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COMPUTER SCIENCE MEETS AUTOMATION

VOLUME I

Session 1 - Systems Engineering and Intelligent Systems

Session 2 - Advances in Control Theory and Control Engineering

Session 3 - Optimisation and Management of Complex Systems and Networked Systems

Session 4 - Intelligent Vehicles and Mobile Systems

Session 5 - Robotics and Motion Systems

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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Paper submitted after copy deadline

2 Advances in Control Theory and Control Engineering

Y. Litvinov / S. Karpovich / A. Ahranovich

The 6-DOF Spatial Parallel Mechanism Control System Computer Simulation

ABSTRACT

The 6-DOF spatial parallel mechanisms are frequently used in industrial robots, motion systems, flight training, test systems, etc. The 6-DOF spatial parallel mechanisms enable development of controllable dynamical electro-mechanical systems, by providing sophisticated 3D movements. However, such systems' control system simulation problem still remains one of the main difficulties in the sphere of robotics [1].
The described 6-DOF spatial parallel mechanism control system simulation is intended for using in motion system construction for working platform 3D movement.

THE 6-DOF SPATIAL PARALLEL MECHANISM

A 6-DOF (degree-of-freedom) spatial parallel mechanism is composed of 6 independent legs connecting the mobile platform with the base. Each of these legs is a serial kinematic chain that is controlled by one motor which actuates one of the joints. The structure chart of the investigated spatial parallel mechanism, presented on Fig. 1, is capable of realizing sophisticated 3D movements of mobile platform. The $A_1A_2A_3A_4A_5A_6$ mobile platform is directly connected to $O_1, O_2, \ldots, O_6$ motors driving shafts by $l_1r_1, l_2r_2, \ldots, l_6r_6$ kinematic joints. The 6-DOF spatial parallel mechanism supports three coordinate axial displacements (x , y , z) and three angular rotations (ψ − yaw, θ − pitch, φ − roll) of the mobile platform about the appropriate coordinate axes respectively.

THE INVERSE KINEMATIC PROBLEM SOLUTION

The output position and orientation of the platform directly correspond to the input actuation from motors driving shafts. Therefore, the 6-DOF spatial parallel mechanism control system modeling often starts with the inverse kinematic problem (IKP) solution, that implies the determination of the input variables (motors shafts rotation angles $\sigma_1, \sigma_2, \sigma_3, \sigma_4, \sigma_5, \sigma_6$) out of the output variables (platform position x, y, z and orientation ψ, θ, φ) [2].

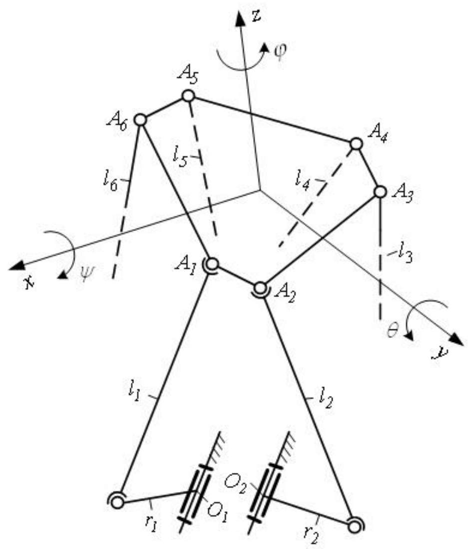


Fig. 1. The 6-DOF spatial parallel mechanism structure chart

The input variables are connected with the output variables by the appropriate equations. The initial equations analysis showed that the inverse kinematic problem doesn't always have general solution. The reason is, that for a given set of output variables there are several valid sets of input variables. A new developed program with implementation in MATLAB/Simulink environment software enables inverse kinematic problem solution for mechanism type proposed on Fig. 1. The inverse kinematic problem computing program screenshot is presented on Fig. 2.

The program provides both immediate and step-by-step solution of the inverse kinematic problem for the 6-DOF spatial parallel mechanism. The step-by-step mode enables consecutive computing of the inverse kinematic problem for specified incremental changes of $x, y, z, \psi, \theta, \varphi$ variables on every step. Moreover, the platform's movement boundary region can be build on the basis of the inverse kinematic problem computing algorithm. For instance, the platform's movement boundary regions for different ψ, θ, φ constant angular values and x, y, z variables incremental changes are presented on Fig. 3.

As it can be seen on Fig. 3 the platform's movement boundary region volume has a nonlinear dependence of angular values ψ, θ, φ.

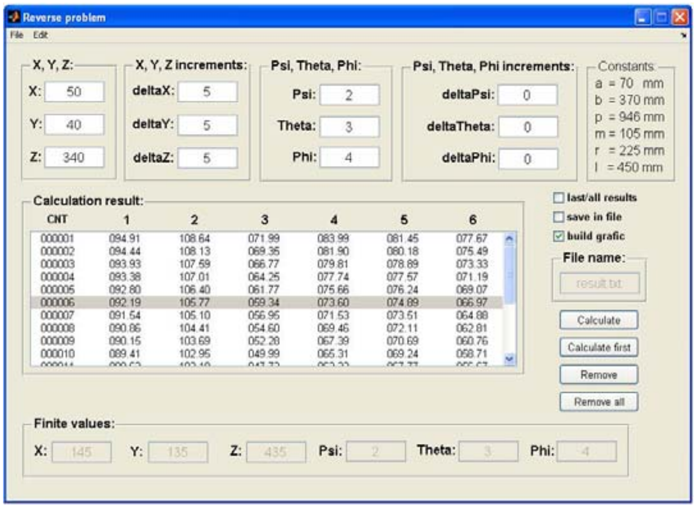
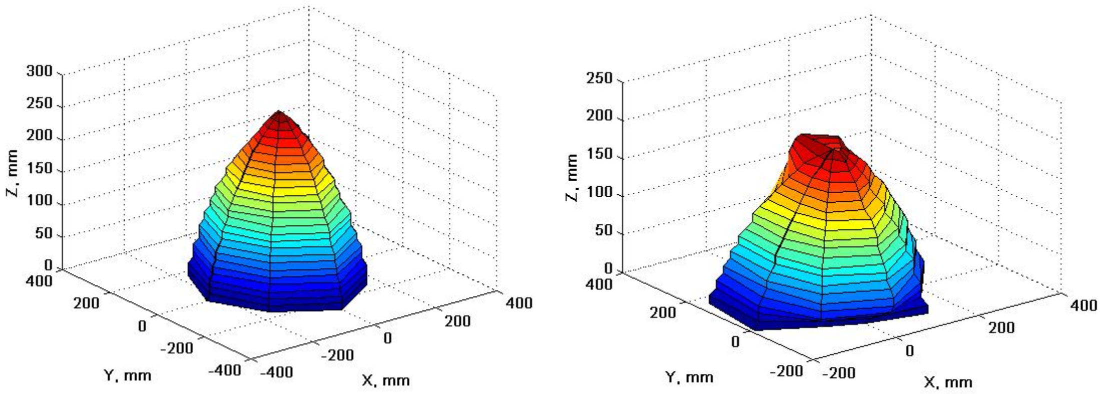


Fig. 2. The inverse kinematic problem computing program

The experiment carries out resulted in boundary region with maximum volume determination with zero angular values ψ , θ , φ .



$\psi = 0°, \theta = 0°, \varphi = 0°$ $\psi = 10°, \theta = 10°, \varphi = 10°$

Fig. 3. The platform's movement boundary regions

In order to build proper 6-DOF spatial parallel mechanism control system simulation the six control motors shafts rotation angles changes should be investigated which directly correspond to the determined platform movement. The inverse kinematic problem computing program provides possibility for building motors shafts rotation angles changes trajectories according to platform's movement from initial to final position and orientation (Fig. 4). The motors shafts rotation angles trajectories are obtained by the inverse kinematic problem solution for specified incremental changes of x , y , z , ψ , θ , φ variables on every step. On Fig. 4 can be seen that the rotation angles has nonlinear variation trajectories and different total angular changes.

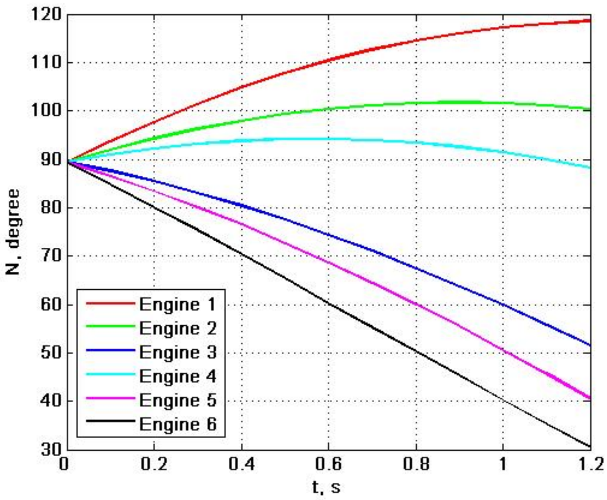


Fig. 4. The motors shafts rotation angles changes trajectories

This means that all six motors to actuate the 6-DOF spatial parallel mechanism must be controlled independently, bringing the demand of six regulators implementation.

THE 6-DOF SPATIAL PARALLEL MECHANISM CONTROL SYSTEM COMPUTER SIMULATION

The 6-DOF spatial parallel mechanism control system consists of the inverse kinematic problem computing module (IKP module), regulators (one per motor) and hardware components to control six motors. However, regulators synthesis and, therefore, control signals tuning are among the main problems that deal with working out such a control system. The rapid solution is to reconstruct simulation loop feedback system in MATLAB/Simulink environment, composed of the control system model and motor model, to carry out simulation (Fig. 5).

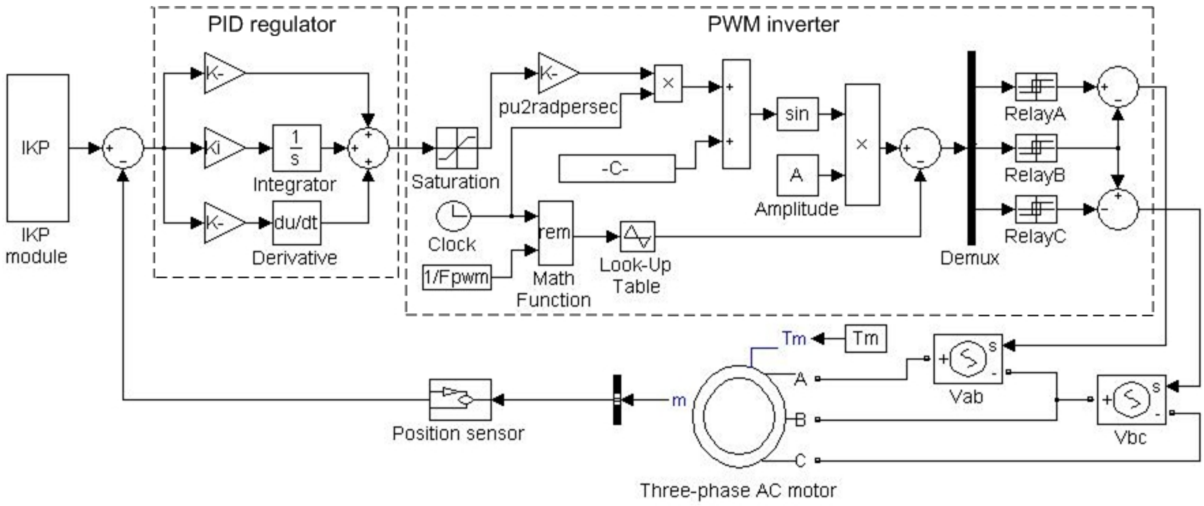


Fig. 5. Simulation system block diagram for one three-phase AC motor

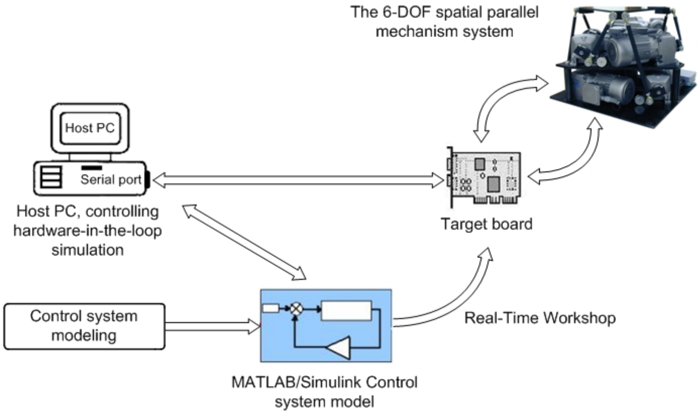
The 6-DOF spatial parallel mechanism control system modeling in MATLAB/Simulink environment starts with such simulation loop feedback system reconstruction. Computer simulation was carried out with usage of PID regulators and three-phase AC motors. The simulation block diagram of one three-phase AC motor control system is presented on Fig. 5. As it can be seen on Fig. 5, AC motor is fed by PWM signals produced by PWM inverter. The three-phase AC motor simulation model is implemented on the basis of the following equation sets [3]:

$$\begin{cases} V_{qs} = R_s i_{qs} + \dfrac{d}{dt}(L_s i_{qs} + L_m i_{qr}) + \omega(L_s i_{ds} + L_m i_{dr}); \\ V_{ds} = R_s i_{ds} + \dfrac{d}{dt}(L_s i_{ds} + L_m i_{dr}) - \omega(L_s i_{qs} + L_m i_{qr}); \\ V_{qr} = R_r i_{qr} + \dfrac{d}{dt}(L_r i_{qr} + L_m i_{qs}) + (\omega - \omega_r)(L_r i_{dr} + L_m i_{ds}); \\ V_{dr} = R_r i_{dr} + \dfrac{d}{dt}(L_r i_{dr} + L_m i_{ds}) - (\omega - \omega_r)(L_r i_{qr} + L_m i_{qs}); \\ T_e = p(i_{qs}(L_s i_{ds} + L_m i_{dr}) - i_{ds}(L_s i_{qs} + L_m i_{qr})). \end{cases} \tag{1}$$

$$\begin{cases} \dfrac{d}{dt}\omega_m = \dfrac{1}{2H}(T_e - F\omega_m - T_m); \\ \dfrac{d}{dt}\theta_m = \omega_m. \end{cases} \tag{2}$$

In accordance with the (1,2) description, the simulation can be carried out with different three-phase AC motors depending on electrical and mechanical parameters which can be set directly via new developed interface. The developed simulation system, implemented in MATLAB/Simulink, enables PID regulator tuning according to motor output characteristics (rotor speed, rotor rotation angle, electromagnetic torque, rotor and stator currents).

The 6-DOF spatial parallel mechanism control system computer simulation is implemented as the hardware-in-the-loop control model simulation in MATLAB/Simulink modeling environment. MATLAB/Simulink in conjunction with Real-Time Workshop can automatically generate, package, and compile source code from Simulink models to create real-time software applications that can immediately be executed on a variety of systems and hardware platforms thus enabling the 6-DOF spatial parallel mechanism control system hardware-in-the-loop simulation as well. The 6-DOF spatial parallel mechanism control system hardware-in-the-loop simulation structure is presented on Fig. 6. As the result of hardware-in-the loop simulation (Fig. 6), the 6-DOF spatial parallel mechanism control system hardware-in-the-loop simulation model has been developed in MATLAB/Simulink for simulation on TI TMS320C2000 DSP debug hardware platform (target board).



The 6-DOF spatial parallel mechanism control system hardware-in-the-loop simulation block diagram

The developed hardware-in-the-loop simulation model enables the execution of the MATLAB/Simulink control system model directly on physical hardware debug platform, giving that way the possibility of rapid control prototyping for the 6-DOF spatial parallel mechanism control system.

CONCLUSION

Control system simulation for 6-DOF spatial parallel mechanism is described in the paper. It covers mathematical and computer models of inverse kinematic problem, AC electrical motor regulator development and simulation with controller code generation using rapid control prototyping approach.

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