Process Based Associative Configuration of Robot System with Extended Sets of Features

László Horváth
John von Neumann Faculty of Informatics
Budapest Tech
Polytechnical Institute
Népszínház u. 8,
H-1081 Budapest, Hungary
horvath.laszlo@nik.bmf.hu

Imre. J. Rudas
John von Neumann Faculty of Informatics
Budapest Tech
Polytechnical Institute
Népszínház u. 8, H-1081 Budapest
H-1081 Budapest, Hungary
rudas@bmf.hu

Spyros G. Tzafestas
Institute of Communication and Computer Systems
National Technical University of Athens
Zografou Campus
Zografou 157 73, Greece
tzafesta@softlab.ntua.gr

***Abstract* - Integrated modeling of robot process is analyzed and a new approach is proposed in this paper. Similarly to other integration efforts in modeling of products and production, associativity definition based integration of assembly and robot assembly process feature models is proposed. Full feature driven shape modeling ensures definition of model entities for objects defined by product design and robot manufacturing engineers. The ultimate aim is an alternative modeling technology to the conventional geometry based programming of robots. The present prevailing boundary represented form feature definition of part shape in models is integrated with robot assembly process model features. Relationship based integration of part models in assembly model is extended to robot assembly configuration relationships. Robot assembly process features are related to relationship features. This paper introduces an integrated product model based approach to robot process modeling and programming. An integrated modeling is outlined for robot applications, where shape aspects defined for parts are configured and related to achieve the required model. Following this, modeling of part placing in an unified representation environment of form features is explained. Finally, the solution for integration of model of task oriented robot process by the authors is introduced and discussed.**

I. INTRODUCTION

The conventional control of robots can not utilize engineering related information described by advanced application oriented product models. Instead, elementary geometric information is necessary for the definition of trajectories. On the other hand, engineering related definition of the shapes involved in the robot process can not be used directly for the purpose of geometric oriented path planning of robots. The only way is application of engineering related model description to produce geometric information for path planning. The main content of the related research of the authors is integration of the related shape and robot process model descriptions in order to achieve geometric information for path planning and, at the same time, to make decisions on the level of engineering related model entity definitions.

Related works deal mainly with issues in separated important problem complexes of description of shapes and trajectories in robot work space, 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.

The authors analyzed the conventional computer aided manufacturing methods applied in control of assembly robots. They proposed form feature based shape modeling method to replace geometry-based definition of robot trajectories in [3]. They also proposed a four leveled robot process model and adapted it to specific applications in robot assembly [4]. During other earlier works, the authors defined application-oriented groups of form features for integrated robot systems in [5], [6].

Form feature driven modeling of the robot system is based on robot assembly process oriented shape aspect definitions. A shape aspect, called as form feature, is application oriented building element of shape. The application in this case is modeling of parts both for the product to be assembled and the robot applied for the assembly. This paper focuses on relating models in the whole robot assembly system including product and robot assemblies.

The proposed modeling covers a possible solution for the problem of advanced product model driven control of industrial assembly robots. Comprehensive solution of this problem have not offered by the numerous excellent researches in related topics as robot navigation, adaptive tracking, autonomous features of robots and behavior of robots. New problems are emerged and solved by application of connected robot arms [7]. Behavior based modeling, especially in the case of motion coordination, can be realized by using of the control approach discussed in [8]. Complex navigation and obstacle avoidance models can be realized by using of neural networks as in [9]. Finally, product models can be completed by model application purposed knowledge in the form of associativity definitions. These models offer the possibility of integration with results of researches as the above mentioned ones.

This paper introduces an integrated model based approach to robot process modeling and programming. An integrated modeling is outlined for robot applications, where shape aspects defined for parts are configured and related to achieve the required model. Following this, modeling of part placing in an unified representation environment of form features is explained. Finally the solution for integration of model of task oriented robot process by the authors is introduced and discussed.

II. INTEGRATED SHAPE ASPECTS FOR MODELING OF ROBOT APPLICATIONS

Planning of robot process by using of models from CAD/CAM is a new objective of model integration. The problem was analyzed by the authors and they considered application of form features for engineering realted description of parts and subassemblies to be assembled in a robot system. Both handling and handled engineering objects are proposed to describe in an extended form feautre driven modeling. 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.

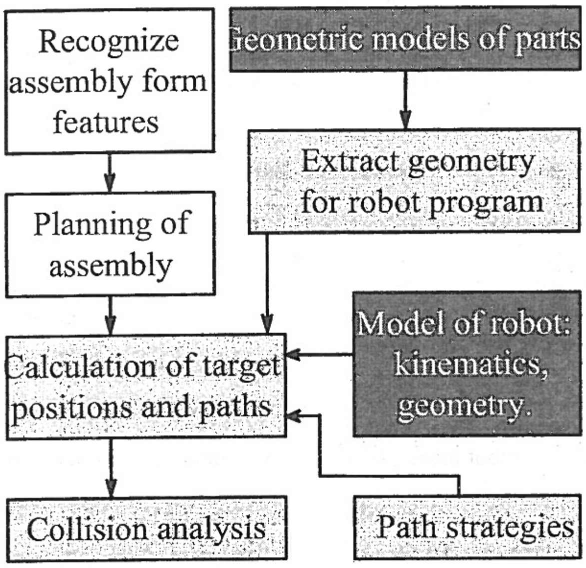

Fig. 1 Conventional robot programming

The authors made an attempt to solve problems in robot programming outlined in Fig. 1 by including new elements in the modeling. These elements are feature based robot process model 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.

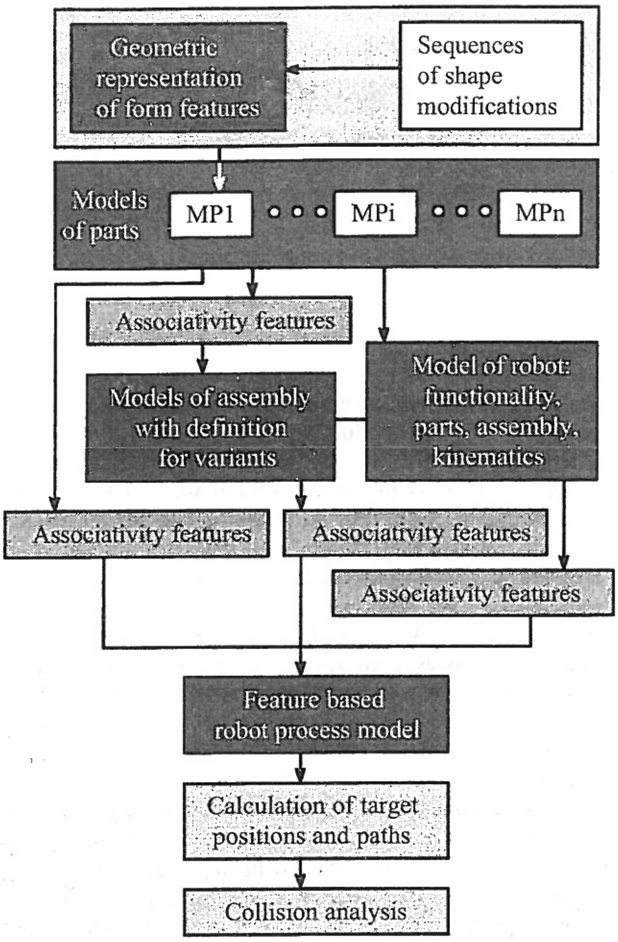

Fig. 2 Integration of robot model system

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 plan 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.

The proposed integrated model organizes computer description of all the involved shape and process objects. Engineering related definitions of these objects are application oriented features. Application refers for application of the model. Fig. 3 outlines the integrated model. At a stage of assembly a part is being placed. Other parts are in the semi finished assembly or are waiting for placement. Several parts of the robot are in fixed or changing positions in the workspace of the robot. Parts are described by shape definitions. The assembly task is defined by robot assembly process. Shape and process definitions are connected by relationship definitions. This approach is compatible with present day engineering modeling so product models created by advanced CAD/CAM systems can be applied or related.

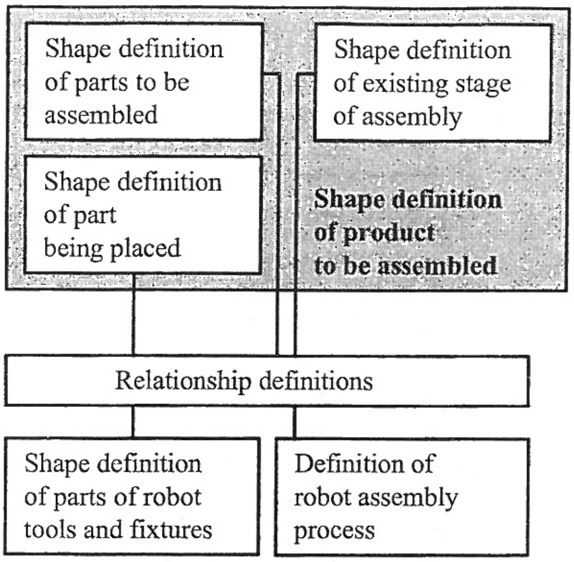

Fig. 3. Shape anf process definitions for robot assembly

The basic concept of modeling is outlined in Fig. 4. All parts in the robot system are defined using form features. Form feature model consists of application, shape aspect and boundary geometric model representation related entities. Different form features on different parts are related by assembly relationships in the assembly model of the product to be assembled. In an earlier work the authors extended the form feature concept to the entire robot assembly system [5]. Similarly, in this paper they propose an extension of the relationship definition concept to the entire robot assembly system by the introduction of robot process configuration relationships.

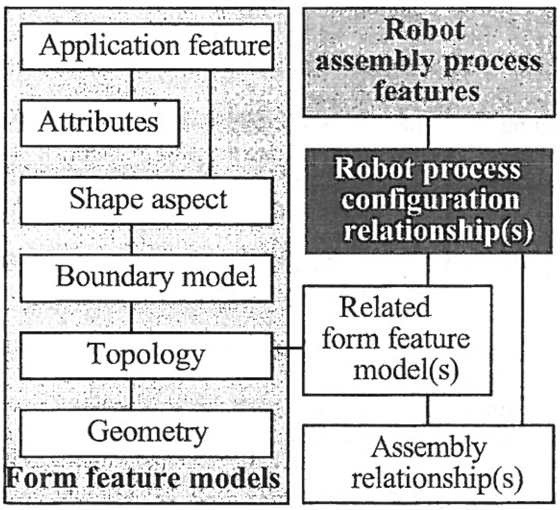

Fig. 4. Relateing shape model entities

While assembly relationship definitions relate form features of different parts in the product to be assembled, robot process configuration relationships relate form features in the entire robot system in close connection with assembly relationships. However, parts of the robot system are related for the purpose of cooperation in the working space of the assembly robot. This requires special form feature definitions.

Robot assembly process defines placing of parts in a sequence. Different sequences can be evaluated from the point of view feasibility and optimal trajectories. Possible sequences can be defined by using of different methods. Assembly model can be used for definition of a disassembly sequence. In this case assembly can be started with the part remained at the end of disassembly. Other method relies on precedence rules. Sequencing is not a topic of this paper.

III. MODELING OF PART PLACING

Parts are related in a robot assembly model by using relationship definitions. These define placing of parts of the product and relationships of parts required in the robot assembly space. The latter ones are in connection with the configuration of the robot assembly system. This is why they are called as robot configuration relationships.

Conventional assembly models in the present every day modeling systems use separated geometric definitions. The method proposed by the authors defines relationship features on three levels. Similarly to form feature, a first level of a relationship feature definition refers to its application. The second level is the level of the feature while the third one is the level of the geometry.

Fig 5 explains assembly relationships defined for a product to be assembled. These features relate purposeful features on parts to be placed. Geometric representations are mapped to form features. Similarly, geometric relationships are mapped to relationship features.

Geometric representation of a form feature consists of topology and geometry. A geometric relationship relates surfaces or lines by their coincidence, contact, distance or angle. In the example of Fig 5 *Placing of a prism* application relationship feature is defined on the *level 1*. In fig. 5 three contact geometric relationships are mapped to the relationship feature *C1*. Relationship feature *C1* is defined between form features *FF1* and *FF2*. Geometric relationships *C11*, *C12* and *C13* are defined between pairs of flat surfaces. Description of these surfaces can be accessed following the topology structure in the boundary representations.

Face *F1* on the Fig. 5 is connected to the topological structure of the form feature *FF1* and to the total structure of the part by closed loop of topological edges *E1*, *E2*, *E3* and *E4*.

Similarly to the product assembly relationship feature definition, robot process configuration relationship is defined on three levels (Fig. 6). On the *level 1*, robot configuration relationship application feature *ACF1* is defined for application, similarly to product assembly relationship feature. Its type *is Part and assembly of product.* It defines relationship between part being placed and a part in the existing stage of the assembly unit. A part in an assembly of a product can be defined as a group of assembled part if individual parts do not affect robot assembly. However, because geometry is mapped to form features on parts, a complex part should be mapped to the individual parts composing it. A single relationship in the case of example on Fig. 4 is defined on the level of form features as robot configuration relationship feature *RCF1* on the *level 2*. It describes the constraint of *contact is not* *allowed* between a pairs of form features *FF3* and *FF4*. flat surfaces.

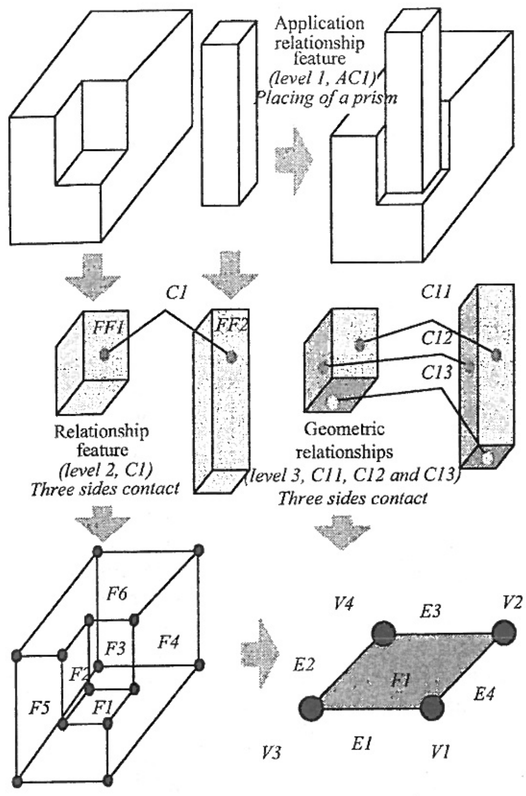

Fig. 5. Placing parts using features

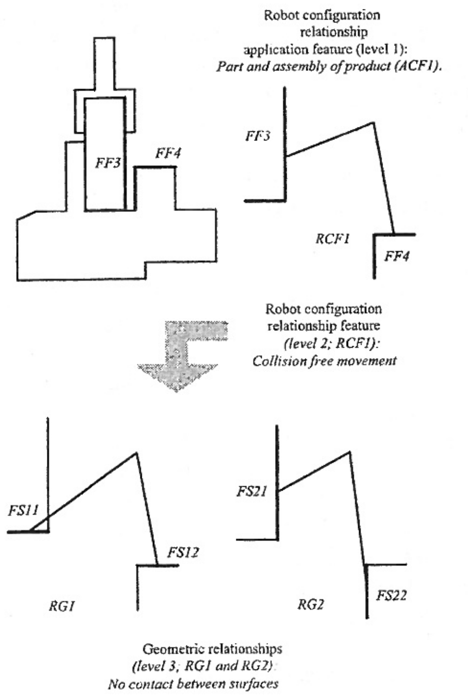

Fig. 6. Robot process configuration relationship

On the level 3, geometric relationships RG1 and RG2 relates two pairs of flat surfaces (*FS11* and *FS12*, *FS21* and *FS22*). The necessary calculations are done using topological definitions in the related boundary representations. The relationships connect the proper elements in the topologies of the two parts then geometry is revealed by their mappings to the related topological entities. This method constitutes the main essence of the proposed integration in shape modeling.

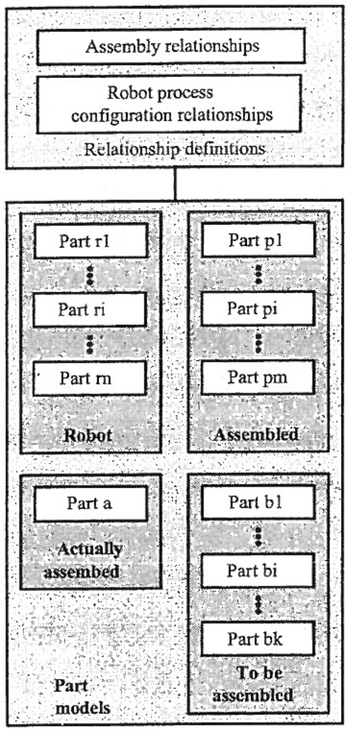

Fig. 7. Integrated relationship definitions

Relationship definitions are considered as features. Consequently, a homogenous feature driven modeling is achieved that ensures harmony of engineering, shape definition and geometric calculations. For the purpose of description of geometry the prospective unified boundary modeling is applied. It is prevailing in the present day geometric modeling and offers good chance for implementation of results of the reported research in industrial CAD/CAM and robot control systems.

IV. INTEGRATION OF MODEL OF TASK ORIENTED ROBOT PROCESS

Relationship features for part placing can be defined between form features on pairs of parts in the robot system. Main groups of parts are illustrated in Fig 8. Earlier assembled, actually assembled and robot structure parts may affect the placing of actually assembled parts. The robot trajectory for placing of a part is constrained by assembly and robot process configuration relationships. The difference is that an assembly relationship constrains a preferred end of trajectory position while a robot process configuration relationship constrains a trajectory itself by relative positions of parts to be avoided.

The relationships are defined in an integrated shape modeling environment. The actual ones are integrated on the basis of actual robot process feature. Consequently, there are two levels of integration; *level 1* is of the shape modeling, while *level 2* is of the process modeling. In other words, shape descriptions from different models are integrated on the *level 1* while robot tasks and shape relationships are integrated on the *level 2*.

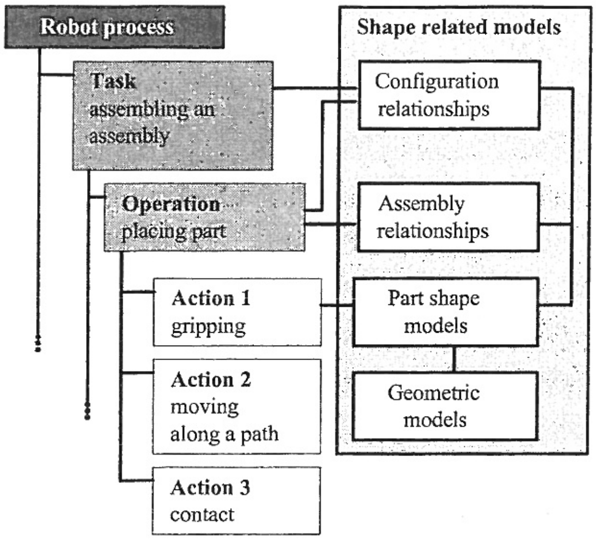

Fig. 8. Relating shape and robot process models

Task oriented robot process is executed using shape information from the models on the *level 1* of integration. Robot process consists of tasks. A task is defined for the creating of an assembly in a continuous process. Meantime, the assembly under construction is in the same position. At the start of a task, the working space of the robot involves the base part and the parts of the positioning and clamping devices. Other parts of the robot configuration in the working space are parts of the gripping tools and the arm entering into the working space. Shape conditions can be handled in the knowledge of configuration relationships and the parts referred by them.

An operation serves the purpose of placing a part. The appropriate assembly relationships are used. Also, operation specific configuration relationships are used when operation specific gripping tools or other operation specific devices are applied in the robot system.

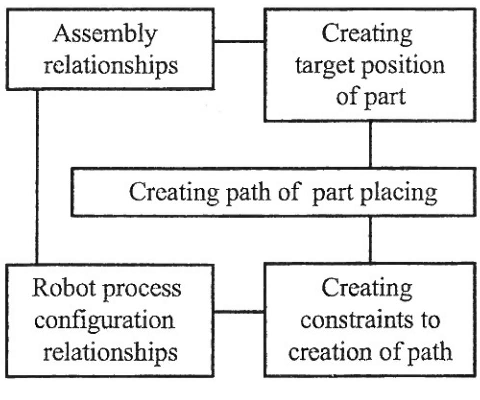

Fig. 9. Constraining

The above outlined integrated model can be used at creating robot trajectories, which is not a subject of the reported research. Assembly relationships give information for calculation of target position of the actual part to be positioned (Fig. 9). The path of the placed part-gripper-arm shape complex is created taking shape constraints into consideration.

V. CONCLUSIONS

The authors proposed a new integration of robot systems for applications as assembly as a contribution to product modeling. The reported research resulted an extension of the feature principle by the application of three level relationship features and integration of models on the levels of shape and robot process. Engineering related definitions of the modeled objects are realized by application oriented features where application refers for the application of the model. The method proposed by the authors defines relationship features on the level of application, feature and feature representation as in case of advanced form feature modeling of shapes. Definitions of assembly and robot process-configuration relationships constrain the preferred end of trajectory position and the trajectory to this position, respectively. For the description of geometry, the prevailing unified topology and geometry based boundary modeling is applied.

Definition of relationship features on the level of their applications requires further analysis of relationship features from the point of view of robot assembly.

VI. ACKNOWLEDGMENTS

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