An Approach to Integrated Modeling of Robot System in an Intelligent Space

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Abstract: *Engineering of industrially applied robot systems using product modeling techniques utilizes the benefits of an advanced solution for integrated computer description of product-production systems. Associative entities in this integrated model communicate modification of any modeled object with any affected modeled objects. This paper discusses a method developed by the authors for model based change management at development and correction of products and their variants. The product-production model complex is considered as virtual space. Modeling and processing capabilities of this virtual space give a great chance for including intelligence in robot application related engineering. The paper starts with a discussion of background of the reported research including engineering modeling and robotics. Following this, integration by the application of shape intensive modeling is considered. Next information structure and procedures in the virtual space are outlined. Finally, methods for verification and management of product and production object changes are explained.*

Keywords: *Index Terms – model based robot engineering, virtual space, behavior based robotics, product lifecycle management*

I INTRODUCTION

Product-production systems can be described using modeling techniques for description and associative connection of engineering objects. Engineering of industrially applied robot systems can utilize the benefits of integrated computer description. Associative entities in this integrated model communicate modification of any modeled object with any affected modeled objects.

Growing of industrial applications of robots among others for welding, material handling, pick and place, material removal, palletizing, packaging, bonding, coating, and assembly urges integration of information for entire lifecycle of products. Essential technique for representation and handling of associative product information is integrated product modeling where large amount of well-organized data can be established taking special requirements by specific product into account. In the recent industrial practice, most of physical prototyping have being moved into virtual. Products are defined, developed, assessed, improved, and optimized inside computers without any physical manufacturing and measurement operations. This is the well-known concept of virtual prototyping or virtual manufacturing. When product works in a physical environment, intelligent model based computer control system can integrate it into highly automated complex system such as building management system and flexible manufacturing system. System decides actions and provides information for actuators and control devices, and human decisions. A question arises: How this system can be thoroughly simulated in virtual? The answer is the concept of integrated automation is intelligent space. All functions in the space are under coordinated integrated intelligent control.

In this paper, the authors propose techniques for integration of model definition, communication, analysis and decision making processes in order to establish an approach to virtual intelligent space as an analogue of physical virtual space. They discuss modeling and processing capabilities of virtual intelligent space for robot applications considering virtual intelligent space as an enhanced and highly integrated application of recent advanced CAD/CAM, human-computer, collaborative, product data management, Internet portal, and intelligent information processing techniques. At an advanced and extended level of simulation, sensor signals of physical intelligent space are replaced by received change information about modeled objects and their environment. Processing of changes is done by intelligent behavior analysis. Adaptive action generators replace actuators. Potential application of virtual intelligent space is analysis of intelligent robot system and simulation of any cooperating intelligent space in the world outside of it.

Intelligent engineering space in a product modeling environment can be established by using of associative data sets, integration techniques, and programming tools in industrial modeling and product data management systems. Most of the software for definition and management of these virtual engineering spaces are available as program products. Virtual space is a highly integrated application of these integrable engineering processes and intelligent software tools. The authors analyzed decisions where humans and intelligent computing cooperate. They conducted systematic analysis of recent techniques for engineering modeling and published the results in book [1]. Other subjects of their analyses were extended application of the principle of model modification by features. In this case, an engineering object such a mechanical part is described as a sequence of modifications of initial objects by predefined features [2], [3]. The authors also did research in modeling of human intent at engineering decision [4], and integration of model description of human intent in product model [5]. Recently, they proposed a technique for handling of changes in models of engineering objects [6].

In this paper, the authors introduce a method for change management during modeling at development and correction of products and their variants. Applying it for product-production model of industrial robot systems, capabilities are gained for virtual space giving a great chance for built-in intelligence to assist decisions at robot application related engineering.

The paper starts with a discussion of background of the reported research including engineering modeling and robotics. Following this, integration by the application of shape intensive modeling is considered. Next, information structure and procedures in the virtual space are outlined. Finally, methods for verification and management of product and production object changes are explained.

II COMPUTER INTELLIGENCE IN ENGINEERING

Two essential and traditional questions in intelligent engineering systems are about definition of intelligence and its integration in engineering systems. Demand for built-in intelligence in engineering systems is increasing because on-line interfacing of humans is often impossible or simply the time necessary for human interaction is not available. Product and production together with other factors change continuously during product related engineering processes. The only solution is modeling of human intelligence for some level of automated decision assistance. Essential problem of modeling of intelligence is that procedures are not available to reproduce intelligence or humans are not aware of work of these procedures.

Actually, engineering systems are increasingly demanded to have capability for analyzing behaviors of the modeled engineering objects. Physical objects are engineered or verified by behavior driven computer procedures. The authors considered the approach of emulation of intelligence in engineering systems by behavior analysis and decision on object parameters according to specified behaviors.

Fig. 1 is a sketch of essential flow of information in a virtual space. Models of closely related engineering objects are stored in the virtual space as interconnected descriptions. Engineering objects are components and structures in the integrated product – robot system. Sensing function watches changes inside and outside of the space and sends change information to behavior analysis. Engineers specify sets of entities, their attributes, and associative connections to describe and relate a set of physical and logical engineering objects. Intelligence in model of an engineering space informs engineer about entities, their attributes, and relations. Relevance of the changed parameters to the specified behaviors is checked. When an engineer modifies a design objective in the form of new or modified behavior, its effects on object parameters and related behaviors are also checked. Actions function communicates changes proposed by the intelligent system inside and outside of the space. Situation is composed by parameters of impact on assessed behavior.

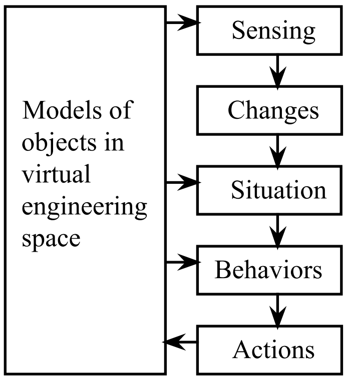

Figure 1
Essential information in a virtual intelligent space

Before presenting more details about methods proposed for virtual intelligent space related engineering, the authors survey related recent modeling technology. Modeling of robots is shape centered. All other information can be attached to shape information. All design and manufacturing form features use the same boundary shape representation where structure of geometrical entities is defined by topology. Unified geometry in the form of B-spline curves and surfaces and unified topology allow for unlimited extension of the form feature principle [1].

Reference models, modeling resources, and application protocols are essential techniques for implementation of application oriented product modeling [7]. Application oriented form features [8] in computer definition of shape models demand conversion of design features into manufacturing features [9]. The authors extended the application of feature principle to behavior and adaptive action definitions [3]. Utilizing modeling related techniques of reverse engineering, existing part can be a source of geometric definition for surface measurement; surface reconstruction; tool trajectory planning, and axis adaptive motion control [10]. Most of industrial applications can work with arbitrary shape, size, and location as predefined in part models. In this case, robot is moving in a priori known environment. One of the methods available for motion planning considering known geometry is proposed in [11]. Smooth curve without self-loops connects the starting and destination points with the shortest possible path. Geometry information in part models and assembly constraint driven complex geometry information for sub-assemblies and products are often used at robot applications requiring a shape to be followed. In [12], distance between any rivets on a path, the number of turns and the overall distance are considered by a geometry driven optimizing process.

Research in intelligent robotics focuses on several issues urged by applications. Behavior [13] and agent [14] based techniques represent an initial stage of intelligent engineering modeling. In [15] Petri net representation is proposed for design and implementation of an execution control, which, through suitable graph-search algorithms, generates sequences of task activation/deactivation operations. Operations execute the desired commands maintaining the system in admissible configurations. Machine learning is essential in case of unforeseen environmental conditions. Environment composed by known and unknown elements is typical at certain applications. Robot controller can learn on-line about its own capabilities and limitations when interacting with its environment. A method is proposed in [16] where off-line supervised neurofuzzy learning and on-line unsupervised reinforcement learning, and unsupervised/supervised hybrid learning are applied at control of gripper. Application of Fuzzy methods is of essential importance [17], among others at reduction of rule sets at representation of corporate knowledge. Authors of [18] demonstrate that notion of the knowledge level based explanations of cognitive processes provided by traditional artificial intelligence and approach of embodied systems interacting with the real world in new AI can be unified. Authors of [19] reported a method that offers possibilities for integration. Advancements in application of computer systems for engineering purposes are stimulated by advancements in the area of digital computer principles [20].

III INFORMATION FLOW AND PROCEDURES

Essential feature of an intelligent virtual space is that digital definitions of engineering objects are based on assessment of behaviors according to intent of engineers in virtual. Modeling of robot and other production equipment can be done by same methods and software as modeling of the handled products. Model of mechanical structure consists of form feature based parts, assembly constraints, and joint definitions. Analyses for strength, heat resistance, motion, interference of parts, minimal distances etc. are included.

Engineering modeling based intelligent space includes typical engineering process related sets of information. Model of the space integrates descriptions and actions in an information structure (Fig. 2).

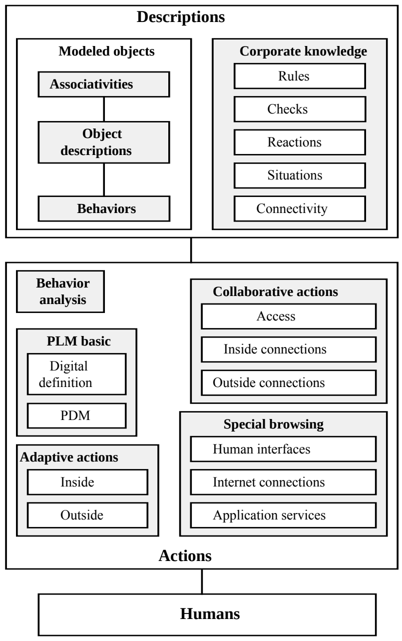

Figure 2
Structure of intelligent space

Descriptions are applied for modeled objects and corporate knowledge. Features, associativities, and behaviors describe modeled objects. Associativities connect features inside and outside of a space. Description of knowledge includes engineer friendly representations as rules, checks, reactions, situations, and connective entities. Rules are applied for the definition of entity parameters, checks help to maintain earlier decisions and threshold knowledge. Other representations allow response to changes, composition of situations for behavior analysis and recording of networked information. Actions include behavior analyses, lifecycle management of product data, inside and outside adaptive actions, collaboration of humans and procedures, and special browsing for group work on the Internet. Collaborative actions serve access and connection purposes. Adaptive actions are generated as attempts for modification. Situations modified by these changes are evaluated by behavior analysis.

Virtual space integrates typical groups of engineering related information processing procedures. A logical structure of interconnected procedures is given in Fig. 3. Engineers within a space and world outside of it are connected by portal procedures. Information exchange communicates associativity building and managing. Behavior analysis and human related procedures define actions. Knowledge management supports behavior analysis including learning and links to knowledge sources outside of the space. Human-computer interaction procedures communicate collaboration procedures. Product definition is under behavior analysis control through action management.

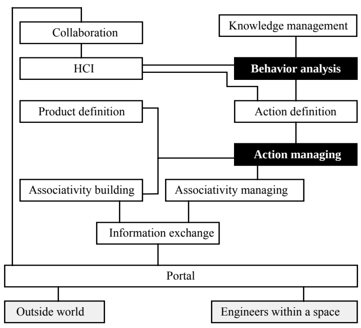

Figure 3
Procedures in an intelligent space

IV VERIFICATION OF PRODUCT OBJECT CHANGES

Engineers control an intelligent space through specified and accepted behaviors for well-defined situations. A modeled object is characterized by several behaviors according to its functions. Behaviors represent engineering objectives. Any change of an object during its development may affect one or more behaviors. Consequently, repeated evaluation of behaviors in affect zone of a change is required when change modifies any situation specified for behavior. Behavior specifications are originated from customer demands, requirements by engineering activities, experiences, and personal intents. Behavior features are applied to describe behaviors of modeled object at defined circumstances. Active behaviors are used at definition of parameters of modeled objects, while passive behaviors serve comparison of specified and defined behaviors.

In the proposed method, situations are identified, behaviors are found for situations, and adaptive actions are created according to the need for correction of situations to behaviors. As an example, circumstances that define situation in case of a swept surface model are listed in the groups of sweeping conditions, attributes of surface, and surface model representation (Fig. 6). Situation handling coordinates analysis of behaviors for the surface. Behavior features are defined according to demands by individual applications. Several examples for behaviors of a surface object are appearance, set of dimensions, change of curvature along the surface, and configuration of surfaces for robot tool. Behaviors are defined according to application and their specification may be modified. Maybe definition of some relevant situations should be modified. New analysis of behaviors is needed and new adaptive actions may be generated.

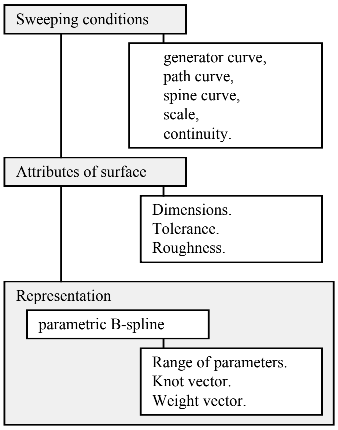

Figure 4
Situations for behaviors of a swept surface

Change management actions are under control both of humans and intelligent procedures for the development of a product. The objects on which a modeled object has any effect are considered to be in the affect zone of that modeled object. Some objects within the affect zone may be accessed only from the world outside of the space. Consequence of changes of interrelated modeled objects extends to outside of a space. Essential management of changes can be followed in Fig. 5. Management considers any changes of descriptions of engineering objects, physical or logical, in the virtual space as one that may modify one or more behaviors. It receives information about proposed and accepted changes from space procedures, humans, and outside world procedures. Changes are mapped as conditional adaptive actions. Then their effects are analyzed in the affect zone of the changed object. The consequence of changes may be modifications of elementary or composition object descriptions. Sometimes change of behaviors is necessary. Sometimes changes of descriptions are abandoned due to improper changes of behaviors as revealed by effect analysis. Effect analysis may generate additional changes to be effect analyzed. Accepted decisions are considered as constraint adaptive actions. Inside changes are executed while outside changes are proposed. In the outside world, change attempts are accepted or rejected, and new changes are generated.

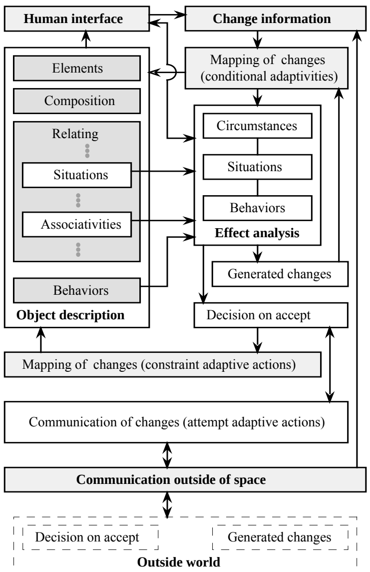

Figure 5
Management of changes

An intelligent system acts as an advanced navigator and not as design automata. In an environment like this, engineers have much more chance to find a conflict free solution than in conventional modeling. Only authorized engineers and computer procedures are allowed to make space related decisions.

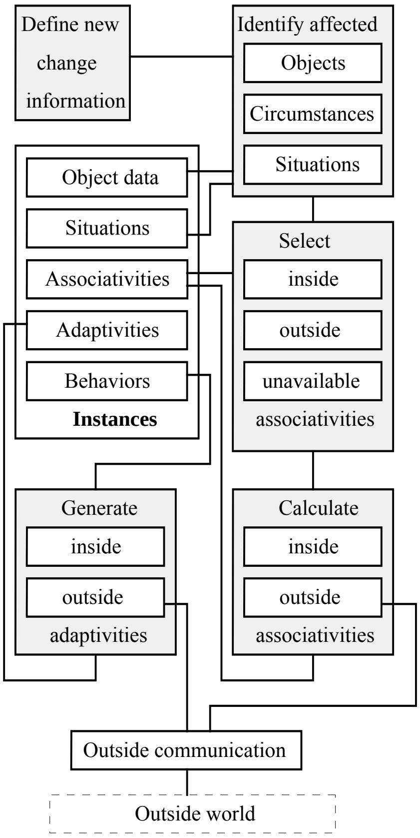

Figure 6
Intelligent communication of changes

Instances of descriptions of product objects, situations, associativities, adaptive actions and behaviors are defined by knowledge driven specialization of generic descriptions. Modeling procedures organize change related communications (Fig. 6). As a first step, affected modeled objects, circumstances, and situations are identified. To establish the communications, inside, outside, and unavailable associativities are selected for the affected entities. The process can reveal unknown associativities but human must define them. Following this, inside and outside associativity values are calculated, and then adaptivities are generated using associativity values and specified behaviors. Value of an associativity may be a simple number, a range, an equation even a procedure.

Conventional knowledge based systems apply domain knowledge for inference or other type of decision assistance. Recent modeling systems apply corporate knowledge. The authors emphasize the personal intent nature of knowledge at engineering in [2]. This is why multiple decision is controlled by combined intent. Simple decisions may have complex human background. For example, decision on a single dimension by an engineer who is responsible for it may apply knowledge also from scientists, standards, legislation, local instructions and decisions of engineers on a higher level of hierarchy or customer demands. Engineers and other humans participating in these decision chains apply knowledge from other sources through a filtering by personal, corporate or even official intent.

Combined intent aspect of decision processes in intelligent modeling is explained in Fig. 7. Decisions are supported by three basic methods. They are behavior analysis, creation of certain views of product data, and combination of intents. Human knowledge sources and outside links to some knowledge are applied in order to complete knowledge information inside of the model. Knowledge items in conventional knowledge base are extended by situations for behavior analysis, typical combined intents to assist combining of intents, effectivity to make views, and effects as rules, checks, etc. In addition, human and outside knowledge link information is included.

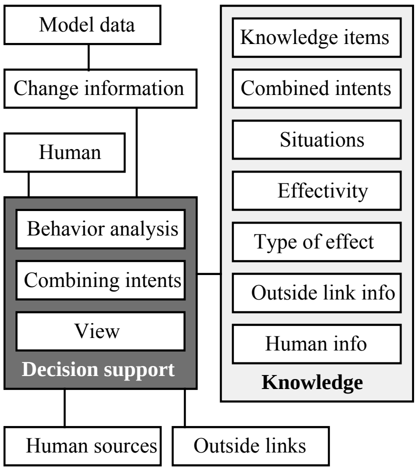

Figure 7
Combined intent aspect of decision processes

Space is considered as autonomous one. Development management generates development effects for an actual space. On the other hand, actual space generates demands for its development as a consequence of inside or outside attempts for its change. Separate coordination of development activities serves protection of intelligent space against undesired modifications even development.

An experimental virtual intelligent space including essential engineering technologies of product lifecycle management is under construction at Laboratory of Intelligent Engineering Systems, John von Neumann Faculty of Informatics Budapest Tech. This pilot system will be applied to analyze potential descriptions of behaviors and behavior related procedures to fit them into intelligent space concept by the authors.

Conclusion

Modeling and processing capabilities in virtual space consisting of models of a set of interrelated engineering objects in a product-production system is discussed. The objective of the reported research is integration in engineering systems for robot applications. Shape intensive product-robot modeling is considered in structure and procedures for virtual intelligent space. In model based engineering, management of frequent changes proved as critical issue in the industrial practice, especially in production related applications as industrial robotics. Methods for verification and management of product and production object changes highlight importance of behaviors of modeled objects. Virtual intelligent space for robot applications is considered as an analogue to physical intelligent space and offers capabilities to establish enhanced and highly integrated application of recent advanced CAD/CAM, human-computer, collaborative, product data management, Internet portal, and intelligent information processing techniques. Human decisions are supported by behavior analysis, creation of views from product data, and combination of human intents.

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