Challenges of an Aspect Driven Way in Product Model Supported Robotics

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Abstract: This paper proposes an approach and method to efficient application of product modeling in robotics. Product model is considered as a very integrated data structure where all information can be handled for the lifetime of a product. Similarly to other integration efforts in modeling of products and their production, associativity definitions are applied to connect application oriented robot process features. Full feature driven modeling ensures a unified definition of shape model entities throughout a robot system. Beyond integrated modeling as an alternative modeling technology to the conventional geometry based programming of robots, enhanced collaboration of product design, robot manufacturing, and other engineers is also an objective of the reported work. Boundary represented form feature definition of part shape in models is proposed to integrate with robot placing process model features. Integration of part models using constraints for placing is extended by handling of robot process based configuration of shapes. In this paper, selected issues to give an outline of the proposed integration of robot model system are covered. Shape model based integration of complex mechanical systems such as robot systems are introduced including a comparison of modeled objects in existing and the proposed modeling and some examples for shape related aspects. Following this, the proposal by the authors for aspect-based integration of robot process is explained through associative shape aspects for integration. Then roles and types of robot specific form features as shape aspects in an integrated robot system and decision assistance by situation based behaviors as a possibility for involving intelligence are detailed. Finally, *implementation in portal based engineering environments and emphases on future work are concluded.*

Keywords: Product modeling, Shape modeling by form features, Model of robotic part placing, Feature based model of robot system, Integration of robot process model.

1 Introduction

Placing of complex part structures, described by advanced modeling in highly information technology assisted digital definition techniques as digital mock-up, virtual prototyping, and virtual manufacturing brought a new challenge for engineers. Models are defined by aspects, integrated in very complex product models and handled by product lifetime management. One of the emerging research areas is integration of robot related models for collaborative group work of engineers. One of the most important benefits is a chance to utilize advanced virtual and group work technologies in leading information technology environments.

In aspect oriented modeling, engineers define aspects to express elementary technical content of modeled engineering objects. The aspect principle was first implemented in form features [3]. Form features are described by using of one of the known model representations in CAD/CAM systems. Consequently, processing of aspects can be supported by proven modeling methods. Frequent modification of models during their continuous development and improvement, and growing demand for custom tailoring of products in the present leading industrial practice emphasizes adaptive modeling. Control considering earlier decisions, other constraints, and hierarchic human intent is necessary for suitability for application in industrial environments. The authors considered several trends from development of similar systems. Generic models, application-oriented reference models, and application protocol based modeling help engineers to achieve optimal solutions [1]. Interactive simulation is assisted and remote controlled by agents [2]. Modeling, analysis and control of behaviors, simulated in virtual systems for product related engineering objects, are applied in robots successfully [4]. The authors considered utilization of the above listed achievements in some of their earlier results. They proposed a new structure and integration as adaptive model objects for engineering [5]. They also proposed a behavior-based analysis of effects caused by changes of engineering objects inside and outside of a model system. That analysis uses integrated, multilevel-structured and environment adaptive model objects [6]. The authors analyzed application of the proposed modeling in an integrated system consisting of product modeling and industrial robot [7]. Some of the areas of robotics most relevant to the reported work are definition of trajectories [8], [9] and solutions for problems at gripping of different shapes [10].

In this paper, selected issues to give an outline of the proposed integration of robot model system are covered. Shape model based integration of complex mechanical systems such as robot systems are introduced including a comparison of modeled objects in existing and the proposed modeling and some examples for shape related aspects. Following this, the proposal by the authors for aspect based integration of robot process is explained through associative shape aspects for integration. Then roles and types of robot specific form features as shape aspects in an integrated robot system and decision assistance by situation based behaviors as a possibility for involving intelligence are detailed. Finally, implementation in portal based engineering environments, and emphases on future work are concluded.

2 Shape Model Based Integration of Complex Mechanical Systems

Engineering modeling for a mechanical system is shape intensive. Related shape aspects describe mechanical parts of products. Any other product related information can be mapped to one or more shape aspect. Application oriented shape aspects are carried by parts (Fig. 1). Description of shape aspects and their geometry has developed into a systematic and unified modeling in engineering. However, application orientation is not so systematic in the practice of description of information about many other products and manufacturing process. For example, technical content of assembly, kinematics, and other relationships between parts are not modeled in close connection with shape aspects. Instead, related information is mapped to the geometry. This leads to a solution that cannot consider human intent. Information for manufacturing processes and production equipment is not or loosely attached to part description. A fully aspect based, unified approach to computer description of product and production related information by the authors is intended to improve integration of product modeling and product related application of robots. Essential aspects in this approach are for description of shapes, functions, associativities, adaptivities, behaviors, and manufacturing (Fig. 1). The resulted structure is simple and easy to define, modify, and survey by engineers in the present industrial practice. To achieve a model structure with minimal redundancy of the represented information, part, manufacturing, and active aspects are connected by associativity aspects in a shape oriented integrated model of product and robot assisted production. Geometry is mapped to shape aspect or it is defined as geometric aspect. Functions are handled on the level of parts. Associativity definitions integrate part level functions into product level functions. Behaviors and adaptivities are also handled as aspects. An aspect is inherently application oriented. In order to integrate in product model, it is specialized as an instance, starting from a generic aspect. Associativity aspect connects other aspects on the level of their technical meaning: it is not only a simple data link. Situation aspects make connections to circumstances for situation-based analysis of behaviors.

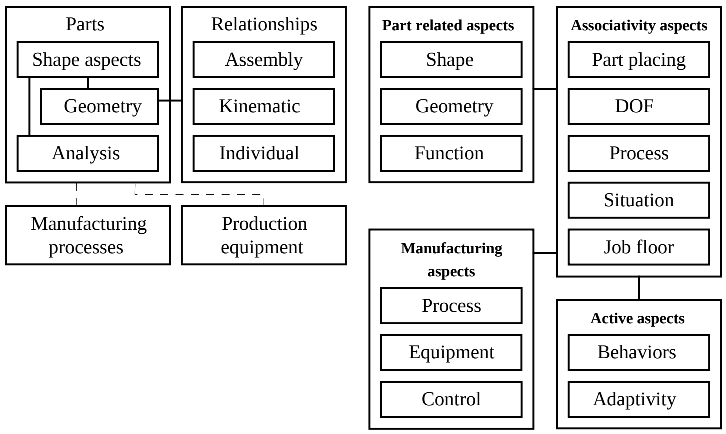

Figure 1

Modeled objects in existing modeling and in the proposed approach

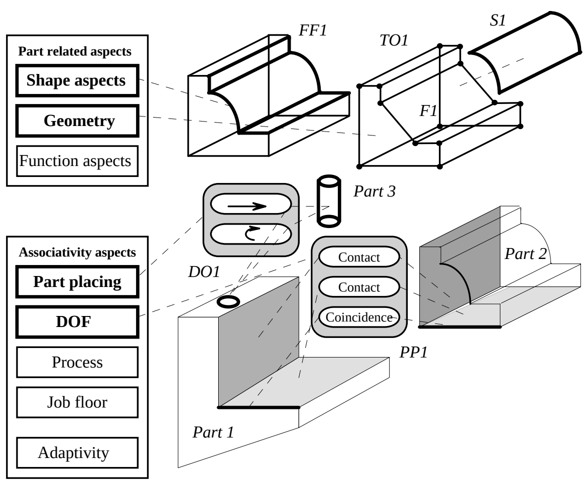

Figure 2

Examples for shape related aspects

Examples for shape, geometry, part placing and DOF aspects and their connection illustrate the aspect approach in Fig. 2. Part placing associativity connects *Part 1* and *Part 2* in an assembly, while DOF aspect *DF1* allows two degrees of freedom between *Part 1* and *Part 3*. Shape aspect *FF1* is mapped to appropriate elements of topology *TO1* in its geometric representation. Mathematical function describing surface *S1* is mapped to topological face *F1*. Specifications are included and linked as attributes to aspects.

3 An Aspect Based Integration of Robot Process

Modeling proposed by the authors uses connection of mechanical part and robot process related aspects by process associativity aspects for the definition of part placings. That robot process consists of a series of part placing as a complex manufacturing activity for mechanical assembly or other purpose. In Fig. 3, *part 2* is placed on *part 1*. Pairs of contacting and coinciding surfaces on parts define part placing aspect. Mating surfaces are mapped to topological faces in the description of geometry. However, as it is explained in Fig. 2, part placing aspect accesses geometric information through shape aspect. In this case, associativity aspect points to an operation aspect in the robot process description. The authors detail structure and entities of robot process description (Fig. 3) in [7]. Task and action robot process aspects are in connection with equipment aspects through job floor associativity aspects. Equipment aspects are also defined for tools and devices because they are allowed to select only by considering their assignments to equipment. In an aspect-based model, tool, fixture and other device aspects modify equipment aspect.

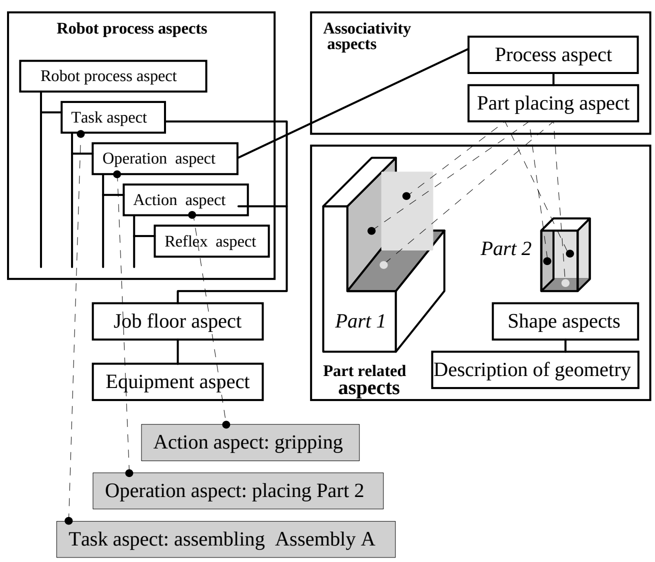

Figure 3
Associative aspects for integration

The authors proposed a multi-layered computer model description of robot process has been by (Fig. 3) for the purpose of integrated application with product and robot models. It includes associativities of robot process entities with product model features. Task, operation, action and reflex robot process features have been defined then 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 define positioning and orientation of parts, moving parts along paths, and placing parts into 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 to task. Part type and shape characteristics are extracted from part models Fig. 4 illustrates a task for an assembly of three parts. Robot must have appropriate workspace to accommodate the assembly and moving grippers with parts. Definition of operation uses general shape information about the part to be manipulated. Action is created using detailed part geometry information for definition of gripping, target and movements.

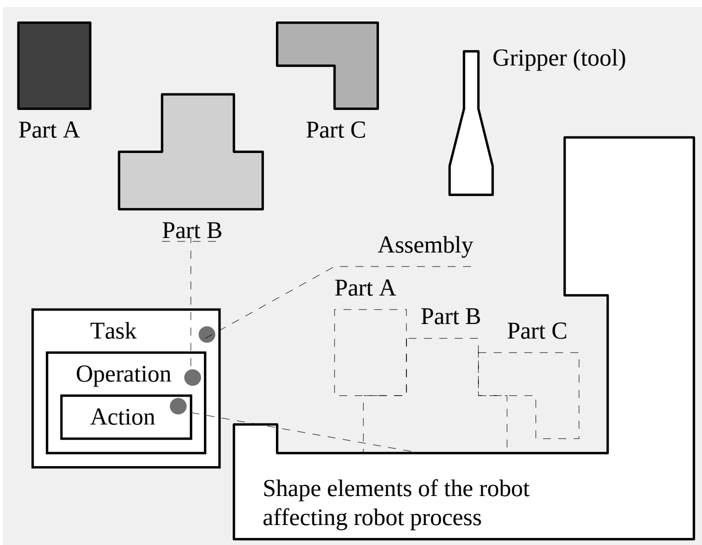

Figure 4

Associative shape and robot process aspects

4 Form Features as Shape Aspects in Integrated Robot System

Associated form features as shape aspects are selected or defined on parts of products to be placed, and on some parts in structural elements of a robot system for a robot process as gripped or placed surfaces, reference elements for gripping or placing, moving volumes, and obstacle volumes. An integrated shape environment of robot placing is established by associative form mfeatures. Environment is composed by shape objects as grippers, parts to be placed, placed parts in the semi finished composition, and shape units of the robot system (Fig. 5). Robot process model features relate form features defined on product and robot parts.

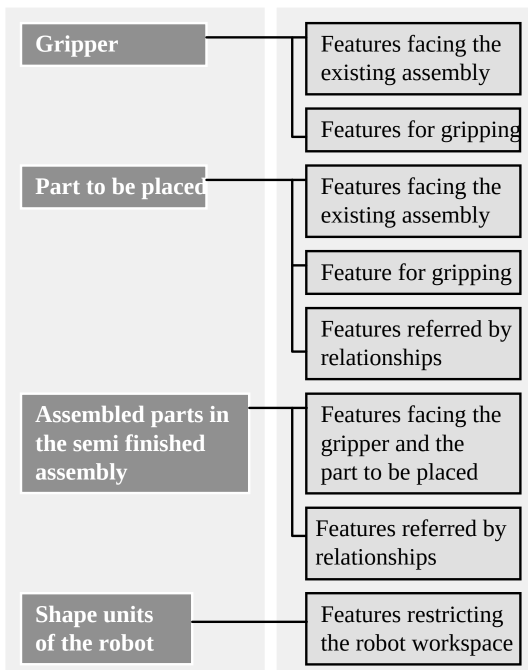

Figure 5

Form features in component units

Fig. 6 explains relationships for part placing as placing associativity features relating purposeful form features on parts to be placed. Geometric representations are mapped to form features and geometric placing associativities are mapped to placing associativity features. Geometric representation of a form feature consists of topology and geometry in the boundary representation. A geometric placing associativity can relate surfaces or lines by their coincidence, contact, distance, or angle. In the example of Fig. 6 *Placing of a prism* application placing associativity feature is defined on the *level 1*. Three contact geometric placing associativities are mapped to the placing associativity feature *C1*. Placing associativity feature *C1* is defined between form features *FF1* and *FF2*. Geometric placing associativities *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. Topological structure is also exampled on Fig. 6. Face *F1* is connected to the topology of the form feature *FF1* and to the total topology of the part by closed loop of topological edges *E1*, *E2*, *E3* and *E4*.

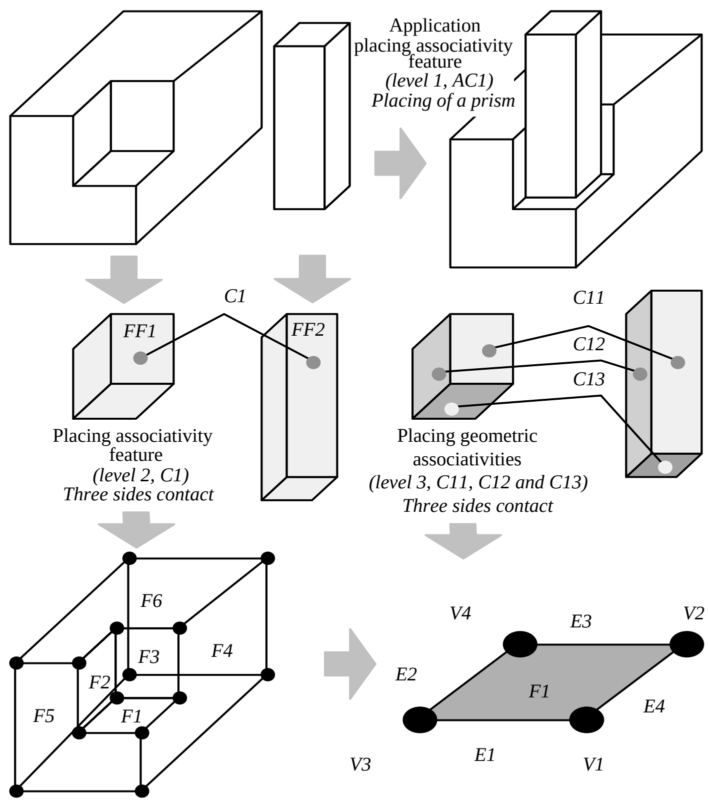

Figure 6

Associativities for placing of parts

Similarly to placing associativity feature definition, robot process configuration associativities are defined on three levels (Fig. 7). On the *level 1*, robot configuration associativity application feature *ACF1* is defined for application, similarly to placing associativity feature. Its type *is Part and assembly of product*.

It defines relationship between part being placed and a part in the existing stage of an assembly unit. A part in an assembly of a product can be defined as a group of assembled parts when 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. 7 is defined on the level of form features as robot configuration associativity feature *RCF1* on the *level 2*. It describes the constraint of *contact is not allowed* between a pairs of form features *FF3* and *FF4*. On level 3, geometric associativities RG1 and RG2 relate two pairs of flat surfaces (*FS11* and *FS12*, *FS21* and *FS22*). The necessary calculations use topological definitions of boundary representation. The relationships connect appropriate elements in topologies of two parts. Then geometry is accessed by mappings to topological entities. Above method represents the main essence of the proposed integration of shape models.

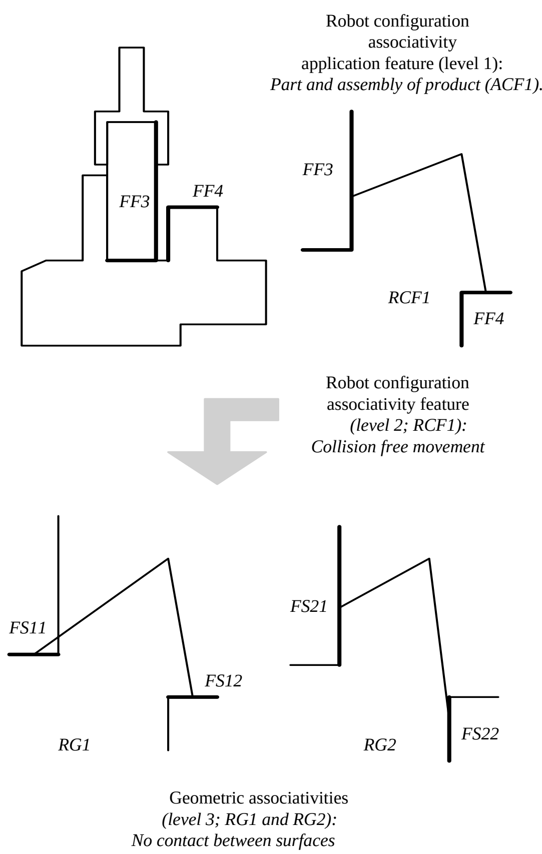

Figure 7
Example for robot process configuration feature

5 Decision Assistance by Situation Based Behaviors

Modeling is increasingly applied at analysis to assess behavior of modeled objects during virtual engineering, excluding any physical manufacturing or measurements. An advanced method is to specify behaviors as representations of design and other engineering objectives. Objectives can be originated from customer demands, requirements by engineering activities, experiences and personal intents.

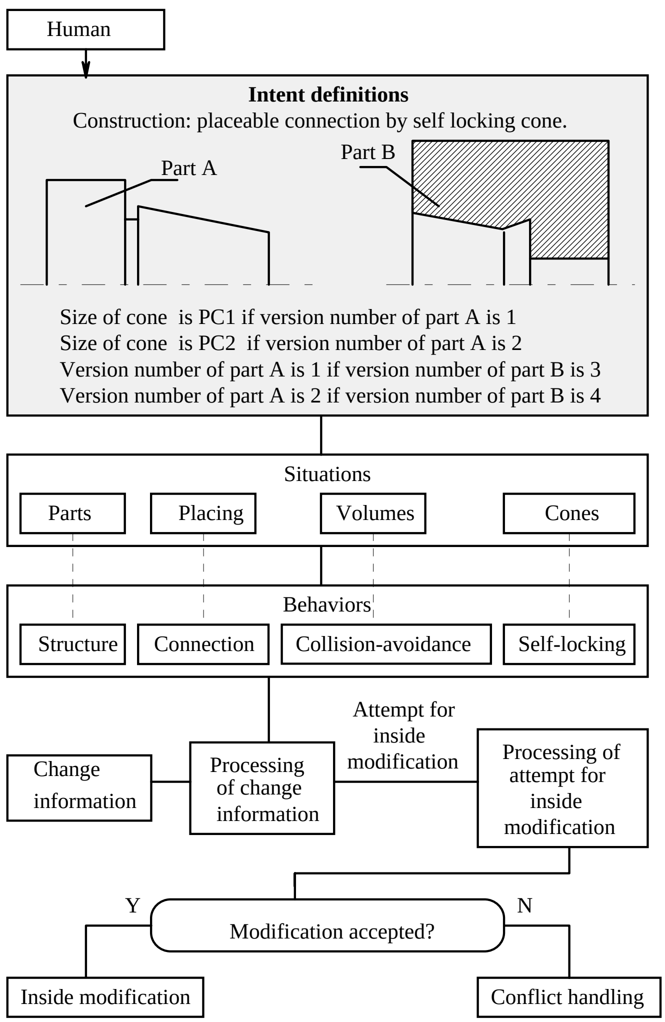

Figure 8
Circumstances for a shape behavior feature

The authors introduced behavior features to define behaviors of modeled objects at different circumstances. An active behavior defines parameters of the modeled objects while a passive behavior serves comparison of specified and actual behaviors. Fig. 8 shows an example for implementation of the proposed behavior based assistance of decisions. A self-locking conical connection is composed by *Part A* and *Part B*. Size of the cone depends on version of *Part A*. On the other hand, version of *Part A* depends on version of *Part B*. Four situations are defined for four behaviors. All behaviors must be effective to serve parallel design objectives. Structure behavior depends on actual parts while connection behavior depends on situation of placing of mated surfaces. Collision avoidance behavior is analyzed by moving volumes of parts. Finally, self-locking behavior requires appropriate cones.

6 Implementation and Future Work

The approach and method by the authors are suitable for computer support of a wide variety of engineering activities. The primary modeling technique is handling of application oriented aspects that can be defined, attributed and related for all possible engineering objects by practicing engineers. A unified, fully aspect based modeling is proposed in this paper mainly for better communication between product modeling and robot related manufacturing engineering activities. As a future work, configuration of human interface procedures needs systematic experiments. The proposed approach ensures that modeling is understandable by engineers. Behavior and adaptivity aspects organize analysis and adaptive actions. The solution is simplified by considering all modifications of engineering objects as adaptivities. The main contribution of the proposed approach and method is a new organization and communication of model data for engineering modeling.

Future works include purposeful configuration of experimental modeling environment, development of pilot modeling procedures, definition of initial sets of aspects. Mechanism of aspect processing and communication amongst engineers during their group work is also to be analyzed. An experimental environment will be applied for future experiments in integrated intelligent environment adaptive model objects. Those objects were proposed by the authors as building blocks of model organization for the proposed approach and method.

Implementation of the proposed modeling is planned as an extension to engineering modeling program packages. Engineers $E_{1i} - E_{ni}$ are participants of a project based work group in a product related engineering environment (Fig. 9). They also communicate with engineers $E_{1o} - E_{no}$ working outside of the work group. Information is added to and retrieved from product model data sets during product development, production planning, manufacturing planning, manufacturing, application, and recycling of product. Recently, product information is coordinated and handled by product data management (PDM) systems. Other newly introduced methodology is to organize all communications of engineers and computer procedures in an Internet portal. An engineering process comprises large number of coordinated proposals, counterproposals, decisions, and modifications about model entities and their parameters in order to develop, modify, correct and variant definition of products. Conventional modeling cannot process decision-related information, especially when frequent changes of modeled objects are demanded by modification of other objects by human decisions. The approach and method proposed by the authors applies human intent originated knowledge to robot modeling. Conventional product modeling processes, product data management and product data are accessed as conventional computer aided engineering resources. Modeling of robot specific objects, behaviors of objects, and intent of engineers are resources proposed by the authors to assist change management. Engineers access resources through Internet portal functions by using of specially configured browsers.

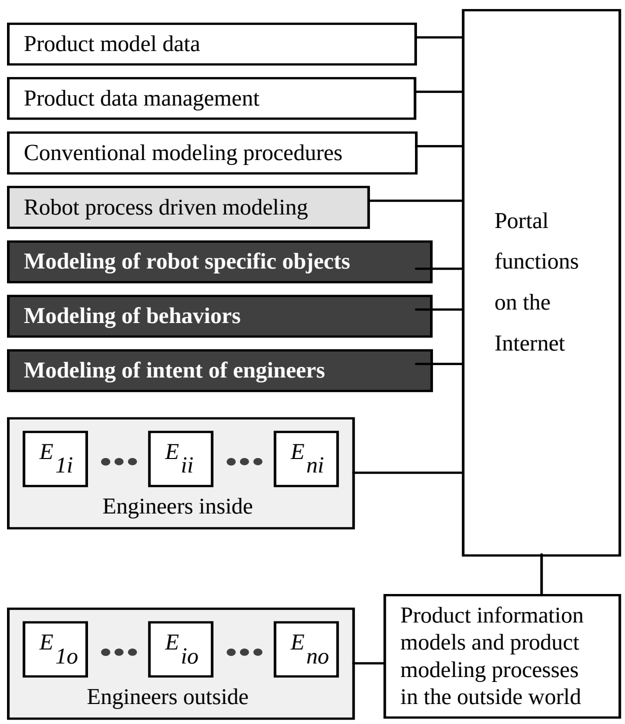

Figure 9

Integration in portal based environment

Conclusions

In this paper, a contribution to aspect and associativity based integration of robot modeling is proposed and essential related issues are emphasized. Shape modeling has been proved as primary method for organized description of a complex robot system. A comparison of modeled engineering objects in recent prevailing and the proposed modeling is given to explain how the proposed modeling improves robot engineering. Integration of robot process by associative shape aspects, roles and types of associativity features as robot specific shape aspects in an integrated robot system, and decision assistance by situation based behaviors as a possibility for involving intelligence at creation and application of the proposed integrated model are detailed to make understanding of significance of the reported work possible. A good chance for implementation is taking the advance of portal based engineering environments. The main contributions of the reported research are extension of feature and associativity based modeling techniques to robot system, application of three leveled associativity features, and integration of shape and robot process models. The method proposed by the authors defines associativity features on levels of application, feature, and feature representation harmonizing the proposed modeling with form feature driven definition of parts in product structures. Placing and robot process configuration associativity definitions constrain the end of trajectory position and the trajectory to this position, respectively. For the description of geometry, the currently prevailing unified topology and geometry based boundary modeling is applied.

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References

[1] L. Horváth and I. J. Rudas, "*Modeling and Problem Solving Methods for Engineers* ", ISBN 0-12-602250-X, Elsevier, Academic Press, 2004

[2] M. Tambe, W. L. Johnson, R. Jones, F. Koss, J. Laird, P. Rosenbloom, and K. Schwamb, "*Intelligent agents for interactive simulation environments*", *AI Magazine,* v. 16, n. 1, 1995

[3] Jami J. Shah, Martti Mantyla, Jamie J. Shah, "*Parametric and Feature-Based Cad/Cam: Concepts, Techniques, and Applications*", John Wiley & Sons, 1995

[4] Yasuhisa Hasegawa, Toshio Fukuda, "Motion Coordination of Behavior-based Controller for Brachiation Robot", In *Proceedings of the 1999 IEEE International Conference on Systems, Man, and Cybernetic, Human Communication and Cybernetics*, IEEE, Tokyo, Vol. 6, 896-901, 1999

[5] L. Horváth and I. J. Rudas, "Virtual technology based associative integration of modeling of mechanical parts," *Journal of Advanced Computational Intelligence*, Tokyo, Japan, vol. 5, No. 5, pp. 269-278, 2001

[6] L. Horváth, I. J. Rudas, G. Hancke, A Szakál, " Integrated Environment-adaptive Virtual Model Objects for Product Modeling," in *Proc. of the 2003 IEEE International Conference on Systems, Man & Cybernetics*, Omnipress, Washington, D. C., USA., pp 498-503

[7] L. Horváth, I. J. Rudas and S. G. Tzafestas, "Relating Shape and Robot Process Model Features," *International Journal of Mechanics and Control*, Turin, Italy, Vol. 4, No. 2, 2003, pp: 27-31

[8] S. Zeng, and J. Weng, "Obstacle Avoidance through Incremental Learning with Attention Selection," *Proceedings of the 2004 IEEE International Conference on Robotics & Automation*, New Orleans, LA, pp: 115-121

[9] K. O. Arras, J. Persson, N. Tomatis, and R. Siegwart, "Real-time obstacle avoidance for polygonal robots with a reduced dynamic window," in *Proceedings of the IEEE International Conference on Robotics Automation*, Washington, DC, 2002, pp. 3050-3055

[10] A. Morales, P. J. Sanz, A. P. del Pobil, and A. H. Fagg, "An experiment in constraining vision-based finger contact selection with gripper geometry," in proc. of the *IEEE/RSJ International Conference on Intelligent Robots and Systems*, vol. 2, 2002, pp. 1693-1698