Virtual model of MKS manipulator, part 1: The mathematical model

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1 Introduction

Presented paper describes creation process of virtual model of manipulator for hull integrity inspection (MKS). Described model is result of the model-based design technique. Proposed solution uses two key parts: mathematical model, visualization tool. Resulting virtual model can be use for MIL and SIL simulations as well as base for control design. This paper deals with the mathematical model part.

2 Mathematical model

The mathematical model is derived by solving the Lagrange equations of the second kind (see e.g. Moon (2008)). Each part of the manipulator is considered as a two-mass flexible system in the model. These parts are: rotating platform, two coaxial pillars mechanically connected to each other and two independent modules moving on the carriage travel located on the bottom of the inner pillar. The protrusion of the inner pillar depends on the protrusion of the outer pillar. The mechanical joint between the pillars doubles the speed of the inner pillar against the speed of outer one. A simplified scheme of the manipulator is shown in Figure 1, where J_1 is the inertia of the platform, $m_{2...5}$ are the masses of the outer pillar, inner pillar with the carriage travel, the left and the right module, φ_1 is the angle of rotation of the platform, $x_{2,3}$ are the vertical positions of the outer and inner pillar, $x_{4,5}$ are the horizontal positions of the left and right module relative to the axis of rotation.

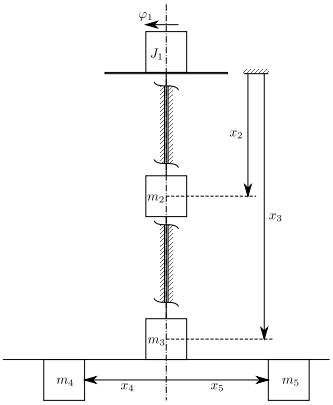

Figure 1: Simplified scheme of the manipulator

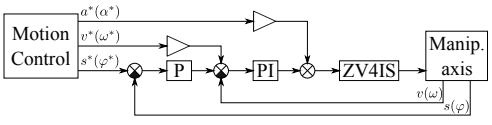

Figure 2: Regulation scheme for single axis

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2.1 Simulation model in MATLAB®

The MATLAB® environment with Simulink™ - SimMechanics™ extensions was chosen to simulate the dynamics of the manipulator. SimMechanics™ provides a multibody simulation environment for 3D mechanical systems. However the SimMechanics is very fast and advanced tool, an error in the block *Velocity Driver* occurred during the modeling of the manipulator. Hence, MATLAB®/Simulink™ environment was chosen to model direct the nonlinear equations of motion.

2.2 Simulation model using RexLib

RexLib is part of the Rex control system development tools (see Balda et al. (2005)). It is extensive function block library which include blocks allowing to model the equations of the motion of the MKS manipulator. RexLib is compatible with Simulink environment, thus mathematical model can be run in both system Simulink or REX. RexLib supports real-time simulation which is used during MIL and SIL.

2.3 Manipulator controller

For a purpose of the virtual model demonstration a controllers were developed. A cascade control was designed for each actuator with a PI controller in a velocity loop and P controller in a position loop. A torque/current controllers included in the actuators driver are assumed. To suppress an unwanted residual vibrations the *ZV4IS* input shaping filter(see Schlegel and Goubej (2010)) is added to the output of the each PI regulator. Signals generated by motion control blocks are used as a feedforward. All blocks used for controllers are included in function block library of the REX control system. The blocks used for motion control are developed according to the PLCopen Motion control specifications (see PLCopen (2011)). The regulation scheme is shown in Figure 2. Each of the manipulator axes (rotation of the platform, protrusion of the pillars, movement of the left and right modules) is controlled separately.

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References

Balda, P., Schlegel M., and Štětina, M. “Advanced control algorithms + Simulink compatibility + Real-time OS = REX”. *IFAC Proceedings Volumes (IFAC-PapersOnline)*. 2005. Vol. 16. pp 121–126.

Moon, F.C., *Applied Dynamics: With Applications to Multibody and Mechatronic Systems*. 2008.

PLCopen, Technical Committee 2. *Function Blocks for Motion Control, Version 2.0*. Mar. 2011.

Schlegel, M., and Goubej, M. “Feature-based parametrization of input shaping filters with time delays”. *IFAC Proceedings Volumes (IFAC-PapersOnline)*. 2010. pp 247–252.

REX system function blocks Reference manual. 2013. [Online]. Available: http://www.rexcontrols.com