MODELING AND SIMULATION METHODS FOR DESIGNING MECHATRONIC SYSTEMS

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Abstract: In the last year's model based design has become an indispensable method in the development of mechatronic systems. Using this method the designers can test and optimize different parts or the entire system using a virtual model of the product, before a prototype is built. Next step in the design process is to create a prototype of the system and validate the simulation results. This stage can be a very difficult one and time consuming. We propose two methods that allow fast testing and prototyping using Matlab and the dSpace platform. The proposed methods are applied in the design of a 3-DOF parallel robot; the obtained results are presented in the paper.

Keywords: mechatronics, Matlab, dSpace, Hardware in the loop, Rapid control prototyping

1. INTRODUCTION

Due to the increasing demands of the modern economy, the development of new products must reach new levels concerning the complexity and the implemented intelligence while saving resources and reduce time needed for designing and production. An answer in satisfying these needs is to use techniques like model based design, which allow simulating and optimizing the behavior of the designed structure in the similar real world conditions [1, 2]. This approach is sustained also by the development of the computers performance and the software applications complexity in the past few years, which offers adequate tools for simulating complex engineering systems.

After the virtual development of the product, the system must be implemented in real world and tested in real life conditions in order to validate simulation results. The testing procedure implies validation of different parts of the product like control algorithms, sensor systems, failure response, electronic boards, etc. This step can be very challenging and time consuming without using adequate tools. For example the development of the code for the control algorithms can take a lot of time for developing, debugging and implementation. Using a rapid control prototyping allows to avoid of these problems. The advantage of using rapid control prototyping is that algorithms which are developed as symbolic models in simulation can be very easy compiled in assembler or C-code. This is very significant as most control engineers are not C-code experts nor do they typically have the skills to port C-code to a real-time target. By virtue of an automated build process, the rapid control prototyping system does this work for you. Also for example the test of the control board can lead to serious hazard situations which can destroy pars of the equipment or put the life of the operator in danger. In this case the control board is tested using the hardware in the loop approach. The control board can be connected to a real time simulator which simulates the other components of the system.

In the paper the mention approaches are implemented for a plan parallel structure with 3 degrees of freedom (DOF). The development of the dynamic model and control algorithms of the robot being presented by the

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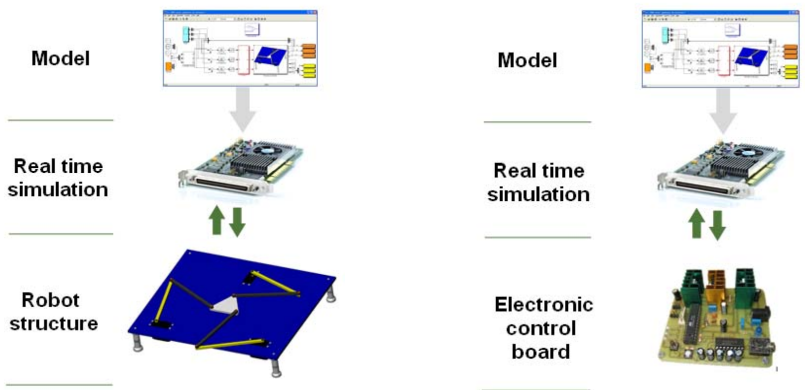
author in [3 - 5], the paper will focus on testing the simulation results using rapid control prototyping and hardware in the loop.

2. RAPID CONTROL PROTOTYPING AND HARDWARE IN THE LOOP

Rapid Control Prototyping is a process that allows implementation and testing of complex control strategies, strategies developed using a model based design, on a real-time hardware [6]. The prototype of the system is connected to the real-time hardware using input/output ports. The control algorithms are developed using a math modelling package such as Matlab. When the results from the simulation are satisfactory the code is automatically generated for the real time platform by the environment. The method allows engineers to concentrate on developing control strategies using a modelling environment without knowing details about translating the model to C-code. Rapid control prototyping is a variant of hardware-in-the-loop (HIL), but it differs from HIL in that the control strategy is simulated in real-time and the plant, or system under control, is real.

Figure 1.a presents an RCP example, as a first step the Simulink model is compiled and downloaded in the dSpace DS1104 board. Before compilation and downloading the model of the system is replaced by the outputs and the inputs of the DS1104 board. The system behavior and parameter tuning is done using a graphic interface developed in ControlDesk.



a) b)

Fig. 1. a) Rapid control prototyping approach; b) Hardware in the loop approach.

Hardware-in-the-loop is a technique that is used in the calibration and test process of complex real-time mechatronic systems. The complexity of the plant under development is included in test using the mathematical representation of all related dynamic systems. These mathematical representations are referred to as the "plant simulation". The typical Hardware-In-the-Loop system is comprised of the following components: A math model of the plant; Sensor models; A real-time target computer(s) with I/O; Real or simulated loads; Fault insertion relay matrix; Graphical User Interface (GUI) application to download and control the real-time process.

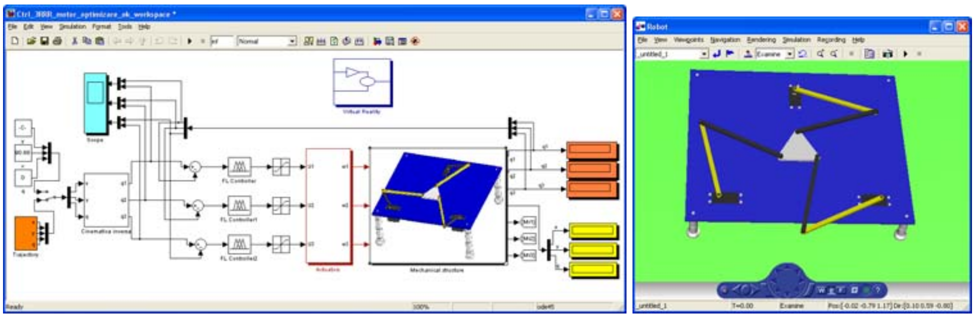
The benefits of a Hardware-In-the-Loop system as defined above are manifold. The topology allows engineers to test complex systems that need, for example, closed dynamic control loop. Another benefit of Hardware-In-the-Loop is that testing can be done without damaging equipment or endangering lives. For instance, potentially damaging conditions in an engine, such as low oil pressure or over-temperature, can be simulated to test if the ECU can detect and report it.

Figure 1.b present a HIL example; in this case the control board of a parallel robot is tested. The model of the robot is modified; the control algorithm is replaced by the inputs and the outputs of the DS1104 board. The model of the robot will be simulated in real time, the control algorithm and the electric board will command the virtual components.

3. CASE EXAMPLE

As a case study a plan parallel robot with three degrees of freedom it was analyzed. The robot is also known as 3-RRR robot. The development of the robot model and the simulation was made using the Matlab/Simulink software.

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.



a) b)

Fig. 2. The model of the parallel robot: a) Simulink model; b) virtual reality model.

Figure 2 presents the model of the robot. The low level control loops for each actuator were implemented using three fuzzy logic controllers. 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 three dc motors, which will actuate the robot structure. The controller parameters were optimized for a given trajectory and a maximum allow error.

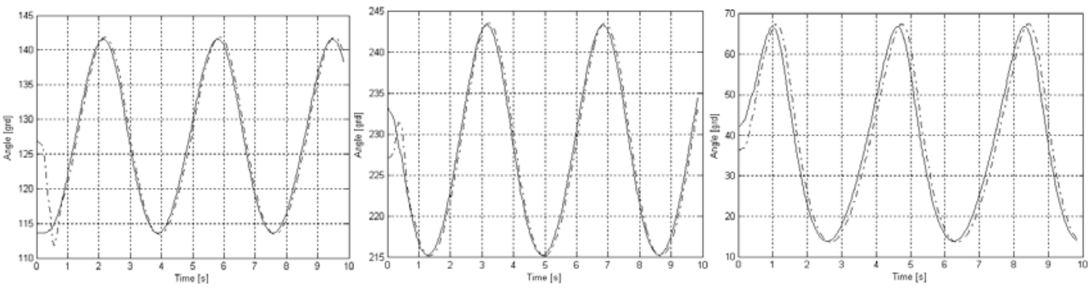


Fig. 3. Simulation results.

The results of the robot simulation for a path following are presented in Figure 3. The reference for the actuators is plotted with a tick line; the simulated behavior of the structure is plotted with a dash dot line.

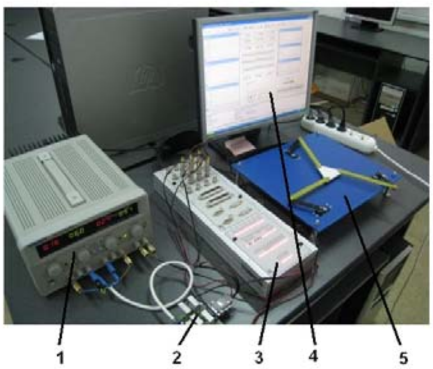
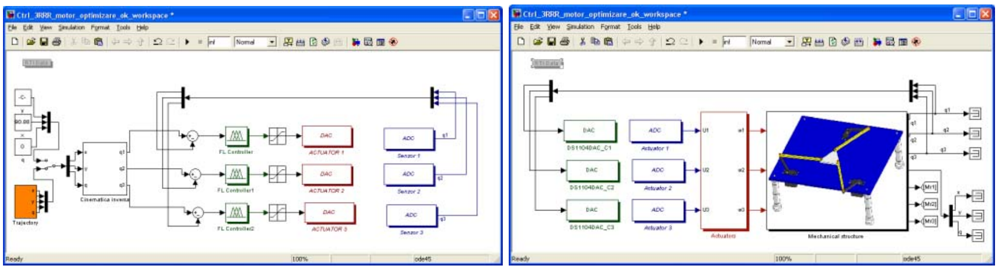


Fig. 4. The experimental stand.

The experimental stand used for testing is presented in Figure 4. The parallel robot (5) is connected to the dSpace board through the interface panel (3). The parameters of the system are supervised and modified using the ControlDesk (4), the interface allows to enter the position of the end effector and to display the data from the sensors. The dSpace DAC ports are interfaced with the dc motor using three power amplifiers (2), the energy needed for the actuators is provided by the power supply (1).



a) b)

Fig. 5. a) Simulink model for RCP simulation; b) Simulink model for HIL simulation.

As mentioned before, the model of the robot is modified in order to use RCP and HIL simulation. In Figure 5.a the model for the RCP simulation is presented, in this case the dynamic model of the mechanical and electrical parts are removed by input and output ports of the control board. For the HIL simulation (Fig. 5.b) the controller of the robot is replaced by the control board ports. In both cases the model is compiled and loaded in the DS1104 board.

The experimental results, saved from ControlDesk, are presented in Figure 6. The figure presents the behavior of the robot for a path following. The reference for the actuators is plotted with a continuous line; the actual behavior of the structure is plotted whit a dash dot line. The response of the robot obtained in the test experiments comply with the constraints that were imposed.

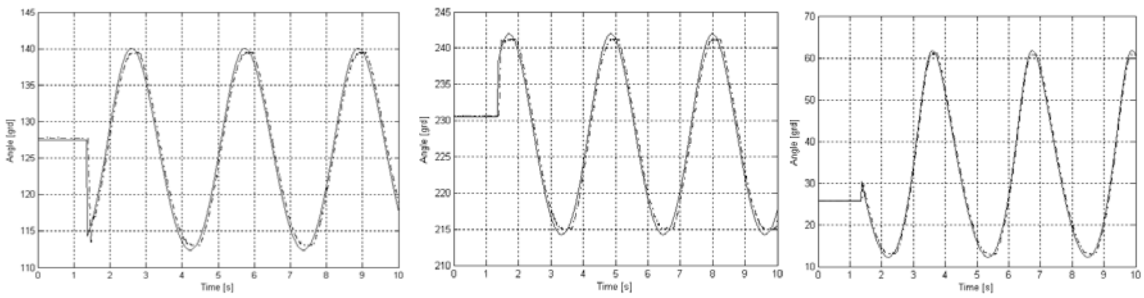


Fig. 6. The experimental results.

4. CONCLUSIONS

The paper presented two novel approaches for testing and rapid prototyping used in the design process of mechatronic systems. The proposed methods use the advantages offered by Matlab and dSpace platforms. Rapid control prototyping allows fast implementation and optimization of advance control algorithms developed using a model based design. Also using hardware in the loop, different components or the whole system can be tested and calibrated. The proposed methods were used in the design process of a parallel robot with three DOF, and the experimental results were presented in the paper.

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