ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Extra Fascicule. (ISSN 1584 – 2673)

[1.]Krassimir E. GEORGIEV

ADVANCED DESIGN OF MECHATRONIC WORKSTATIONS FOR TECHNOLOGICAL CONTACT OPERATIONS

[1.]BULGARIAN ACADEMY OF SCIENCE, INSTITUTE OF MECHANICS, MECHATRONIC SYSTEMS DEPARTMENT, SOFIA, BULGARIA

ABSTRACT: The objective of this paper is to outline the necessity of understanding vertical and horizontal system integration in advanced mechatronic systems. A Methodology, theoretical aspects and some practical results of creating and research of distributed mechatronic environment are presented, based on robotic assembly systems and 3D virtual models. A global algorithm for simulation and advanced design is presented as well.

KEYWORDS: advanced mechatronic systems, system integration, global algorithm, simulation

❖ INTRODUCTION

The flexibility of a mechatronic system can be obtained either by making its mechanical and electronic part as universal as possible or by constructing a large set of simple models which will be interchanged whenever the task of the system changes. In the latter case the mechanical and electronic structure of the system can be tailored exactly to the needs of the task at hand.

In both cases the control of such system is implemented in software. The software should be structured as a library of procedures and functions possibly concurrent, which will be used as software blocks for construction of the control system.

Virtual product models, together with adapted development methods and processes are the key to an integrated view of development, manufacturing and usage of products as they promise a significant increase of efficiency, quality and flexibility of product development.

For ROBOTIC and MECHATRONIC systems the coupling of subsystems could be realized on three different levels – physical modeling, mathematical modeling and behavioral modeling. At physical description and modeling a system is represented by physical models, for example as a multibody system, containing rigid bodies, joints and coupling force elements. The mathematical description and modeling is a representation of a system by mathematical equations which can be derived from the physical model description, e.g. the equations of motion of a multibody system.

The simulation results of the mathematical model description are considered as the behavioral model description - the trajectories of position and velocity of the bodies. Then coupling of models in the behavioral model description is referred to as simulator coupling, modular modeling and simulation or virtual assembly of them. The simulation of the global system is realized by time discrete linker and scheduler which combines the inputs and outputs of the corresponding subsystems and establishes communication between the subsystems to discrete time instants. Therefore it is possible to use different software packages for each subsystem and then to link the solvers together. Now the general modeling and design of MS may be presented in form with respective levels of task simulation and planning (distributed mechatronic environment).The modular description of systems allows for independent and parallel modeling of the internal dynamics of each subsystem. The inputs and outputs of the physical model are also physic quantities such as forces or motion of the bodies.

Here the main goal is to present a modular –block concept, mechatronical approach and 3D virtual environment for real time computer control, complex simulation and interactive user’s design solutions of mechatronic (robotic) systems for contact operations.

❖ DESIGN APPROACH AND MODELING OF DESIGN ALTERNATIVES

The full dynamic model is presented in previous author’s publications and here we shortly note that, the models derived, based on the Lagrange’s equations have the advantage that they are in closed form concerning the geometrical, inertial and functional parameters of the mechanical system. The joint reactions are excluded and considering the immense computational power of today’s computers one can successfully explore various aspects of the dynamic modeling of the robotized system. This enables us to carry out dynamic synthesis of the technological movements and to build a strategy for dynamic behavior. Based on the derived equations we can compute the appropriate joint torque of the regional structure of the assembly robot, considering the predefined generalized coordinates $q_i = q_i(t)$ and the finite increments of the generalized coordinates $o_i = |q(t_i) - q(t_i - 1)|$, in order to minimize to total system energy and power consumption. Using MATLAB and Solid Works environments, we can derive effective solutions for the corresponding parameters m_i, l_i, h_i, J^i_{sk} as well as get results applicable in the practice in order to achieve higher velocities and minimal duration of the technological assembly.

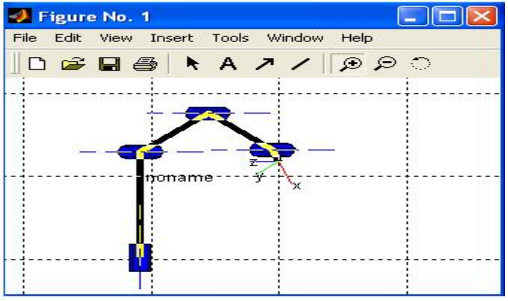
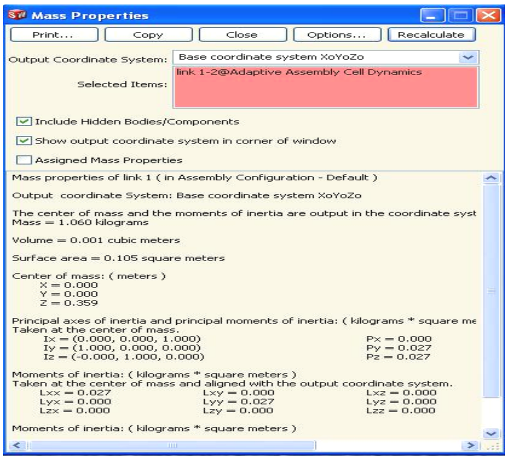


Fig. 1. Matlab simulation of robotic regional structure



Output Coordinate System: Base coordinate system XoYoZo

Selected Items: link 1-2@Adaptive Assembly Cell Dynamics

☑ Include Hidden Bodies/Components

☑ Show output coordinate system in corner of window

☐ Assigned Mass Properties

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Mass properties of link 1 ( in Assembly Configuration - Default )

Output  coordinate System: Base coordinate system XoYoZo

The center of mass and the moments of inertia are output in the coordinate syst
Mass = 1.060 kilograms

Volume = 0.001 cubic meters

Surface area = 0.105 square meters

Center of mass: ( meters )
      X = 0.000
      Y = 0.000
      Z = 0.359

Principal axes of inertia and principal moments of inertia: ( kilograms * square me
Taken at the center of mass.
       Ix = (0.000, 0.000, 1.000)                        Px = 0.000
       Iy = (1.000, 0.000, 0.000)                        Py = 0.027
       Iz = (-0.000, 1.000, 0.000)                       Pz = 0.027

Moments of inertia: ( kilograms * square meters )
Taken at the center of mass and aligned with the output coordinate system.
      Lxx = 0.027              Lxy = 0.000              Lxz = 0.000
      Lyx = 0.000              Lyy = 0.027              Lyz = 0.000
      Lzx = 0.000              Lzy = 0.000              Lzz = 0.000

Moments of inertia: ( kilograms * square meters )
```

Fig.2. Solid works simulation of mass/inertia properties of robot links

Using the original author's idea of designing the system from modular structures with 3R active joints and adaptive sockets (accommodating the concept of local dynamic compliance), we are able to combine higher speed, thus obtaining solutions to the extremely difficult assembly tasks of prismatic details without chamfers. After the virtual 3D model is built (using Solid Works environment) it is possible to conduct various simulations. This enables us to research the model, carry out different scenarios to see what will be the behavior of the real adaptive assembly cell. The results from the kinematic simulations are presented further in the paper. However the question of the validity of the model is always open. Even in the user's guide of the simulation product is written that one shouldn't rely solely on the obtained results. That is why it was necessary to validate the results. For this purpose a mathematical kinematic computer model was built and researched using Matlab v6 combined with the specialized software toolbox Robotics Toolbox. The kinematic model was introduced using Denavit-Hartenberg convention. The direct and inverse kinematics was solved and the results were exported to the 3D robot model .Based on respective simulations we obtain the following results: at lower values of angular velocity of driving shaft and higher spring stiffness the driving robot torques are extremely low and the influence of initial contact between the assembled details is minimal. This fact is confirming at the investigation of robot joint reactions at the computer simulations. The ultimate purpose is to achieve a system performance superior to what can be achieved by traditional development and design cycle. The author's idea follows this approach and mechatronics principles to close the open kinematic chains, using control and information loops. Then is possible to estimate different parameters of RS, to compliance them and to achieve complex properties: Adaptively, reconfiguratible structure, energy efficiency and high performance.

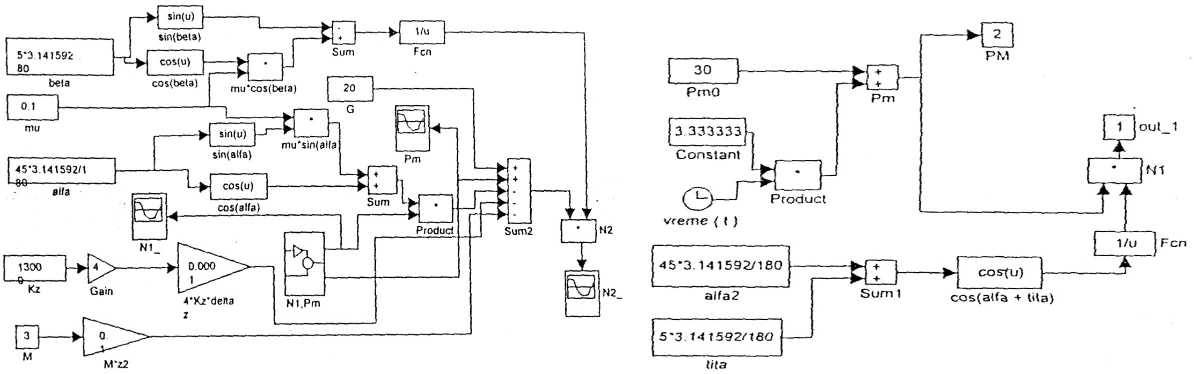


Fig.3 Simulink modeling of contact stages, during adaptive assembly

Therefore for the 6 R robotic structure the axis models are represented with the modules (blocks)- controller, motor, gearbox (including gear elasticity, damping and bearing friction) and mechanical part The calculated parameters are involved in the 3D kinematic model of the robotic system, using Solid Works 2005 - Cosmos Motion 2005. It is also possible to simulate the space contact at the adaptive assembly, using appropriate data of materials and dry friction forces. The respectively modular component of distributed mechatronic environment is shown on fig 4.

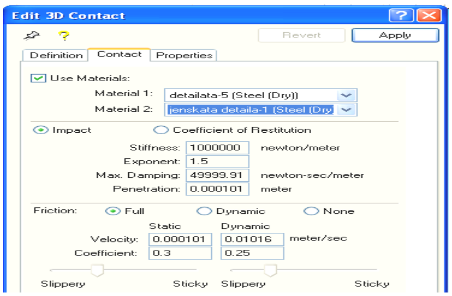
The mechatronic environment consists of different number modular components and mechatronics procedures. Each procedure consists of 5 steps:

- Initial synthesis of 3D kinematical models
- Preliminary metrical synthesis
- Preliminary synthesis of control functions, direct and inverse dynamic tasks

- Using multivariant analysis and varying the important characteristics to obtain optimal design of building modules
- Final synthesis of the control functions (optimization) accounting for the full dynamic models

The full process of modeling and design we denote as synthesis by using analysis.

The modular component structure of environment supports a rapid exchangeability of models and allows spreading out modeling tasks and skills to different researchers in order to achieve sophisticated integration of capable models, reduce developing time and costs. The given examples show both the necessity for applying a mechatronic design and simulation environment. This way the feasibility of highly complex systems can be studied by the combined efforts of numerical computation, simulation and CAD design (fig.5,6,7) . Effective system modeling needs of distributed simulation environment and respective subfunctions and subconfigurations F^{i}_{J}, C^{i}_{J} (fig.7), concerning to database of different components: Sockets, actuators sensors, controllers, etc.



☑ Use Materials:

Material 1: detailata-5 (Steel (Dry))

Material 2: jenskata detaila-1 (Steel (Dry

● Impact ○ Coefficient of Restitution

Stiffness: 1000000 newton/meter

Exponent: 1.5

Max. Damping: 49999.91 newton-sec/meter

Penetration: 0.000101 meter

Friction: ● Full ○ Dynamic ○ None

	Static	Dynamic	
Velocity:	0.000101	0.01016	meter/sec
Coefficient:	0.3	0.25	

Fig 4 .Module of 3D contact interaction

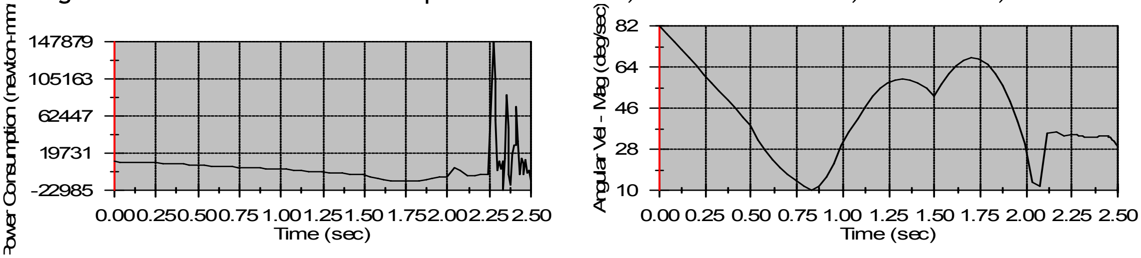


Fig. 5. Power consumption and angular joint velocity

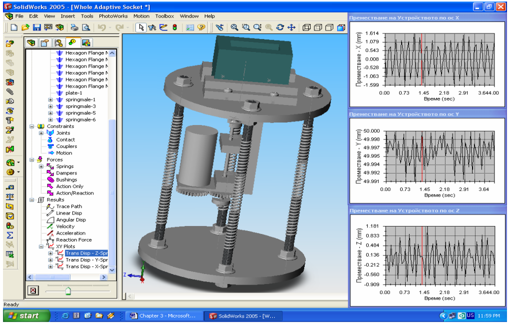


Fig.6. Modeling and simulation of adaptive assembly socket

In accordance with the above mentioned principles a virtual model of an adaptive assembly socket is realized and it is further more developed to a whole The three dimensional model of the device is built using Solid Works 2005 environment assuming that all main dimensions of the real model are exactly reproduced. The correct construction and mating of all the details in the assembly allows us to create a virtual assembled model of the adaptive assembly socket and a family sockets.

Furthermore a 3D model of a whole robotized unit is developed. The goal is to investigate and research the process of adaptive assembly using the developed devices. There have been various simulations with different parameters of local micro motion.

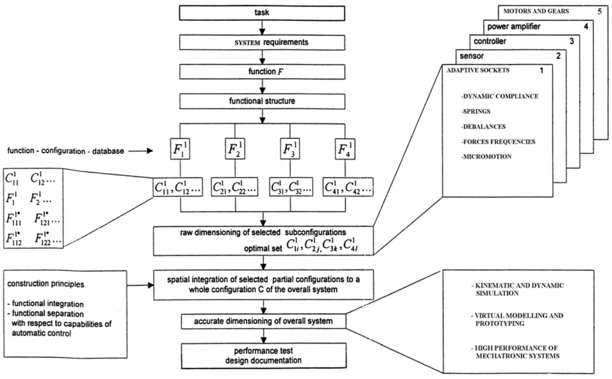


Fig.7. Design and simulation algorithm (subfunctions and subconfigurations of complex robotic system)

Based on this methodology and interactive mechatronic environment, a real structure and solutions of adaptive robotic system are obtained. Real positioning accuracy and speed are improved, more than 15 % and the development time reduced more than 40%. Emphasis has been put on lightweight design and simulation, reconfiguration and different controller solutions. A raw draft of a controller or topological optimization can already be done with quite simple mathematical descriptions at an early stage of development. The model development can be performed in steps and adding of sensors will not affecting the modeling procedure of the submodel. The massive computational resources now available make it possible to treat the full parametric description of a much more general class of robotic units ,so the researcher can think much more freely of generic design and control strategies which should lead to a maximum level of productivity of new ideas and technology evaluated by complete simulations. The next step is to use elaborate ways of modeling and description methods to cover all subtasks of this system in an integrative matter.

❖ SENSOR BASED TASKS- MODELING AND SIMULATION

Let us first summarize the similarities and differences between non-contact sensor based tasks and force based tasks. The task-function approach applies to both problems. The implementation of a control law involves two levels:

- High level consist of specifying the task to be performed and of choosing the vector of signals to be regulated in order to fulfill the user's objectives (choice of so called task function)
- Low level consists of writing and computing a control law (actuator torques):

$$T = M(q)\ddot{q} + N(q,\dot{q},t), \dim(q) = \dim(M) = n(1) \qquad (1)$$

where: T is the vector of applied actuator torques; M is the kinematic energy matrix; N gathers gravity, coriolis, centrifugal and friction forces; q, $\dot{q}$ - constitute the natural state vector of the system.

It may be shown that an efficient way to specify the objective that researcher wishes to reach with the robot consists of defining an output n-dimensional function e (q,t), called task to be regulated to zero during a time interval [0,T], starting from initial position q_0. A realistic approach to practical design and simulation of control laws is suggested in the form:

$$T = -K\hat{M}\left(\frac{\partial \hat{e}}{\partial q}\right)^{-1} \underline{G}\left(\mu\, \underline{D}\, e + \frac{\partial \hat{e}}{\partial q}\dot{q} + \frac{\partial \hat{e}}{\partial t}\right) + \hat{N} - \hat{M}\left(\frac{\partial \hat{e}}{\partial q}\right)^{-1} \qquad (2)$$

where: symbol ^ points out that models (approximations, estimates) are used instead of the true terms. In this general expression all the terms except μ, D, G are allowed to be functions of q and t (here f comes from the difference of e, G and D are positive matrices; K and μ are positive scalars, all to be tuned by the researcher). Some terms ($\hat{M}, \hat{N}$) depend mainly on the used robots, while others also depend on the considered tasks, sampling period of the control laws. The performance of the feedback control loops is very sensitive to the sampling rates and propagation delays between measurements and control emission. Their value must be guaranteed in order to tune the gains of the loop.

At the equilibrium i.e. in the absence of motion the model reduces to:

$$T_{eq} = G(q_{eq}) + T_c = G(q_{eq}) + J^T(q_{eq})F_{eq} \qquad (3)$$

where: J is the Jacobian matrix associated with the gripper. The differences between two classes of tasks – contact and noncontact come in part, from the physical characteristics of real contacts. For example – friction forces have to be modeled so as to estimate their contribution to the measured contact force. Then we may say that virtual contacts are easier to control than real contacts (assembly, grinding and polishing). Some knowledge of the interaction matrix is needed in the case of non-contact sensors and in both cases fine control of sensor-based tasks may require the use of dedicated estimation algorithms. Problem solutions very commonly rely on decomposition into smaller more easily understood solutions, ie the braking down of a problem into soluble parts. The whole process of investigation and creation can be represented in the form of splitting, effectively component solutions and integration after that via electronical (information) means. Physical integration is possible as well, for example intelligent actuators with sensors and etc.

CONCLUSION

- To improve the reliability of Complex robotic systems ,make them faster and reduce the costs we have to use mechatronic environment for design and investigation,
- mechatronic modular-parameric approach to the horizontal and vertical integration and CAD integrated solutions (3D solutions)
- Sensor based control via aggregation of sensor data
- Virtual prototyping of mechanics and control via iterative mechatronic procedures (including so called hardware in the loop simulations)

This is perhaps the most efficient and modern way to the creation and application of High-performance intelligent manufacturing systems in the industry.

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