from component-level relations, whereas less relations have to be specified compared to geometric-level relations.

A subdivision is made in contacts and attachments (Sanderson and Homem de Mello 1990). *Contacts* between components reduce the degrees of freedom for relative motion. Some contacts eliminate all degrees of freedom between components; such contacts are called *attachments*. An attachment has always an *agent* that enforces the attachment. The agent can either be the attached contact or another component. Eliminating the agent will also eliminate the attachment.

The idea of connection features is that characteristics of connections can be incorporated in these features, eg insertion point, insertion path, final position, tolerances, contact faces, internal freedom of motion, attachment agent, and geometric refinements such as chamfers and rounds to ease assembly operations. The final position, or goal position, is the position and orientation of the assembled component relative to the partial assembly, after the assembly operation has been completed. The insertion point is the position and orientation relative to the final position where there is not yet contact between the assembled component and the partial assembly, and where the insertion operation is started. The insertion path is the trajectory from the insertion point to the final position. Tolerances and contact faces between assembled component and partial assembly give clues for calculation of the internal freedom of motion, ie the set of motions that can separate the component and the partial assembly.

As in many other features, also in connection features a distinction can be made between elementary and compound features. Compound connection features can be subdivided into simpler compound features or elementary features. The basic connection feature is the plain mating connection, see figure 6. By combining such basic connection features, almost every connection feature can be described. For example, a rectangular slot, a V-shaped slot and a dove-tail relation are all a combination of three plain mating connections, and even a pen-hole relation can be described by a number of plain mating connection features.

Although most connection features can be described as a combination of plain mating connection features, and therefore as a compound connection feature, it is better to have a predefined set of common connection features; some examples are given in figure 6.

A connection feature can contain relations, or constraints, similar to those used in design and manufacturing features. Placing a slot on a block involves defining mate, co-planar and offset constraints between slot and block. Such constraints can also be used when a connection feature is defined between components.

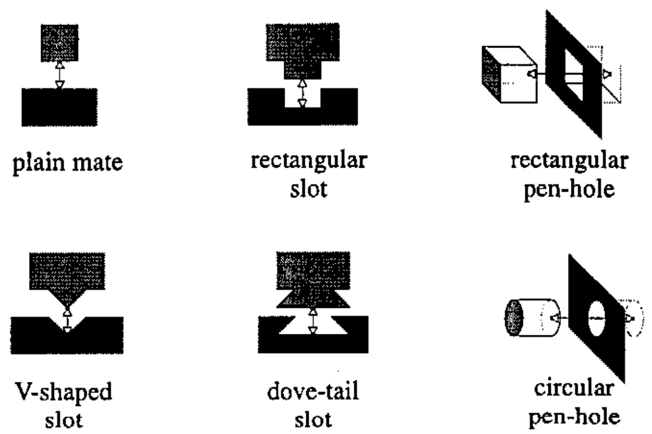

Figure 6: Examples of connection features

Connection features can also point to one or more agents if the feature is representing an attachment, eg a bolt-nut feature attaching two plates. This connection feature has as agents bolt and nut, and removing either of them will eliminate the attachment, assuming that there is no thread in one of the plates. As already mentioned, a characteristic of these attachments is that all internal freedom of motion between the components involved in the attachment is eliminated. Some elementary attachment connection features are shown in figure 7. Of course these features can be combined with other connection features to get more sophisticated features. Two examples of compound connection features are given in figure 8: the combined feature is a combination of two rectangular slot connection features and one plain mate connection feature, the other is a pattern of bolt connection features to fasten a plate on a box.

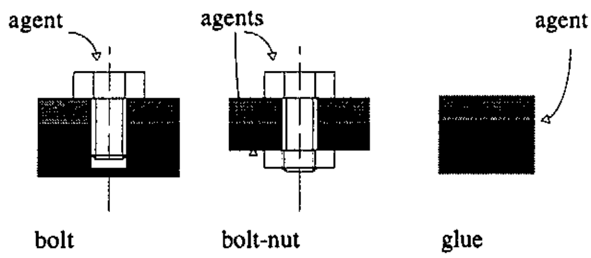

Figure 7: Elementary attachment connection features

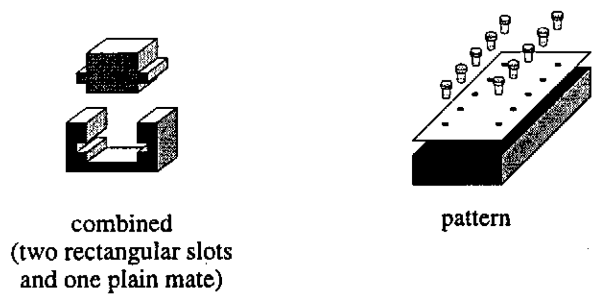

Figure 8: Examples of compound connection features

4 Assembly planning using features

In the previous section several examples of assembly features have been given. Assembly planning consists of determining how a product can be assembled. This requires modules for stability analysis, motion planning, grasp planning and assembly sequence planning. An overview of the usefulness of assembly features in these planning modules is given.

Stability analysis

In assembly planning, very often stability checking or analysis must be performed. For example, the product must be decomposed into stable sub-assemblies, components must be assembled on stable partial assemblies, and therefore assemblies must be checked for stability. According to Boneschanscher (1993), three types of stability can be distinguished, depending on the forces considered: gravitational stability (only gravitational force), assembly stability (forces caused by the joining process) and motion stability (forces caused by acceleration during motion).

Assembly features can be very useful for stability analysis when it has to be determined which components can move relative to each other. The traditional relation graphs on part level can give some information, but the internal freedom of motion of a specific component relative to other components can hardly be found from these. A connection feature can give far more information on this. Each connection feature contains the internal freedom of motion between the mutually connected components. Combining the internal freedom of motions of the connection features of a component, gives information on the resulting internal freedom of motion for that component relative to other components. If an attachment is involved with a connection, then no internal freedom of motion is left after the attaching agent has been assembled. Because the internal freedom of motion is known for every connection feature, it is no longer necessary to calculate it from the geometry of the components, which makes stability analysis simpler and faster.

Analysing stability using internal freedom of motion gives only solutions for translational instability, and not for rotational instability.

See van Holland and Bronsvoort (1995) for more details on internal freedom of motion, and how it can be represented with visibility maps.

Motion planning

In motion planning, a path is searched to move a component from its feed position to its final position on the partial assembly. Motion planning can be subdivided into gross and fine motion planning.

During gross motion planning, a collision-free path for the assembled component from its feed position to the insertion point is searched. Because connection information is not used here, the assembly feature concept can hardly be exploited. Only the position and orientation where the gross motion must stop, and change to fine motion, can be gathered from the connection feature.

Fine motions, however, can hardly be planned without assembly features. In fine motion planning, the final stage of assembling a component onto a partial assembly is planned. Component and partial assembly are very close to each other, or even make contact. All kinds of subtle movements, including compliant movements, must be executed to make the connection. For example, for assembling a round pen-hole connection other fine motion strategies are needed than for assembling a square pen-hole connection. Associating predefined fine-motion-strategy information with a connection feature can result in better strategies and in a reduction of planning time.

Grasp planning

Grasp planning is done to determine the areas on components where grippers can grasp. Here both handling features and connection features can be used. Most of the time a designer knows where not to grasp a component, but cannot store this information in a geometric model. Handling features can be used to store information about the areas of a component where it cannot, or, alternatively, where it can be grasped. The position of the component in the partial assembly is not taken into account here.

Connection features can give additional information on areas where not to grasp, because of involvement of the areas in a connection.

By combining information derived from the handling features and the connection features, the areas where the component can eventually be grasped can be determined. The handling features can give additional information on how to grasp the component, eg which gripper can be used and which forces the gripper should apply on the component.

Sequence planning

Assembly sequence planning computes possible assembly sequences to assemble a sub-assembly or a product. It is mostly done by searching disassembly sequences, and then reversing these sequences to get assembly sequences.

Finding a candidate component for disassembly, requires that the remaining partial assembly and the component that is taken away must be stable, that there is a disassembly motion direction, that there is a motion plan for the component, and that the component can be grasped. Dissatisfaction of one of these requirements means that the candidate component cannot be disassembled yet. The previously mentioned planning modules can be used to check some of the requirements.

The internal freedom of motion stored with the connection features can directly give possible disassembly directions.

However, more information for sequence planning can be made available using assembly features. Some connection features have a predefined assembly sequence, for example a bolt-nut attachment attaching two plates: the plates must be assembled before the bolt, and the nut must be assembled after the bolt. In several connection features, in particular attachments, such predefined assembly sequences can be incorporated.

Altogether, this means that using assembly features can result in a reduction of sequence planning time and in more effective sequences.

5 Conclusions

The assembly feature concept can be used to link a conceptual functional model to its detailed model. Two types of assembly features have been given: handling and connection features. Handling features contain assembly specific information concerning one component, whereas connection features contain assembly specific information concernig relations between components.

It has also been shown that the use of features can significantly improve assembly planning. More specifically, the extra information, besides geometric information, stored in handling and connection features, can profitably be used in stability analysis, motion planning, grasp planning and sequence planning.

References

Ambler, A. P. and Popplestone, R. J. (1975), 'Inferring the positions of bodies from specified spatial relationships', *Artificial Intelligence* **6**, 157–174.

Boneschanscher, N. (1993), Plan Generation for Flexible Assembly Systems, PhD thesis, Delft University of Technology, The Netherlands.

Bronsvoort, W. F. and Jansen, F. W. (1993), 'Feature modelling and conversion - Key concepts to concurrent engineering', *Computers in Industry* **21**(1), 61–86.

Libardi, E. C. J. , Dixon, J. R. and Simmons, M. K. (1988), 'Computer environments for the design of mechanical assemblies: A research review', *Engineering with Computers* **3**, 121–136.

Roy, U. , Banerjee, P. and Liu, C. R. (1989), 'Design of an automated assembly environment', *Computer-Aided Design* **21**(9), 561–569.

Sanderson, A. C. and Homem de Mello, L. S. (1990), Automatic generation of mechanical assembly sequences, *in* M. J. Wozny, J. U. Turner and K. Preiss, eds, 'Geometric Modeling for Product Engineering', Elsevier Science Publishers B.V., Amsterdam, pp. 461–482.

Shah, J. J. (1991), 'Assessment of features technology', *Computer-Aided Design* **23**(5), 331–343.

Shah, J. J. and Rogers, M. T. (1993), 'Assembly modeling as an extension of feature-based design', *Research in Engineering Design* **5**(3 & 4), 218–237.

Srikanth, S. and Turner, J. U. (1990), 'Towards a unified representation of mechanical assemblies', *Engineering with Computers* **6**, 103–112.

van Holland, W. and Bronsvoort, W. F. (1995), Assembly features and visibility maps, *in* '1995 ASME International Computers in Engineering Design', Boston, to be published.