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MECHATRONIC APPROACH FOR DESIGN AND CONTROL OF A 6 DOF PARALLEL ROBOT

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Abstract (TNR 9 pt Bold): *The paper presents a novel approach for designing and control of a 6 DOF parallel robot using Matlab and dSpace platform. The method offers an integrated solution that allows the engineers to analyze and optimize the system using a virtual model of the product, before a prototype is build. The implementation and validation of the simulation results is made using rapid control prototyping based on the dSpace platform. The results regarding the development and the performance testes of the robot are presented in the paper.*
Keywords: *mechatronics, rapid control prototyping, parallel robot, Matlab, dSpace*

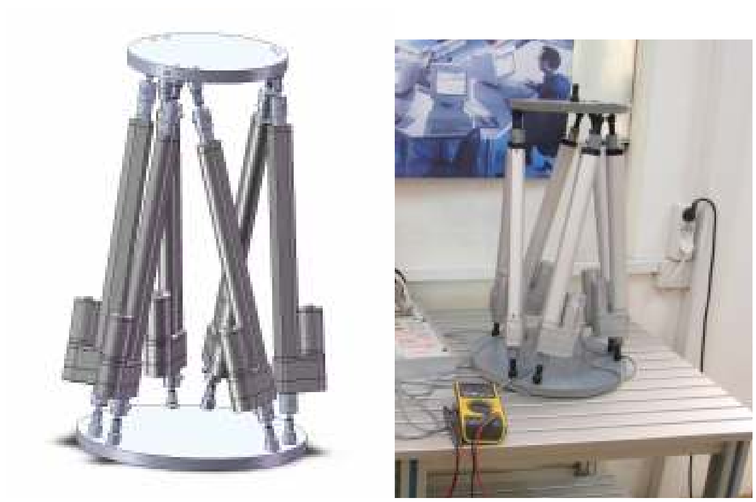
1. INTRODUCTION

The increasing complexity of the modern mechatronic products implies the use of new approaches regarding the design and testing processes. The use of model based design became an indispensable tool for the engineers. Model Based Design is a mathematical and visual method of addressing the problems associated with designing complex control systems. It provides an efficient approach for the four key elements of the development process cycle ("V" diagram): modeling a plant, analyzing and synthesizing a controller for the plant, simulating the plant and controller, and deploying the controller thus integrating all these multiple phases and providing a common framework for communication throughout the entire design process.
The advantages that this method offers are: the engineers can locate and correct errors early in system design, where the time and financial impact of system modification is minimized; the model based design facilitate the design reuse, both for system upgrading and for developing derivative systems with expanded capabilities; the method provides a common design environment for all developers, facilitating general communication, data analysis, and system verification between different development groups.
The implementation process of the simulation results is the next step in the system development. This way the control behavior of the simulated system can be tested on a real prototype. The development of the necessary hardware and software for this step can prove to be very expensive and time consuming; a solution to the problem is to use the method rapid control prototyping. This is a technique in which a standard computer or a real time board temporarily replaces the actual controller, and provides a way to rapidly test algorithms during a product development. If problems with the control algorithm are discovered while using a rapid control prototype, designers can quickly modify their code and run another test. Often, rapid control prototyping uncovers operating conditions and transient phenomena that designers couldn't account for in initial simulations. Rapid control prototyping saves time because the power-plant designers don't have to wait for a complete prototype of the final controller before they can test their control algorithms.
The robot is considered a representative mechatronic system. Due to its complexity the classic approach in designing electromechanical system must be replaced with an integrated approach. In most industrial cases, the robot design process is divided into two sequential phases: the mechanical design and the control system design; usually, the mechanical design is not influenced by the control system conception: the designer simply tries to obtain high structural stiffness, because a very stiff machine is easily controllable by means of decoupled linear loops applied separately to each axis. In the mechatronic approach the mechanical architecture is conceived in parallel with a more sophisticated control strategy. This way it is possible to study exhaustively the behavior of the overall system, emphasizing the peculiar properties of the mechanical architecture itself.

In the following chapters the paper presents an application using the methods model based design and rapid control prototyping for developing and testing a 6-dof planar parallel robot with three degrees of freedom.

2. SYSTEM DESIGN

The robot presented in the paper is a 6 DOF parallel structure also known as the Stewart platform. The robot structure is made from six kinematic chains; each chain is connected to the base and the mobile platform by two spherical joints. The robot is actuated using six linear actuators. The robot is first mention in the literature by D. Stewart in 1965 in a paper published by the Institution of Mechanical Engineers. Stewart proposes a platform mechanism for use as a helicopter flight simulator, however, is remarkably similar to Gough's Universal tire test machine, designed in 1949. After 1983 researchers acknowledged its high load capacity and precise positioning capabilities, and started to make detailed analysis of the structure. The Stewart Platform is used in application in fields like aerospace, defense, automotive, transportation, machine tool technology, and recently is used in medical application for its precise positioning capability.



a) b)

Figure 1: a) CAD model of the robot b) The experimental stand

Figure 1 presents the CAD model of the robot, the model was developed using SolidWorks, and the experimental stand that was developed. The actuation of the robot is made using 6 linear dc actuators with screw transmission. Each actuator has the maximum stroke of 300 [mm].

2.1. Kinematic analysis of a Stewart Platform

The equations of inverse kinematic are used to determine the workspace of the robot. For the inverse kinematic problem it is known the position of the end effector, position of each joint for the frame and the dimensions for the frame and the moving platform and have to determine the length for all 6 actuators q_i *{i=1..6}*.

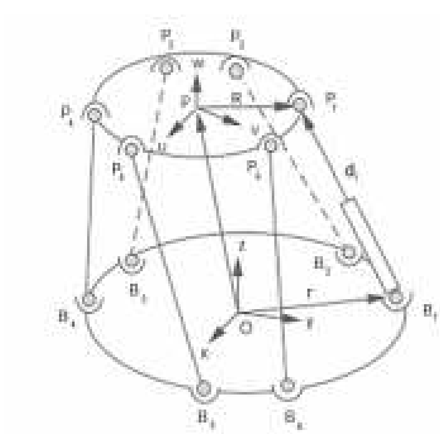


Figure 2: Kinematic scheme

The position and orientation of the mobile platform is represented by a position vector P $[P_x,P_y,P_z]$ and a set of three angles $[\alpha,\beta,\gamma]$ in the base coordinate system, where: α - roll, β - pitch and γ - yaw. In order to determine de length for each translation actuator first the position for all platform joints must be found. The position vector for each joint P_i must be expressed in the based coordinate system; to do that each vector must be rotated and translated:

$$P_{Bi} = T + R_{\alpha\beta\gamma} P_i \tag{1}$$

The matrix $R_{\alpha\beta\gamma}$ represents the rotation matrix, and it is computed by multiplication of the three individual rotation matrices.

$$R_{\alpha\beta\gamma} = \begin{bmatrix} \cos\beta\cos\alpha & -\cos\alpha\sin\gamma + \sin\alpha\sin\beta\cos\gamma & \sin\alpha\sin\gamma + \cos\alpha\sin\beta\cos\gamma \\ \cos\beta\sin\gamma & \cos\alpha\cos\gamma + \sin\alpha\sin\beta\sin\gamma & -\sin\alpha\sin\gamma + \cos\alpha\sin\beta\sin\gamma \\ -\sin\beta & \sin\alpha\cos\beta & \cos\alpha\cos\beta \end{bmatrix} \tag{2}$$

Knowing the position of each joint of the mobile platform P_{Bi}, and the position for the frame joints B_i, the problem is reduce to find the distance between two points in space. The equation used is presented next:

$$q_i = \sqrt{\left(P_{Bix} - B_{ix}\right)^2 + \left(P_{Biy} - B_{iy}\right)^2 + \left(P_{Biz} - B_{iz}\right)^2} \tag{3}$$

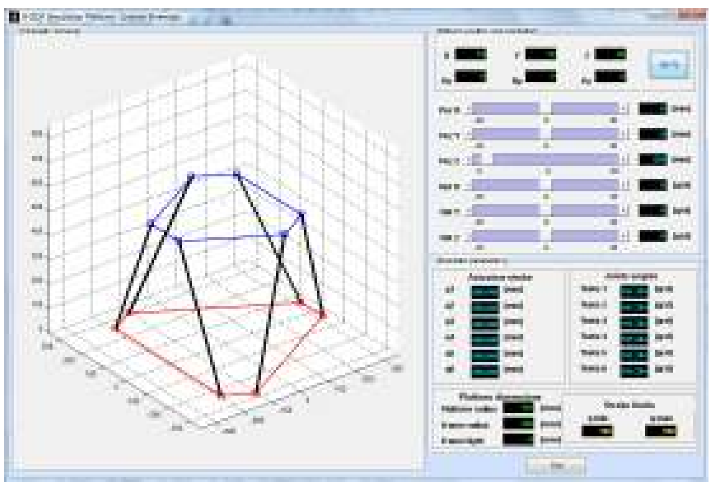


Figure 3: Matlab GUI for kinematic computation

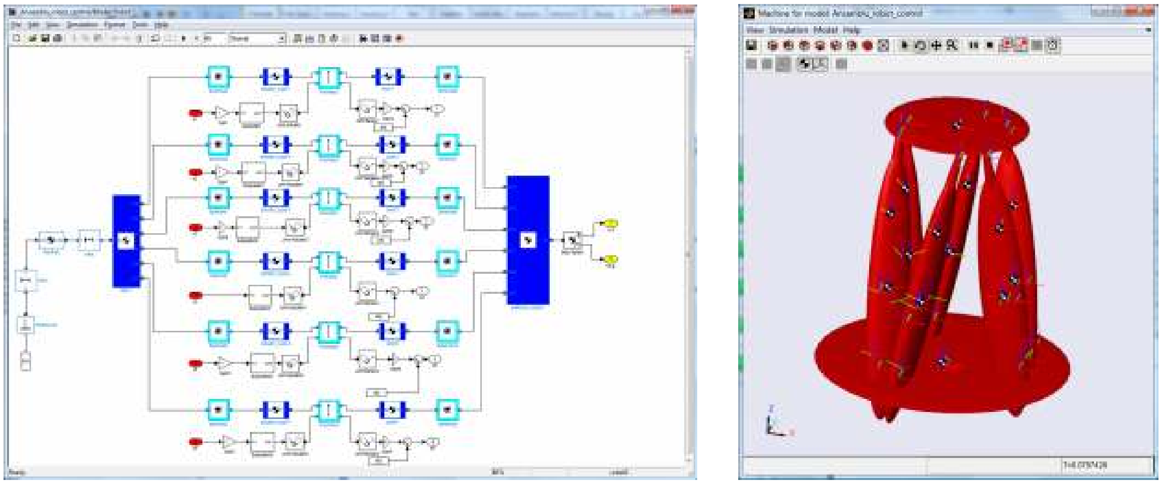
The obtained equations were implemented in Matlab. Figure 3 presents the developed GUI; the user can set different position and orientation for the mobile platform and the application computes and displays the position and length for each kinematic element.

2.2. Dynamics analysis

In order to simulate the behaviour of the robot, the dynamic model of the structure has to be built. This is a complex subject and different methods were developed in order to solve it. A classical method for calculating the dynamic models of closed-chains is to be considered first as an equivalent tree-structure, and then to consider the system constraints by the usage of Lagrange multipliers or d'Alembert's principle (Duffy, 1996). Other approaches include the use of virtual work, Lagrange formalism, Hamilton's principle, and Newton-Euler equations.

The article propose a new approach to develop the dynamic model of the robot using the SimMechanics toolbox from Simulink. The toolbox uses the standard Newtonian dynamic of forces and torques in order to solve booth direct and inverse dynamic problem. The model is built using Simulink blocks; blocks that represents the kinematic elements and the joints of the robot. The blocks from the toolbox allow to model mechanical systems consisting of any number of rigid bodies, connected by joints representing translational and rotational degrees of freedom. In order to build a Simmechanics model one have to specify the body inertial properties, degrees of freedom, and constraints, along with

coordinate systems attached to each body of the structure. This procedure can be a tough one when it comes to bodies with complex geometric forms, the process can be simplify by using a CAD software like SolidWorks.
The developed model of the mechanical structure is presented in fig. 4. All six kinematic chains, the mobile and fix platforms, are defined by bodies and joint blocks. The inertia properties and the coordinates of the joints for each body were imported from the CAD model of the parallel robot.



a) b)

Figure 4: The dynamic model of the robot a)Simulink representation b)graphical representation

The connection dynamic model of the mechanical parts of the robot to the rest of the robot model is made using actors and joints block. As input in the model, using actuators, can be chose between the generalized force and position/speed/acceleration of the motor joints. In this chase the inputs are the speed of all six motor joints of the robot and as outputs the stroke for each motor element. Also in simulation sensors are used to determine the position and orientation of the end effector.

2.3. Simulation results

The control of the robot is implemented using a joint-based control scheme. In such a scheme, the end effecter is positioned by finding the difference between the desired quantities and the actual ones expressed in the joint space [1]. The command of the robot is expressed in Cartesian coordinates of the end effecter. Using the inverse kinematic problem, these coordinates become displacements. These displacements will become the reference for the control algorithm.

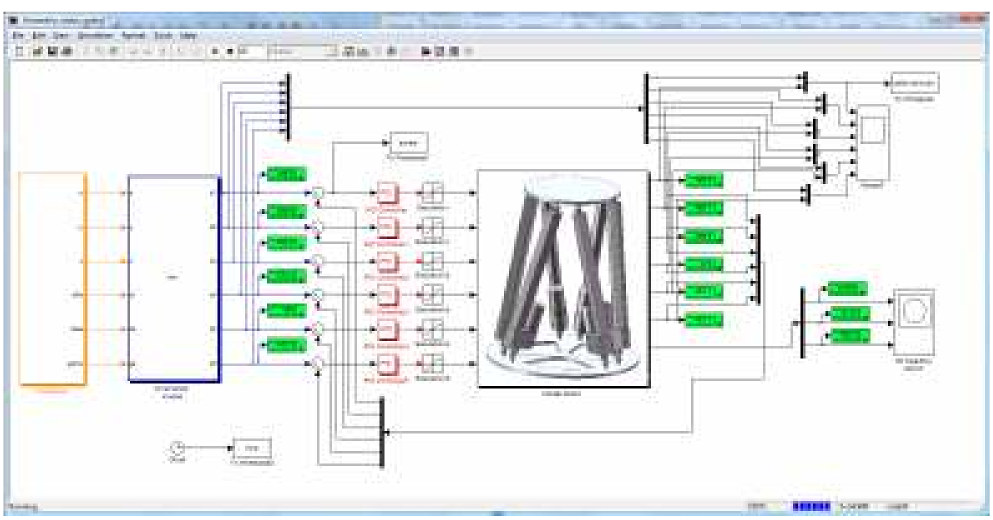
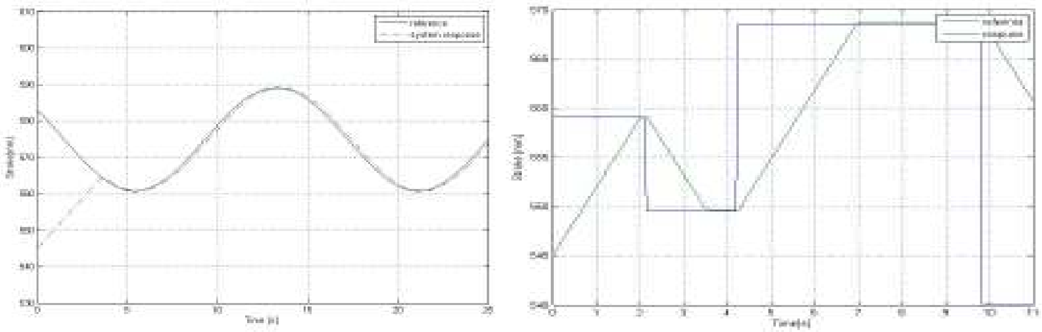


Figure 5: Robot model

Figure 5 presents the model of the robot. In order to control each motor element is used for each actuator a PI control algorithm. The inputs of the algorithm are the differences between the computed angles using inverse kinematic problem equations and the values from sensors. The control signal is applied on six dc motors which will actuate the robot structure.



a) b)

Figure 6: System response a) circular reference b) step reference

Using the block Signal Constraint from the Simulink Response Optimization toolbox the controller parameters *kp* and *ki* were optimized for a given trajectory and a maximum error. Figure 6 presents the results obtained in simulation for a circular trajectory (fig. 6.a) and for translation between different points in the workspace of the end effector (fig.6.b).

3. EXPERIMENTAL RESULTS

Figure 7 presents the experimental stand used to test the simulation results. The main components are: the parallel robo,t dSpace platform, power supply, actuator drivers, sensor interface. The actuation of the robot is made using 6 DC Transmotec actuators with screw transmition. The stroke of the actuator is [300] and the loading capacity of 700 [N].

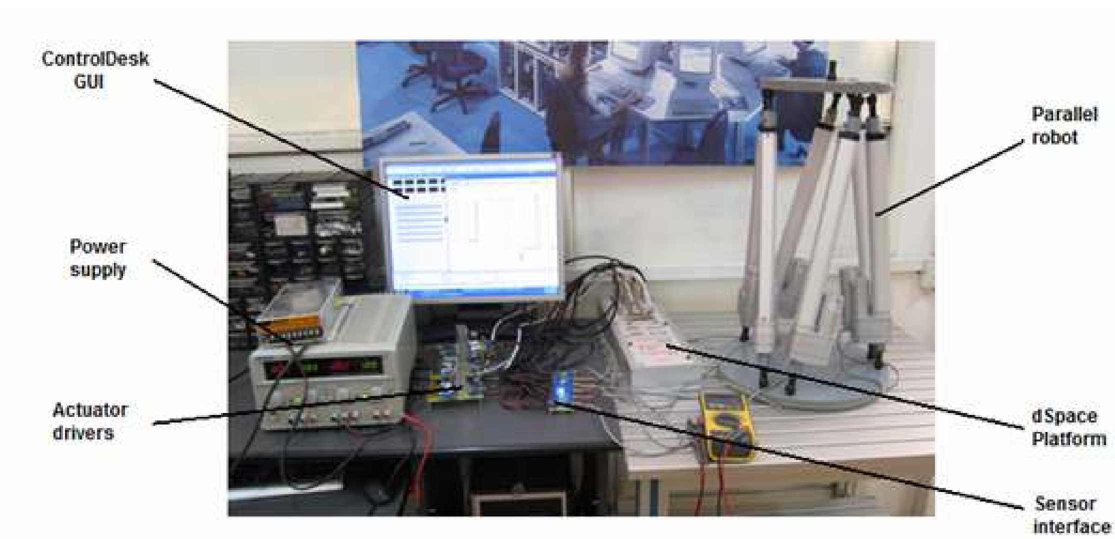
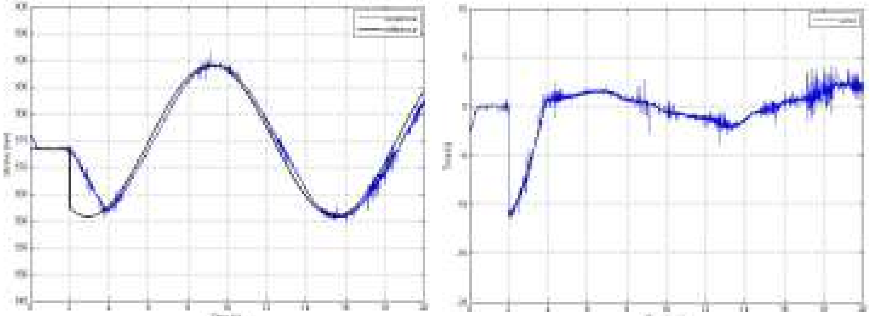


Figure 7: Experimental stand

In order to implement the control algorithm to the dSpace board, the plant and the actuators model must be removed from the Simulink model. They are replaced by the input and output ports of the control board. Through these ports the dSpace system will communicate with the real plant.



a) b)

Figure 8: System response

Figure 8 presents the results obtained from the real platform. Figure 8.a presents the response of an actuator, the thick line represents the reference and the thin line is the sensor signal. The error of the system is presented in figure 8.b.

4.CONCLUSION

The paper presented an integrated approach for designing of a parallel robot with 6 DOF. The propose method use Matlab to implement and simulate the behavior of the system. The approach offers tools that allow different component of the robot to be tested and optimized before a prototype is build. The implementation and validation of the simulation results is made using rapid control prototyping based on the dSpace platform.
The algorithm used for the robot control was PI algorithm; the results were presented in the paper. Based on the obtained results is intended to implement more advance control strategies like fuzzy or model based control algorithms.

REFERENCES

[1] Craig, J., Robotics, Mechanics and Control, Addison-Wesley Publishing Company, USA, 1995

[2] Isermann, R., *Modeling and Design Methodology of Mechatronics Systems,* IEEE/ ASME Transcation on mechatronics, Vol 1, Nr. 1, 1996

[3] de Silva C., Mechatronics. An Integrated approach, Ed. CRC Press, USA, 2005

[4] Lapusan*, C.*, Balan ,R., Sergiu, S, *„Aspects Regarding Integrated Design and Interfacing of an 3RRR Parallel Robot“*,Journal of Romanian Society of Mechatronics,Decembrie 2005 nr. 4/2005, ISSN 1583-7653, pag. 37-40

[5] Lapusan**,**C., Maties,V., Balan,R.,*" Integrated approach for designing mechatronic systems"* The IFToMM-COMEFIM-9 The 9th International Conference on Mechatronics and Precision Engineering, 12-14 Iunie, 2008, Iasi, ISSN 1011-2855,pag 53-60

[6] Lapusan, C., Maties, V., Hancu, O., „ Workspace analysis and design of a 6-DOF parallel robot", WSEAS 8th International Conference on Signal Processing, Robotics and Automation (ISPRA'09), ISBN:978-960-474-054-3, Cambridge, Anglia, 21-23 Februarie, 2009, pag. 337-340

[7] Lapusan, C., Mătieş, V., Bălan, R., Hancu, O., Stan, S., Lateş, R., *Rapid control prototyping using Matlab and dSpace. Application for a planar parallel robot*, 2008 IEEE International Conference on Automation, Quality and Testing, Robotics AQTR 2008, Cluj-Napoca, 22-25 May 2008, Romania; ISBN:978-1-4244-2576-1, pag. 361-364

[8] L.W. Tsai, Robot Analysis: The Mechanics of Serial and Parallel Manipulator, John Wiley & Sons, New York, 1999