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ROBOTIC WORKSTATIONS WITH RECONFIGURATION OF STRUCTURE

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Abstract
This paper aims to suggest some solutions for reconfiguration of robotic systems (RS) A Methodology, theoretical aspects and some practical results of distributed mechatronic environment are presented, based on robotic assembly systems and 3D virtual models. Some important issues of hardware in the loop simulations are presented as well.
Key words:
mechatronical approach, robotic systems, modeling, 3D virtual simulation

1. INTRODUCTION

The modular description of mechatronic systems (robotic workstations) 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 of workstation. [1,2,3,4,5]

It is assumed that the conditions for decoupling of movement are present. Sensors for position and velocity of joint displacements are present, assuming that the elasticity of links is considered as zero. It is also assuming that additional system devices like positioning tables, feeders, conveyors, adaptive sockets (patented by the author) are presented in the system structure. 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 solutions.

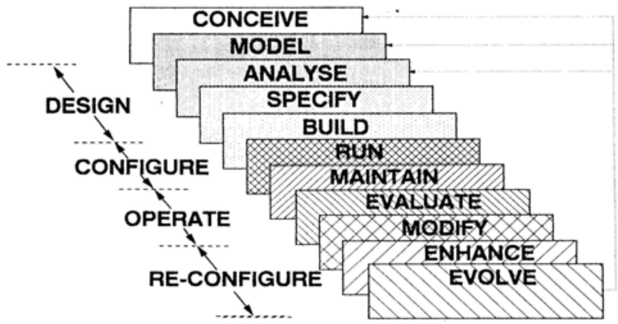

Fig.1. - Design – redesign and reconfigured process

2. MECHATRONIC APPROACH FOR MODELLING AND DESIGN OF ROBOTIC WORKSTATIONS

The key idea of Mechatronics is a system –thinking approach to intelligent – machine design by synergistically combining Mechanics, Electronics and Control during the development. 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: Adaptivity, reconfiguratible structure, energy efficiency and high performance.(fig 1) 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 – Figure 2.

The goal is to achieve efficiency of the technological macro movements, high speed, productivity and energy efficiency. The results from this research are very important when designing complex methodology and creating new strategies for high performance and human scale intelligent mechatronic systems. Following so called design–redesign procedures (fig.1), based on respective stages of investigation we have to simulate the dynamic of robotic workstations in order to control overall system most optimally.

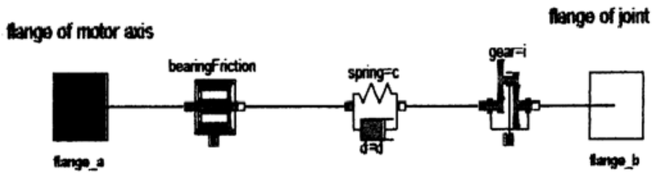

Fig.2 – Servo controlled drives for robotic workstations

3. DYNAMIC MODELLING AND VIRTUAL SIMULATION

The object and basic example of interest is a generalized structure (R⊥R||R) of an anthropomorphous technological robot with three degrees of freedom (three regional macro motions) and corresponding generalized coordinates: $q_1 = \varphi_1; q_2 = \varphi_2; q_3 = \varphi_3$, assuming that the links are rigid bodies and the joints are frictionless and non-compliant. :

a) The dimensions of the links are given in advance (lengths $l_i; i = 1,2,3$) and their mass $m_i; i = 1,2,3$ are computable as well as the corresponding axial and centroidal moments of inertia from the individual tensors of inertia $J^{(i)}_{s_k}$; h_i – distances to the links gravity centers.
b) Link 1 rotates with $\dot{q}_1$, link 2 realizes spherical motion with angular velocity $\dot{q}_2 = \dot{q}_1 \overline{k_1} + \dot{q}_2 \overline{k_2}$; link 3 does a complex movement represented by a translation along with the centroid and a spherical movement around it: $\dot{q}_3 = \dot{q}_1 \overline{k_1} + (\dot{q}_2 + \dot{q}_3)\overline{k_3}$.
c) We assume that the gripper is fixed to link 3.

The equations of differential motion are derived using the Lagrange's equations:

$$\frac{d}{dt}\left(\frac{\partial E_k}{\partial \dot{q}_i}\right) - \frac{\partial E_k}{\partial \dot{q}_i} + \frac{\partial E_p}{\partial q_i} = M_i^d \tag{1}$$

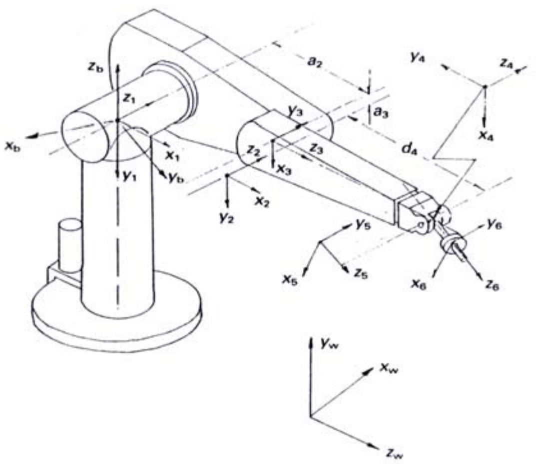

Fig.3 - Robot structure with space coordinates

Although the energy –based method of Lagrange is originated in the theory of mechanics it is also capable to generate the coupled electromechanical equations including electrical networks. In this case for all system components e.g. rigid bodies, electrical elements etc., there has to be set up an own energy–term. They are summed up and result in the total kinetic energy, where the differential equations for the mechanical displacements and electrical currents will be obtained from.

This enables us to carry out dynamic synthesis of the technological movements and to build a strategy for dynamic behavior and control when performing assembly operations. 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: $o_i = |q(t_i) - q(t_i - 1)|$. Using MATLAB, we can derive effective (iterative) 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 operations of the joint drives. We investigate the complex motion in a predefined operational space and the affordable reserves of:

a) Mass of assembled details
b) Lengths and mass of the links with possible reduction and accommodating to given peripheral automation (positioning and feeding tables etc.)
c) Minimal transporting time between points.

The direct dynamics is solved numerically with coordinated (simultaneous) control of the three motors for regional macro motion and given trajectory $x_i(t) \rightarrow q_i(t)$ for determining the joint torque. We define a cosine pattern for individual joint velocities $(\dot{q}_i)$. Given the maximum velocity $\dot{q}_{max}$ for achieving the coordinated regional macro motion, we introduce the condition that the axis realizing the largest rotation Δq has $\dot{q}_{max}$, while the other joint axis have smaller velocities in order to complete the motion simultaneously $[\Delta q_i;[t_0, t_1]]$. The algorithm for speed control of the regional macro motion is given by:

$$\dot{q}_i(t) = \dot{q}_{max}[q_i(t_i) - q_i(t_0)]/(\Delta q)_{max} \tag{2}$$

The global algorithm of mechatronical parameter – modular approach is following 3 main stages of the investigation: initial synthesis – multivariant analysis – final synthesis, using 3D software environment Solid Works (for physical modeling)-Fig.3, Malab/Simulink for mathematical modeling and Modelica/Dymola for behavioral modeling and simulation. Then we can determine the main goal of author's approach as: estimation of control influence on the geometry, mass and energy of RS and consisting modules, respectively. Effectively hardware –in the loop simulation is easy to obtain.

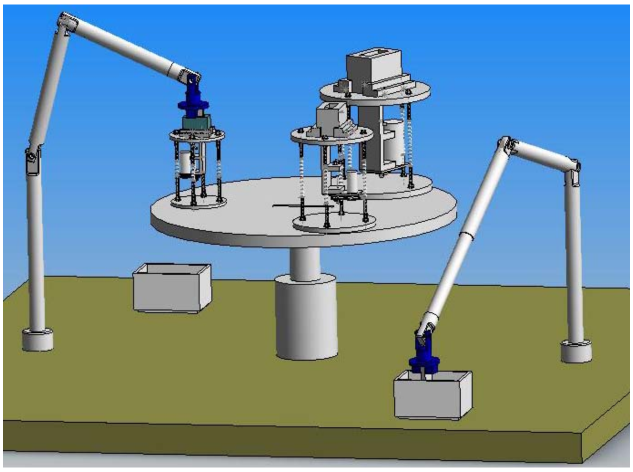

Fig.4a – Virtual 3D simulation of Robotic systems, by using of distributed mechatronic environment (adaptive sockets and positioning table are presented)

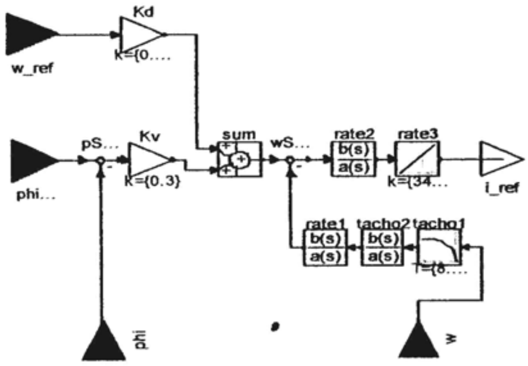

Fig.4b - Respectively joint controller solution

The proposed recommendations lead to optimal ratios between robot link lengths and masses and using 3D interactive solutions is easy to obtain optimal ratios for actuator sizes and placemen.

Table 1. Joint position at modeling and design

t [s]	q_1 [rad]	q_2 [rad]	q_3 [rad]	q_4 [rad]
0	0.0000	-1.0823	1.2478	1.4053
2	0.0000	-1.0818	1.2497	1.4029
4	0.0000	-1.0796	1.2584	1.3920
6	0.0000	-1.0766	1.2707	1.3767
8	0.0000	-1.0744	1.2794	1.3658
10	0.0000	-1.0739	1.2813	1.3633

Table 2. Joint velocity at modeling and design

t [s]	qd_1 [rad/sec]	qd_2 [rad/sec]	qd_3 [rad/sec]	qd_4 [rad/sec]
0	0	0	0	0
2	0	0.0065	0.0258	-0.0323
4	0	0.0146	0.0580	-0.0726
6	0	0.0146	0.0580	-0.0726
8	0	0.0065	0.0258	-0.0323
10	0	0	0	0

Table 3 – Joint acceleration at modeling and design

t [s]	qdd_1 [rad/sec^2]	qdd_2 [rad/sec^2]	qdd_3 [rad/sec^2]	qdd_4 [rad/sec^2]
0	0	0	0	0
2	0	0.0487	0.1933	-0.2420
4	0	0.0243	0.0966	-0.1210
6	0	-0.0243	-0.0966	0.1210
8	0	-0.0487	-0.1933	0.2420
10	0	0	0	0

The calculated parameters (presented on the tables 1, 2, 3) 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.

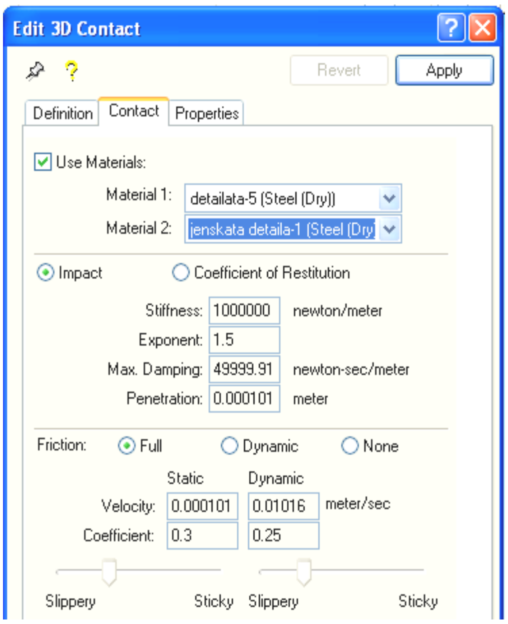

Fig.5 - Module of 3D contact interaction

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

1. Initial synthesis of 3D kinematical models
2. Preliminary metrical synthesis
3. Preliminary synthesis of control functions, direct and inverse dynamic tasks
4. Using multivariant analysis and varying the important characteristics to obtain optimal design of building modules
5. 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 to spread 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. 4, 5) Effective system modeling needs of distributed simulation environment and respective sub functions and sub configurations $F^i{}_{J}$, $C^i{}_{J}$, concerning to database of different components: Sockets, actuators, sensors, controllers, etc.

4 .ROBOTIC WORKSTATIONS FOR CONTACT TASKS

Main aspects of this research could be formulated as follow : How to combain miro and macromotion and orienting of details ; How to create hybrid system for different contact operations – assembly, grinding and polishing ; Suggest new possibilities for buiding of Rapidly adaptable manufacturing cells; Discussion on easy reconfiguration of the robot workststion (cell) and ad-hoc integration of peripherals; Problems of cooperating robots and etc. The system state can be described as:

$$S = < e , r , c > \qquad (3)$$

Where s, r, c are usually expressed as vectors of the state of the effectors, sensors and control. The row data obtained from real sensors usually cannot be utilized directly to control the system, so it has to be transformed into a useful form and this transformation is called data aggregation. As a result of this a virtual sensor reading v is obtained:

$$V = F_v (r) \text{ - here } F_v \text{ is called aggregating function} \qquad (4)$$

The software should be structured as a library of concurrent procedures and functions, which will be used as software blocks for construction of the control system. These software blocks must have the ability of reading and influencing each of the components of the system state – e,r ,c ., so whether the mechanical and electronical part are modular or not the software part can be created as a set of modules and in such case at least the software component of the system can be tailored to the needs of the executed task . The proposed methodology of constructing controllers take cares of 2 problems: one is aggregation of data obtained from real sensors and the other is: sincronization between sensor data processing and the effector motions.

$$V = F^*{}_v (r, e,c) \qquad (5)$$

Now the system state s can be decomposed by taking into account that the system can have several effectors and rather aggregated sensor readings v than real sensor readings r are used by the researcher.

$$s = < e_1 , \ldots\ldots, e_k , v_1, \ldots, v_n ,c > \qquad (6)$$

where: k is the number of effectors in the system; n is the number of virtual sensors; Treating the system as a discrete time system, the next state of each of the effectors can be computed using a transfer function F_e :

$$E_j^{I+1} = F_e \, (e^i_j , v^i_1 \ldots\ldots v^i_n , c^i) ., \quad j = 1 \ldots\ldots k \qquad (7)$$

Each effector control process creates or kills virtual sensor processes according to the needs of motion control. The effector control processes in each step I obtain data from the virtual sensor processes. The both kinds of processes can be treated as device dependent drivers. Both kinds of processes change the state c of the control subsystem. The virtual sensor process reads the real sensors, aggregates the obtained data and sends the result through data pipelines to the effector control process. For further speed-up, each effector control process can be portioned into 3 concurrent processes: future trajectory position generation taking into account virtual sensor readings, solving inverse kinematics problem and executing the joint control algorithms (reaching the generated position).

$$T_{min} = f\,(N, m^i, l^i, v^i, t_k) \tag{8}$$

where: N - number of details, m^I - mass of the details, L_I - details dimensions, V^i – velocity, T_k - time of contact operations;

$$T_{min} = 2\,S^n{}_i\,N^I\,(H_I / v_I + t_I) \tag{9}$$

where : S denote the sum of respective calculations on given I-group of details ; H_i – an optimal distance to the placement of group of details ;

5. CONCLUSION

Based on this methodology and interactive mechatronic environment, a real structure and solutions of robotic workstation 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 sub model. 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.

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