INTEGRATED WORKPLACE FOR THE DEVELOPMENT OF ROBOTIC SYSTEMS

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Abstract *¾ This contribution presents modern approaches and modern software tools for the development and design of robotic systems that are characteristic with high demands on engineering solution, utilization of new technical knowledge and innovation and quality of fulfillment and manufacturing. Especially in the present extremely competitive surrounding world evoked by globalization processes, the new products are developed under the pressure of terms, quality and economical requirements and it is important to search for methods and tools, which make the design of the optimal products more efficient. These methods and tools should cover all stages of the robot design, including the invention stage of a robotic system, design stage and also verification stage of a virtual or real prototype of a robot. Creation of the "integrated workplace" for development of robototic systems, which cover all the above-mentioned approaches, belongs to long-term research projects of the Department of Robotics, VSB - Technical University Ostrava.*

Index Terms ¾ design of robotic systems, CAI, CAD, simulation tools.

METHODS AND TOOLS FOR DESIGN OF THE ROBOTIC SYSTEMS

Project of the integrated workplace for the development of service robots and robotic systems comes primarily from new knowledge in the area of design methodology for machine system generally, further from specific requirements on modern robotic systems as well as from unusual development of computer-assisted techniques [1] and CAD systems. The objective of the project was creation of the workplace that is equipped with hardware and software means for solving of the specific tasks of robotic systems that are for its mechatronic nature with high portion of control and sensors demanding on compatibility and interdisciplinarity of the used CAD systems. Choice of the computer support systems was founded on their possibility to realize requirements of the fundamental stages of the design:

- fulfillment of the functional analysis and synthesis of the machine as a mechatronic system, allocation of the functions to individual subsystems with reference to their optimum reshuffling, utilization of the new principles, technologies and materials on basis of the all the time updated database of knowledge.
- coordinated and concurrent creation of the individual subsystems by professional specialists with consequential exercitation of the mechatronic approach and understanding means and links to other subsystems, optimization of the individual subsystems
- optimization of the entire machine system in co-operation of all subsystems, simulation of the whole mechatronic system

On basis of the above-mentioned requirements and analyses of the available software systems were purchased development systems for implementation of the particular methodical steps. These are systems TechOptimizer for computer support of innovation (CAI), efficient CAD system Pro/Engineer for creation of the 3D model of the mechanical subsystem including integrated computing and simulating system Pro/Mechanica and computing and simulating system Working model 4D, that supplement CAD system Pro/Engineer in the area of the contacts and collisions of the bodies. For an area of simulation of the mechatronic systems are used systems Dymola and Matlab.

COMPUTER AIDED INNOVATION (CAI)

Functional analysis and synthesis of the generated system is accomplished with the support of the CAI system TechOptimizer 3.0, that provides computer support in the area of innovative tasks formulation and their solving. This system provides access to huge extent of technical information around the world, enables suppression of uneconomical approach "invent invented" and provides tools for classification and utilization of the information. System contains open database of animated scientific and technical effects and principles, that are based on generalized results of 2,5 mil. patents and enable connection through Internet into databases of patents around the world. This system is interdisciplinary and enables functional analysis and synthesis of general mechatronic equipment. The more detailed description of the system TechOptimizer is shown in [2].

TechOptimizer contains seven modules. Three support analysis of the object, three support synthesis of the solution and one provides adequate knowledge database. TechOptimizer evaluates interaction among individual parts

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of object, execute series of calculations and provides diagnosis: which system part should be improved and how. TechOptimizer also enable analysis of the manufacturing process of the specific products and advise improvement for enhancement of the efficiency of the process and decreasing his costs.

COMPUTER AIDED DESIGN (CAD)

For the realization of the second design stage of the robotic system has been chosen CAD system Pro/Engineer, whose individual modules satisfy preferably requirements appointed for this stage. This fully parametric CAD/CAM system provides means for 3D modeling of parts, modeling of assemblies, purchasing of the design documentation, modeling and simulation of the mechanisms, kinematic and dynamic analysis of the mechanisms, stress analysis of the parts and thermal analysis, thus essential computer support for design of robotic system.

Among decisive advantages, which affects selection of this system as a fundamental CAD system for development of the robotic systems are tools for concurrent engineering, where belongs beyond management system of a project (Design Management) and support of the Top-down Modeling, also latest progressive approach to development of the machinery systems, that is presented by so-called Behavioral Modeling. Farther it is possibility to use mechatronic elements (Routed Systems) and approach that enable connection with other simulating systems for simulation of the mechatronic system in the whole. Next subsidiary modules from areas of CAM enable computer support for manufacturing and assembly technologies. Figure 1 shows as an example a service robot for the inspection of the large tubes and Figure 2 shows angular robot with 6 degrees of freedom as a results of the student's final projects.

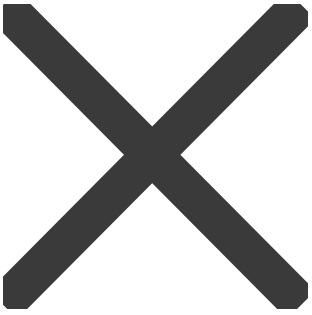

FIGURE 1
SERVICE ROBOT FOR THE INSPECTION OF TUBES

DESIGN MANAGEMENT (DMX)

Design Management Extension of the CAD system Pro/Engineer provides the data management activities of concurrent working on product development and continually communicates ongoing design activities between multiple users. It highlights interrelated design changes and updates out-of-date information directly in Pro/Engineer sessions. This collaborative environment is based on authorization controls. DMX provides administrative tools to control when changes can be made to designs and which users are authorized to make changes.

Design Management Extension provides a shared, centralized database, known as the Common space. This is used as a collection point for design activities and tracks all design iteration, relationship, and configuration information. To provide users with up-to-date design information, the Common space also communicates related design activities.
As a powerful tool for Design Management serves module Pro/Intralink Web Client, that provides enterprise-wide access to information throughout an organization. By providing access to the data management package, the Pro/Intralink Web Client enables non-engineers to access and add to the wealth of information contained in the product model. Behind every engineered part there is a wealth of information in document format, for example, specification sheets, design proposals, and timelines. The close relationship between a part and its associated documents requires that they be managed together. Pro/Intralink Web Client enables to bring documents into the design management environment of Pro/Intralink and to treat them as another type of Pro/Intralink object. Pro/Intralink Web Client provides management and viewing capabilities for Pro/Engineer files as well as files from other applications.

TOP-DOWN DESIGN

Top-down design is a method of designing a product by specifying top-level design criteria and passing those criteria down from the top level of the product's structure to all of the affected subsystems. System Pro/Engineer provides tools for such approach. The main tool for application of this method is so-called Skeleton, which contains important space claims, dimensions and functions. The top-down design process consists of a few fundamental steps:

- Creating Design Intent - Functional analysis and synthesis of a designed system using CAI system, creating end specifying of subsystems and their functions
- Creating of the Product Structure - The product structure consists of a list of components and their hierarchy within the assembly design. Pro/Engineer allows creation of subassemblies and parts without having to create any geometry. Existing subassemblies and parts can also be added to the product structure

without actually having to be assembled. Defining the preliminary product structure helps to organize the assembly design into manageable tasks that can be assigned to design teams or individual designers.

- Creation of the Skeleton Models - Skeleton models act as a 3-D layout of the assembly and can be used to represent space claims (form or fit), important mounting locations, function of an assembly (motion) and design parameters such as critical dimensions. Changes can be made to the skeleton and these changes will be propagated to the subsystems of the entire design
- Sharing of the Design Intent throughout the Assembly Structure - Top-level design information, such as important mounting locations and space claim requirements, can be placed in the top-level assembly skeleton model. This information then can be distributed to the appropriate subassembly skeleton models as needed. Each subassembly then contains a skeleton model with only the pertinent design information for that subassembly.
- Design of the individual components or subassemblies - When the skeletal representation of the assembly has been defined, and the top-level design criteria have been distributed, individual component design can begin. Components can be assembled or created in the context of the assembly.
- Managing Part Interdependencies - Managing interdependencies allows components from one design to be used in another and provides a means for controlled change and update of the entire assembly design. Tools exist in Pro/Engineer to help guide users in setting up the dependencies between parts and subassemblies that will propagate the desired changes throughout the entire design.

Top-down design methodology can be used to manage large assemblies, organize complex designs, and share information within a design team.

BEHAVIORAL MODELER (BMX)

Behavioral Modeler is such modeling system, when required features of the resulting product come into design as objectives from beginning and become one of design parameters. The other design parameters (mostly dimensions) are changed automatically to satisfy these input objective parameters.

As the objectives can be used any analysis features like simple measurements (curve length, distance between selected entities, angle between selected entities, area of surface etc.), mass properties (mass, volume of model, principal moments of inertia), curve properties, surface properties and relations between them. In addition to the rich capabilities included in BMX, the architecture is fully extensible so that design objectives and requirements can be solved by an external proprietary or third party application and the results can be included as part of the design objectives.

BMX includes capabilities for the assessment of behavior across an entire assembly. Designers can quickly and easily apply joint types to parts as they are assembled and then assess how the real product will perform. Assembly connection features, such as pin joints, ball joints, and sliders, which have been added to Pro/Engineer as part of the Adaptive Process Features, and resulting assembly constraints, facilitate the easy assembly of closed-loop systems, such as four bar linkages. Once assembled, engineers can observe how their mechanism designs will behave geometrically through interactive part dragging and user-defined motion simulations. Any location on a assembly can be dragged interactively by the user to animate the mechanism.

FIGURE 2
ANGULAR ROBOT WITH 6 DOF

COMPUTATIONAL SUPPORT (PRO/MECHANICA)

Pro/Mechanica [3] is an extensive computational support in area of mechanics that is integrated into environment of the system Pro/Engineer. One of the biggest advantages of this system is possibility of automatic multiparameter optimalization of designed product that enables for example finding of several optimal dimensions of a part or an assembly with respect to maximum stress in part, maximum reaction forces in link and other criteria. The Pro/Mechanica product line features three main products:

- Pro/Mechanica MOTION — a complete 3D static, kinematic, dynamic, and inverse dynamic simulation and design optimization tool.
- Pro/Mechanica STRUCTURE — a structural analysis package that provides structural modeling and optimization capabilities for both parts and assemblies. This product features static, modal, buckling, contact, prestress, and vibration analysis.
- Pro/Mechanica THERMAL — a thermal analysis package that features many of the capabilities of

Structure along with heat transfer analysis and thermal design optimization.

ROUTED SYSTEMS

The Routed Systems Option offers comprehensive, associative capabilities - and libraries - for electrical, cabling, and piping design through manufacturing. Electrical Wiring Schematic Layout provides tools to create fully detailed electrical wiring interconnect and ladder diagrams. All the connectivity information and the parameters associated with the components, connectors, wires, and cables are captured, the input and output of information from the schematic diagram is automated, reducing the number of errors and the need for rework. Schematic Layout automatically generates Bills of Materials (BOMs), wire lists, and component lists.

3D Cable Routing provides comprehensive functionality for the easy creation of 3D harnesses completely detailed with connectors and components. The design of harnesses is fully associative with the Pro/Engineer assembly, enabling concurrent engineering by ensuring that cable paths and lengths automatically update when assemblies are modified.

Parametrically Routed Pipes allows piping designers and manufacturers to parametrically route pipes in Pro/Engineer assemblies and quickly create 3D piping systems consisting of large fitted pipe, bent tubing, and flexible hose, with accurate bills of material for correct ordering of pipe stock, fittings, and equipment.

Designers can use large library of components: connectors, pipefittings, electrical symbols, piping and heating symbols etc.

SIMULATION OF THE ROBOTIC SYSTEM

Tools for simulation of mechanical subsystems behavior are integrated into system Pro/Mechanica Motion. During the complex technical solution of the robotic systems their individual subsystems interact in such a degree that appears the necessity to realize a simulating model of the mechatronic system on the whole. For this purposes serves module Pro/Mechanica EQUATIONS that enables creation of an encapsulated model of a mechanism and export of this model in an independent simulation program. This way Pro/Mechanica serves as a preprocessor for creating a complicated mechanism model in encapsulated form.

The equations of motion are generated symbolically and used to produce automatically coded C subroutines. These subroutines are compiled automatically, and then linked together with preexisting numerical libraries. This forms a self-contained linkable object module containing the mathematical equivalent of the model and routines for accessing and analyzing it. This linkable object module has to be linked with a driver program written in C or C++ to make calls to its routines. A general simulation software tool Matlab (Simulink) provides means for integrating of an encapsulated model of mechanism into entire mechatronic model.

A common use for such simulations is control system verification, in which a high-fidelity model of the mechanical subsystem is desired. In this context, the simulation includes models of the control system sensors, actuators, and control algorithms. All of these entities may be dynamical systems in their own right, and may exist as working blocks within the simulation block library.

CONCLUSION

Under pressure of high demands on engineering solution of technical systems is necessary to apply the modern methodical approaches and tools to its design that lead to essential improvement of the quality and shortening of the cycle development – manufacturing. Presented software development line meets all designers' requirements to 3D creation of the parts and assemblies, analysis of the mechanisms and its optimization and offer tools for so-called parallel (concurrent) design, when engineering system and its subsystems are designed concurrently by more subjects, which operate above common database of the created product. This approach respects also another important aspect of the engineering system design and this is complex mechatronic approach to technical solution, when they are at the same time with mechanical subsystem created also driving and control subsystems, with optimal allocation of functions among individual subsystems. This approach carries high demands to project management and his coordination, but considerably accelerate solution. Developed methods and also software systems that form the "software development line" have been involved into educational process at the Mechanical Engineering Faculty VSB – Technical University of Ostrava since 1997.

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