An Integrated Approach to Model Driven Control of Robots at Placing for Assembly

László Horváth*, Imre J. Rudas**

John von Neumann Faculty of Informatics, Budapest Tech Polytechnical
Institution, Bécsi út 96/B, H-1034 Budapest, Hungary
*horvath.laszlo@nik.bmf.hu
**rudas@bmf.hu

Abstract: Modeling of products is undergone a final stage of integration in these years. In this paper, the authors discuss an integrated modeling method for robot assembly of products as a contribution to methodology for integrated robot model systems. Advanced product modeling uses feature and associativity definitions for description of engineering related objects in part models instead of simple geometric elements. For the purpose of homogenous model definition, the authors propose replacing the conventional way of geometry based assembly path definition by form feature driven definition of paths. The proposed method is based on an integrated and homogenous model consisting of part and assembly models of assembled product and assembly robot as well as robot process model. Two contributions of the authors to integrated definition of the related models are an extension of the feature principle and definition of associativities between shape and process feature entities. They propose extension of the feature principle of part models to task oriented robot process model and model of robot. An enhanced and integrated modeling offers solution especially for the assembly of custom demanded products variants. In this paper, conventional and feature based approaches are compared. Following this, feature definitions for modeling of task oriented robot process are proposed. Finally, application of associative form features in integrated robot model is detailed, explained, and concluded.

Keywords: product modeling, model of robot assembly, feature based robot process, integration of assembly and robot process models, shape modeling by form features.

1 Introduction

Essential methods of engineering changed from conventional drawing and separate modeling of objects to integrated modeling of product. Product related information is handled in comprehensive wide area system. One of the challenges in the application of robots is integration of robot system into product model system. Vast amount of shape information for numerous variants and modifications of the same product is to be communicated with the robot system. Variants of the same product are often defined using several different parts in the same assembly structure. Custom tailored product needs quick change of product. Flexible assembly system with the ability of quick change of product is demanded. This is why wide application of robot based assembly systems are forecasted for he next years.

Automation of assembly by robots needs flexible and integrated product and assembly design. Fortunately, concept of product data management offers methods for handling product variants in connection with computer models of product structures and parts. Advanced part and assembly modeling handles product variants and modifications. Robot systems can accept part and assembly model information if communication amongst part design, assembly design, robot process planning and robot control is well established. Communication between existing engineering oriented shape aspect driven part and assembly design and geometry driven robot control does not support integrated process and data flow from the part design to the movements for placing parts. Valuable research results in the field of product modeling and robot control do not offer overall answer to this problem. This is why the authors analyzed the integration aspect of modeling and discuss some of their contributions in this paper. They intended to avoid complicated methods that proved to be difficult to implement in modeling of the engineering practice.

Related works deal mainly with issues in separated important problem complexes of description of shapes and trajectories in robot work space as strategies of assembly, disassembly and assembly path planning. In [1], a comprehensive environment is discussed for definition of assembly. Solid models are used at feature recognition. In [2], an approach is applied to generate a graph of collision free paths, in which the nodes are the milestones and the edges the simple paths. Several methods for optimal definition of robot trajectories suppose modeling and analysis of the shape system [3]. Other aspect is computer model driven adaptive control of robot [4]. Task oriented robot programming was an important step towards extended application of robots in factory automation [5]. A general purpose, application specific and reference model based standard modeling of products and other engineering objects is available in STEP, ISO 13303 [7]. The form feature information model in the STEP makes it possible for the authors to extend the feature principle to an entire integrated robot assembly environment. Considering the above listed results, the goal of the reported research was to establish an approach and method for a new integration of product modeling and robot planning environments using predefined and robot assembly oriented form and process features.

The authors analyzed modeling methods in advanced CAD/CAM systems and concluded that there are successful efforts for integration part and assembly modeling. However, these modeling systems are not capable of creating shape information for definition of robot assembly process. An additional problem is improper integration of product, robot structure and robot process modeling.

The authors considered task oriented and feature based product model driven path definition for robots. Conventional computer aided calculation of robot trajectories is complicated and time-consuming because complex geometric information is to be processed extracted by interactive selection of geometric entities. Definition and modification of the above outlined environment can be done only by handling functional shape elements instead of geometric elements in part models. This principle has been extended to the robot model by the authors. Geometry of parts in product and robot is described in the form of interrelated and application oriented sets of features.

As a preliminary of the reported research, the authors analyzed the possible methods for feature-based integration of part and part manufacturing process models [8]. They also proposed robot process model entities of which are related to entities defined in models of the handled parts [9]. In this paper, they report the third step of this research towards an extension of modeling into robot assembly process. The feature driven approach inherently offers utilization of results of an earlier research by the authors in modeling of design intent [10]. In this paper, conventional and feature based approaches are compared. Following this, feature definitions for modeling of task oriented robot process are proposed. Finally, application of associative form features in integrated robot model is detailed, explained, and concluded.

2 Conventional and Feature Based Approaches

One of emerging robot applications is placing parts for various purposes including robot assembly. However, robot assembly has not been integrated with the prevailing form feature based part modeling. Parts or subassemblies to be assembled are considered as handled objects. Description of part geometry is applied as source of shape information for definition of gripping, target position and path and for analysis of collisions directly (Fig. 1). Robot is modeled by its geometry and kinematics separately. This approach supports only communication of geometry between part modeling and robot programming, engineers are forced to use geometric model entities instead of engineer defined entities.

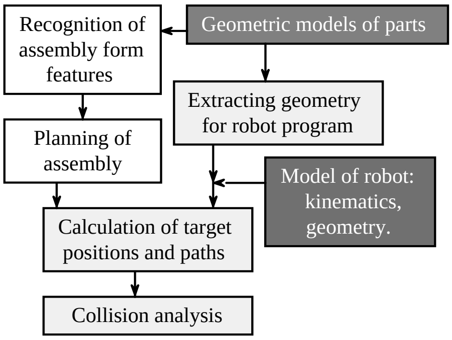

Figure 1

The present approach to robot programming

The authors propose a solution for robot programming by including new features for robot process model. These features are associative with shape models, robot oriented application features for all parts in the system, and assembly associativity definitions between pairs of form features in the workspace of the robot (Fig. 2). Models of parts of the product to be assembled and parts of the robot system affecting part placing operations *MP1-MPn* are described as sequences of shape modifications represented by topology and geometry. For the definition of form features for robot assembly, the sequence of shape modification for design of the part is reordered then shape modifications are integrated or detached. Form features that do not affect robot process are suppressed. Engineers work with attributed, robot process related shape objects while geometric model representation is available for geometric calculations. Form features defined in part models are interconnected by assembly associativity features defined in assembly model. Assembly model is a generic one and it makes description of assembly variants possible. A homogenous, feature driven and application oriented modeling has been established for the whole system.

The shape is only one of the essential aspects in robot assembly. Other aspects such as modeling of dynamics, collaboration of robots are in close connection with the shape aspect. This paper focuses to the shape aspect. Integrated analysis of shape and other aspects constitutes future work of the authors. Other plan of future development in the presented modeling is application of environment adaptive active model entities of mechanical parts to improve application of part models in the robot assembly system.

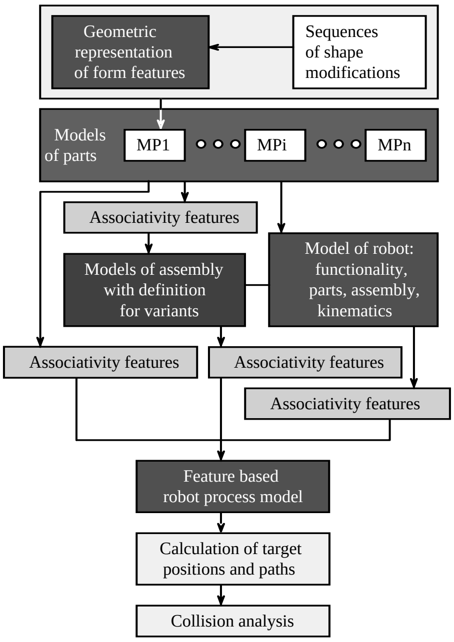

Figure 2
The proposed integrated model

3 Features for Modeling of Robot Process

Robot process defines optimal trajectories for robot control taking into account obstacles constituted by parts existing in the actual stage of assembly process and by moving and fixed volumes in the structure of robot. Robot assembly consists of a sequence of part placing. Robot, similarly to any other a mechanisms, is modeled as sets of part, assembly and kinematics entities. Simulation using this model answers actual positions of shapes in all positions of the joints defined in robot kinematics [6]. Several joint movements compose movement of a gripper. This gives relationship between joint and assembled part movements in order to reach the target position of the part predefined for the assembly under construction.

During its placing, a part is picked then moved into a target position in relation to other parts in the assembly along a trajectory. Trajectory is defined as the collision free shortest route. Fig 3 explains model entities and their relationships as they were considered by the authors using virtual world in recent advanced modeling systems. In Fig. 3, *Part B* is placed in *Part A* by using of relationships defined between form features of the related parts in the assembly model. Representation of form features uses topology for the purpose of definition of place of curves and surfaces in the structure of boundary representation. Topological faces and edges are used at the definition of assembly relationships between geometric elements mapped to them. Sometimes form features defined on a part do not contain all the geometric elements necessary to part placing. In these cases, additional reference elements as an axis are to be defined for the purpose of assembly relationship definitions.

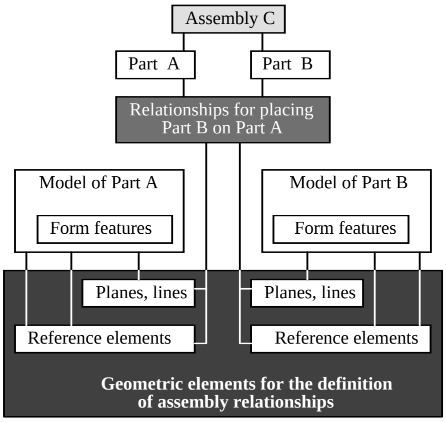

Figure 3

Information for assembly robot control in assembly model

Computer description of multi-layered robot process model structure and its associativities with product model features have been proposed by the authors (Fig. 4) for the purpose of its integrated application with product and robot models. Task, operation, action and reflex robot process features have been defined and placed in different layers of the model. Robot task feature defines manipulation of different objects together with the strategy of manipulation. Operation feature is related to manipulation of a single object and consists of independently executed actions. An operation feature describes picking of a part and placing it in the assembly. Action features are positioning and orientation of parts, moving parts along paths and placing them in contact with other parts. Task, operation and action features use geometric information both from manipulated and manipulating objects for the recognition of type and shape of objects, programming grippers, calculation targets and trajectories and analysis of collision.

Task level requires general information about the assembly to be produced. Robot with gripper or grippers is assigned or selected for the task. Part type and shape characteristics are extracted from part models. Fig. 5 illustrates a task for an assembly of three parts. Robot must have appropriate workspace to accommodate the assembly and moving grippers with parts. Operation definition uses general shape information about the part to be manipulated. Action is created using detailed part geometry information for the definition of gripping, target and movements.

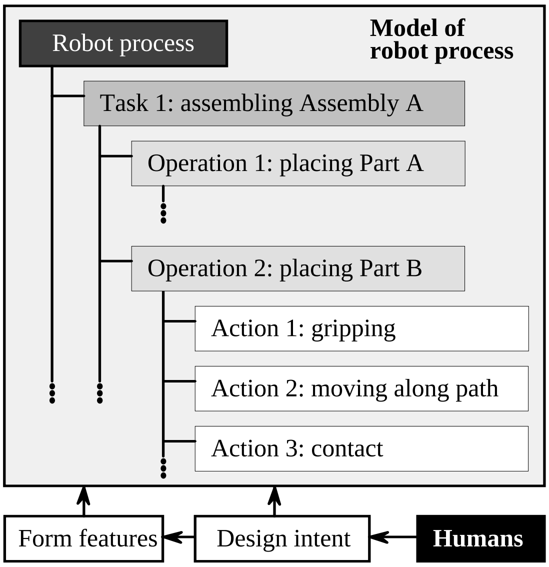

Figure 4
Robot process model features

Besides shape information, robot process features are also based on design intent for the process itself. From the point of view of shape centered product modeling, design intent in the robot process represents non-geometric considerations about robot assembly process. At the same time, shape model entities in product and robot models are also relied on design intent. Consequently, decisions of the robot engineers on robot processes are restricted by design engineers. Design intent is communicated to robot engineers by product model. Authors proposed a method for mapping intent model entities to geometric model entities [3].

Conventional path planning defines then simulates trajectories. The authors also considered robot assembly by real time trajectory generation as a more appropriate method for assembly of recent products under frequent changes. As a next step towards intelligent robotics, autonomous robot processes have own visual data about the environment around their path. Reflex, an additional robot process feature has been involved in the robot process model for the purpose of real time creation of robot processes. Function of the reflex is direct transformation of current sensor data into motion where it applies. However, most of robot assembly processes can be generated using stored geometric information and real time trajectory generation is not necessary because predetermined environments do not change during the work of the robot.

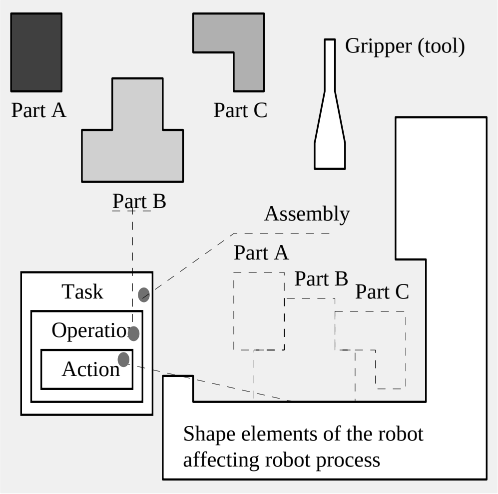

Figure 5

Shape information for robot assembly process

4 Associative Form Features in Integrated Robot Model

Problematic of feature driven robot assembly has been divided into sub-problems by the authors. Solutions for sub-problems rely upon answers to following questions, respectively.

- How robot assembly oriented form features are defined for the product to be assembled and for the robot selected together with grippers and fixtures for assembly.
- How form features on parts to be assembled are related at definition of assembly relationships.
- How form feature information is accessed and related at definition and collision analysis of robot trajectories.

A form feature is considered as a shape aspect that modifies a previous shape to achieve a new shape. Form features are defined for different aspects. One of the aspects is robot assembly. The authors considered application of the three leveled form feature definition of STEP (ISO 10303) [7]. This international standard acts among others as a basis of present form feature driven modeling and defines form features in the levels of application features, form features and form feature representations.

Fig. 6 shows a sequence of shape modifications at construction of the *Part A*. This part is in the central position of the assembly. Shape modification starts from the basic feature *BF*. Form features *FF1*, *FF2* and *FF3* modify *Part A* according to their function at placing *Part B*, *Part C* and *Part D*, respectively. Parts are also to be placed in the direction perpendicular to the plane of the sketch. Flat surfaces on *FF1*, *FF2* and *FF3* constitute *Part A* sides of relationship definition pairs. Other sides are on the mating parts. Form feature *FF4* is for assembly of additional parts. The above outlined information in the assembly model is well appropriate for the purpose of robot assembly process definition.

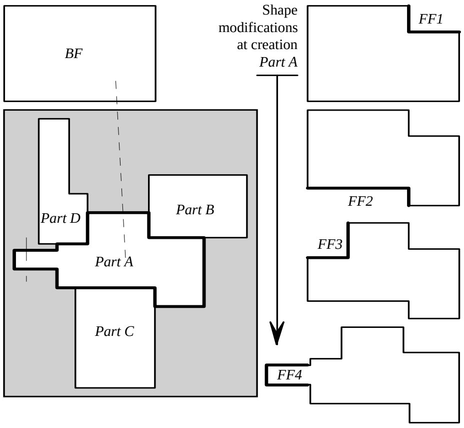

Figure 6

Assembly relationship driven definition of form features in parts

Shape modification defines new entities in the topology and geometry of the part. Consequently, geometric elements for relationship definitions can be identified then extracted easily based on shape modification. Fig. 7 illustrates the relationships by a simple example. Shape modification by form feature *FF1* is a volume subtracting one in the form of a depression. Shape modification results faces *F1* and *F2* and edge *E1*. The new topological entities are added to the previous topology together with other topological edges for loops enclosing faces. Flat surfaces mapped to faces *F1* and *F2* and the line mapped to *E1* are used as reference geometry for the purpose of assembly relationship definitions *R1*, *R2* and *R3*.

Robot assembly process is defined then simulated using form features defined on the parts of product to be assembled and on some parts in the related structural elements of the robot system. These form features affect the robot process as gripped or placed surfaces, reference elements for gripping or placing, moving volumes and obstacle volumes. Form features are selected or defined on the objects involved in the integrated environment of robot assembly. These objects are grippers, parts to be placed in the assembly, placed parts in the semi finished assembly and shape units of the robot system (Fig. 8). Robot process model features relate form features defined on product and robot parts.

Fig. 9 illustrates form feature driven definition of integrated robot assembly model by an example. Fig. 9 explains the situation using a section of the complex mechanical system so that placing in the direction perpendicular to the section is omitted. Definition of part placing is driven by relationships *R1*, *R2* and *R3* in the assembly model for the product. The aim of the operation robot process feature is placing *Part 3*.

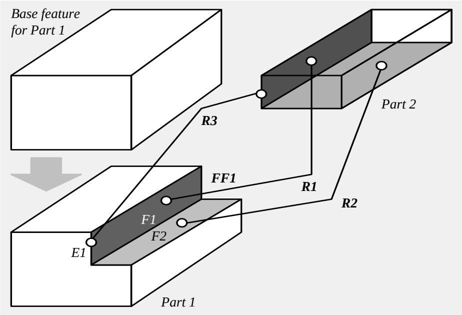

Figure 7

Volume subtracting form feature for the purpose of assembly *Part 2*

Assembly relationships are defined by using of form features *FF1 – FF6*. Other form features affecting the trajectory for placing *Part 3* are *FF8* on the *Part 4*, *FF9* and *FF10* on the gripper and *FF7* on a structural element of the robot.

The complex model system is considered as an integrated product information model and can be implemented using resources, methods and application protocols in the STEP of ISO. Open surface of existing modeling system can be applied for the purpose of the related modeling program development. Existing features can be accessed, new features can be defined by using of existing procedures and new procedures can be written and related to existing procedures and features. Definition of generic and instance assembly process features and their analysis in a pilot modeling system constitute the main research by the authors in the next future.

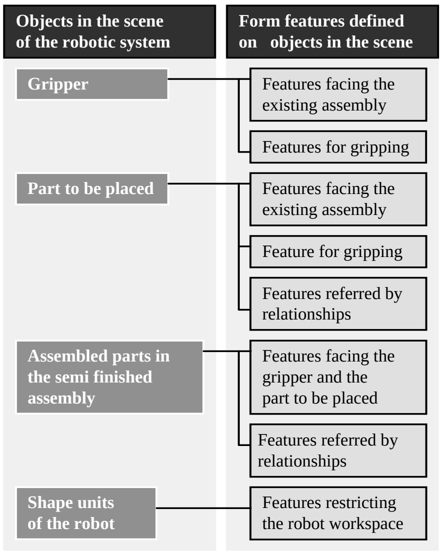

Figure 8

Form features in the integrated robot assembly environment

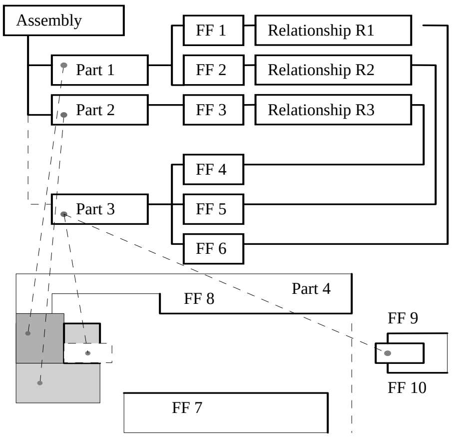

Figure 9

Geometry handled by creation of an operation robot assembly process feature

Conclusions

The paper introduced a modeling for the purpose of integration of robot model system into product model system. One of the objectives is placing parts in products developed in the form of high number of custom variants. The proposed integrated model is capable for all representations needed to create robot movements by using of feature based part, assembly and robot process information stored in advanced product models together with other product information. Feature entities are integrated by associativities. One of the contributions by the authors is an extension of the feature driven approach to robot process and robot system. The proposed method of the robot assembly oriented assembly modeling can do with arbitrary number of product variants and modifications in a single model system. Assembly specific form features in part models are different from those defined at normal part design. As other contribution by the authors, feature based, task oriented robot process model has been integrated in the shape model environment. Design intent is involved in the integrated model through part and assembly models and robot assembly process model. Boundary geometric model representations of form features provides full geometry for robot trajectory definition and simulation.

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