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NI LabView — Matlab SimMechanics Stewart platform design

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Abstract

The article deals with approach of using NI Labview and Matlab SimMechanics for the designing of Stewart platform model of dynamics and its control. Matlab SimMechanics was used as a tool for the multi body dynamics modeling of the mechanism. The advantage of working within this computational environment is the possibility of the model linearization at a specified operating point and receiving linear state space model. Another benefit is the option of designing of the machine control and also the control simulations may be performed in the same environment. On the other hand NI LabView seems to be better for the real-time control implementation because of the possibility of real-time computer communication and possibility of FPGA chipset direct configuration. NI LabView has also ability to work with Matlab commands, thus possibility of Matlab models importing. Advantages of using both of environments are presented on the example of Stewart platform. The presented approach is quite complex and seems to be suitable for a dynamics modeling and a control designing of mechatronic systems.

Keywords: Stewart platform, dynamics, linearization, control

1. Introduction

Simulation of dynamics and control design of mechatronic systems are often very complicated tasks. The main problem is to build a model of system dynamics fast enough to be suitable for designing of the control. This is even more challenging in case of parallel kinematic machines where the kinematic structure consists of closed loop kinematic chains. The representative example of parallel kinematic machine is a Stewart (also known as Gough) platform originally designed in the middle fifties for testing of tires against wear [5]. Fig. 1 presents an example of a Stewart platform mechanism consisting of a movable platform and six linearly actuated links. In our case the linear actuator consists of a DC motor with a planetary gearbox (part 1), a spur gearing (part 4), actuated screw nut (part 3) and a ball screw (part 2), fig. 2.

Commonly used methods for the machine dynamics modeling, e.g. [3, 4], are consuming a lot of computational time. Models created by using such methods are inappropriate for the machine control design. Thus models with approximate dynamics [6] or simplified models [7] are often used for that reason. On the other hand control based on simplified mechanism model usually needs some kind of compensation [6].

One of possibilities how to create a model describing a machine dynamics and at the same time model suitable for the control design is the use of linear state space representation of the model. This may be obtained by using multi-body dynamics modeling of the machine in Matlab SimMechanics followed by linearization at a specified operating point.

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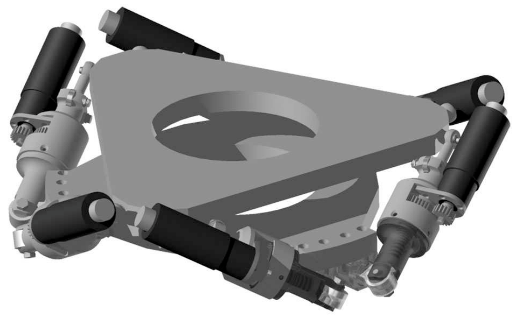

Fig. 1. Stewart platform

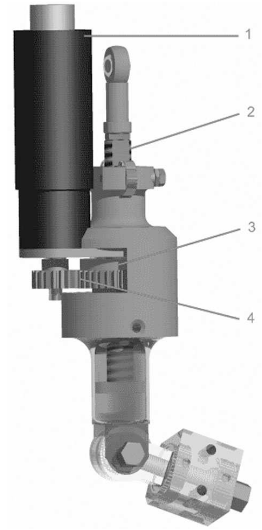

Fig. 2. Single linear actuator

For real-time control implementation seems to be suitable NI LabView with possibility of graphical programming and many other advantages. Among others it is an option of importing Matlab data, thus possibility of importing Matlab linear state space model of the machine.

The general approach of using Matlab SimMechanics and NI LabView for the designing of Stewart platform model of dynamics and its control is described in the article.

2. Modeling of the Stewart platform dynamics in Matlab SimMechanics

Stewart platform dynamics model was built in Matlab SimMechanics environment which works on the principle of multi body dynamics and it is directly intended for modeling of kinematics and dynamics of various machines. The environment works with block schemes which represent kinematical structure of a machine. The routine is able to work in dynamic mode by assigning of inertia moments and masses to the each body of the modeled machine. It was profitable to use information about body inertia moments and body masses from previous engineering design in CAD software [1] in case of the Stewart platform, fig. 3.

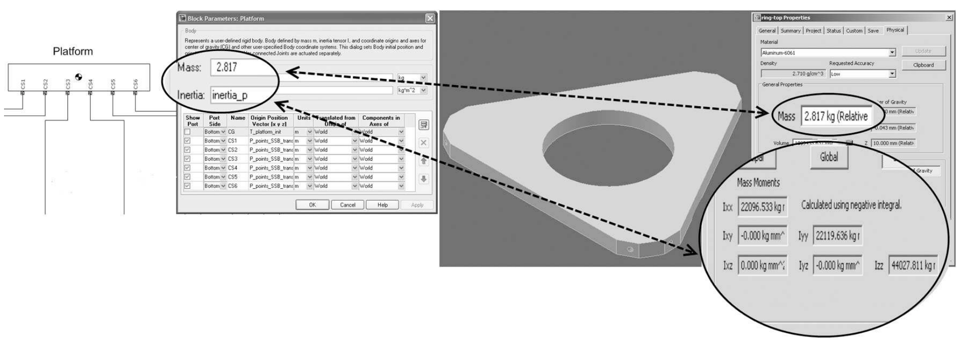

Fig. 3. Example of body inertia moments and body masses value transfer (from Inventor (right) to Matlab SimMechanics (left))

The model is ready for the simulation of dynamics after creating of a single link subsystem with all joints, bodies, planetary gear and spur gearing, and completing whole Stewart platform model. Inputs of the model are defined as shaft torques of the each motor and outputs are angular position and angular velocity of the each screw nut, fig. 4.

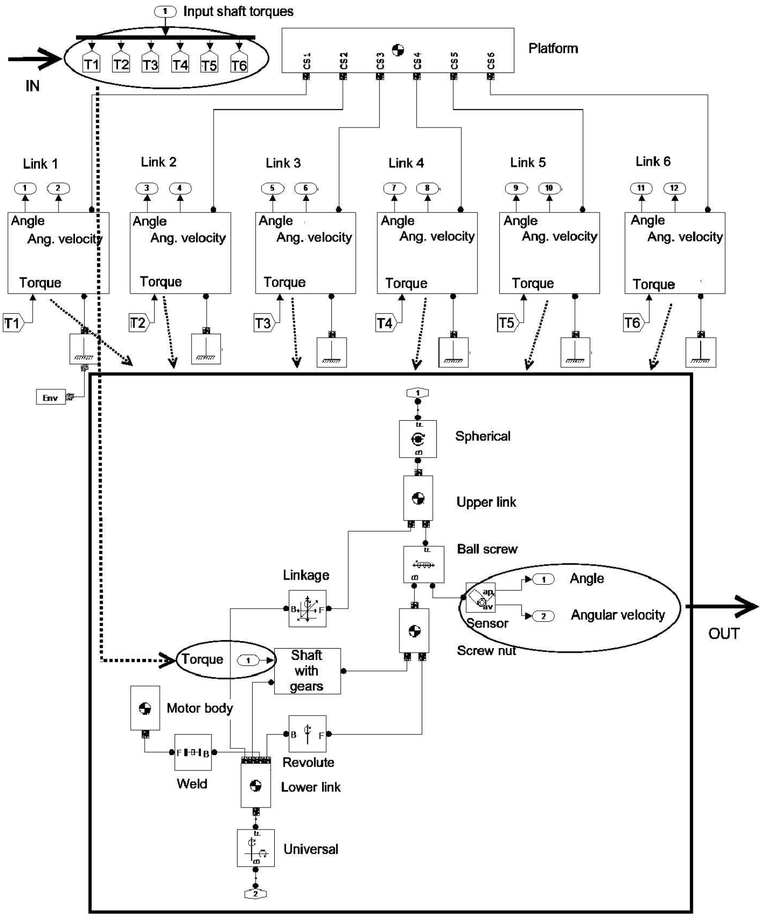

Fig. 4. Stewart platform SimMechanics model with six single link subsystems and input/output definition

3. Linearization of the SimMechanics model

The model itself is nonlinear and consuming quite lot of computational time thus it is not appropriate for the controller designing. This may be solved by the model linearization which is also possible to implement in Matlab SimMechanics. SimMechanics works with linearization at a specified operating point. There are generally two linearization approaches in SimMechanics — block-by-block linearization and linearization by numerical perturbation.

Block-by-block linearization works on principle when are linearized single blocks and results are combined to the linearization of the whole system. The advantage is that many blocks contain analytical information for precise linearization. Thus the method is useful in cases when blocks also contain some discontinuities and results obtained by numerical perturbation are not precise. On the other hand linearization by the numerical perturbation linearizes whole system.

The method is simple and fast but the disadvantage is that even blocks containing analytical information for the precise linearization are numerically perturbed. From this reason was in our case chosen block-by-block linearization.

The operating point for the linearization is chosen as an initial point in which is the platform situated (for the platform radius 0.125 m is the initial distance between base and platform 0.06 m). The point is defined by shaft torques of the each actuator, needed for holding the platform nonmoving in the initial state. The torque value was from the model measured as 0.019 3 Nm.

The linear state space model of the Stewart platform defined by matrices **A**, **B**, **C**, **D** is obtained after the linearization. The meaning of these matrices, well known from the state space representation theory, is following: **A** is the "state matrix", **B** is the "input matrix", **C** is the "output matrix" and finally **D** is the "feedforward matrix".

The received linear model is of the twelve order. It has twelve states automatically chosen by SimMechanics.

Nonlinear and linear model comparison proved that the difference in reaction on the same constant input is in the worst case lower than 3 % (in extreme testing configuration, can't be reached with the real device), fig. 5–8. The comparison was performed by simulation where both models were for 5 seconds actuated by constant shaft torques of 0.03 Nm.

The state space representation of the model is advantageous because of small requirements on the computational time.

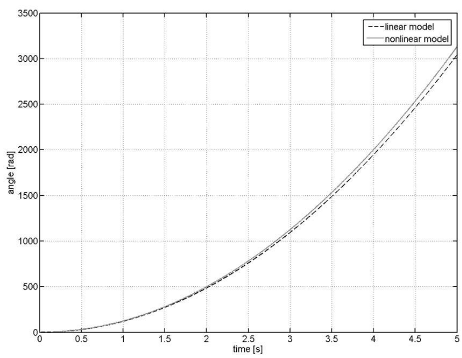

Fig. 5. Output angle of the single screw nut — linear and nonlinear model

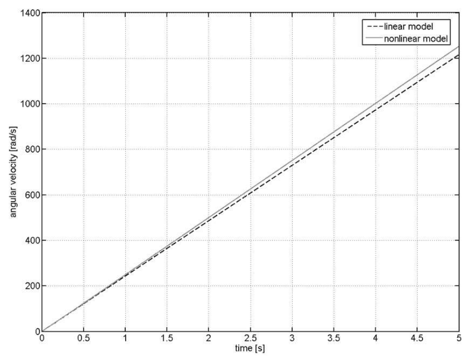

Fig. 6. Output angular velocity of the single screw nut — linear and nonlinear model

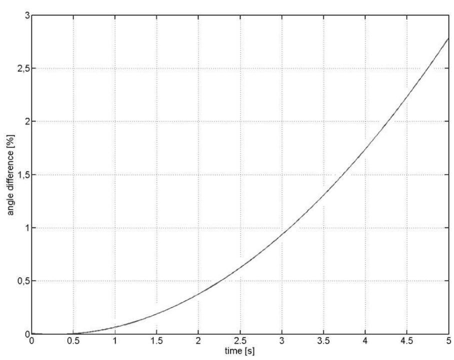

Fig. 7. Difference between output (angle) of the linear and nonlinear model

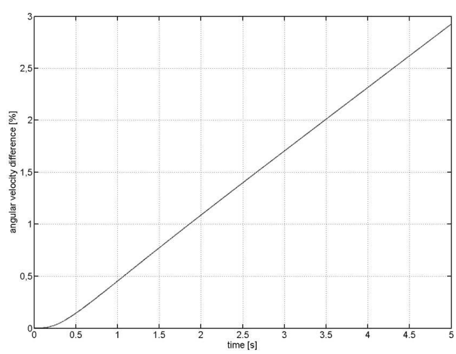

Fig. 8. Difference between output (angular velocity) of the linear and nonlinear model

4. Control design

Now the obtained linear model is prepared for the design of the control, which is in detail described in [2]. For the control purposes the nonlinear SimMechanics model had to be completed with six DC motor Simulink models providing single link actuating.

Basically the control itself is designed of two layers. Fig. 9 presents higher control layer which synchronizes all six actuators to reach the desired screw nuts angular orientations by specifying shaft torques. The lower control layer presents isolated torque control of each actuator, fig. 10. The actuator input is a voltage.

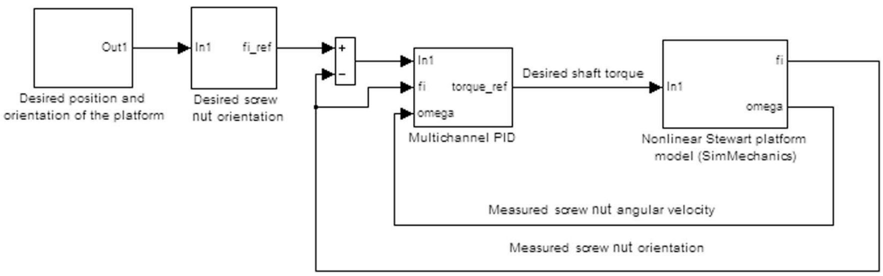

Fig. 9. Higher control layer structure

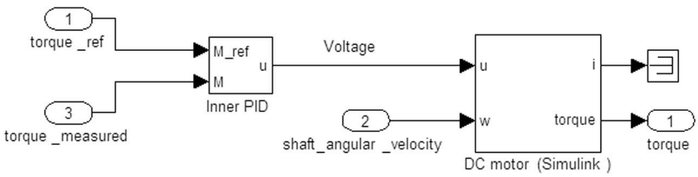

Fig. 10. Lower control layer structure

The control was designed in Matlab Simulink with use of the linear model. Control preciseness testing simulations were performed with the original nonlinear model. The Stewart platform model was moving with platform gravity center orientation and position according to the desired values during the simulation. Desired time courses of platform gravity center orientation and position are presented in fig. 11 and fig. 12. During the simulation were mea-

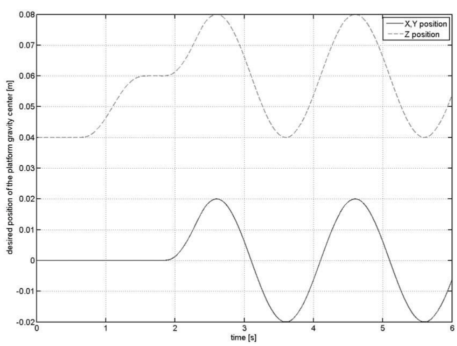

Fig. 11. Desired position of the platform gravity center

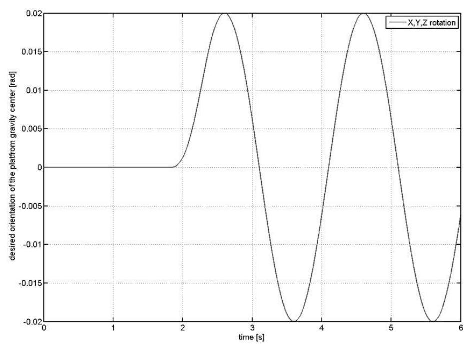

Fig. 12. Desired orientation of the platform gravity center

sured errors in orientation and position as well as desired shaft torques and driving voltages, fig. 13–16. The overall positioning error is for the referential trajectory in the worst case 4.2 %. Measuring of shaft torques and motor driving voltages is necessary for the future examination of the chosen actuator suitability.

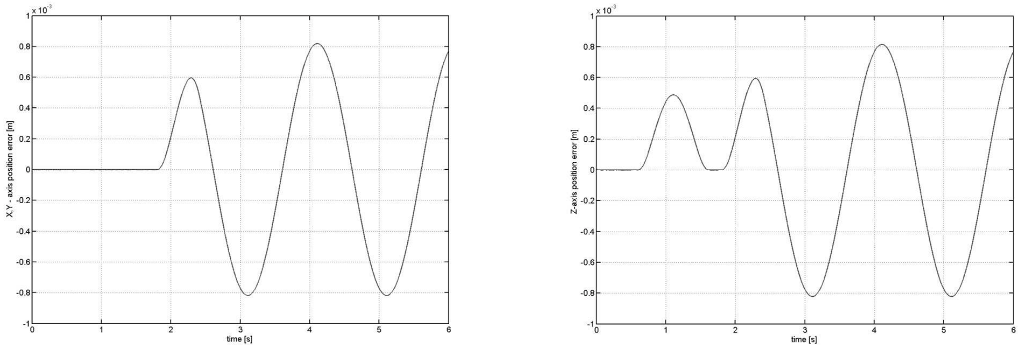

Fig. 13. Position errors (X, Y axis – left, Z axis – right)

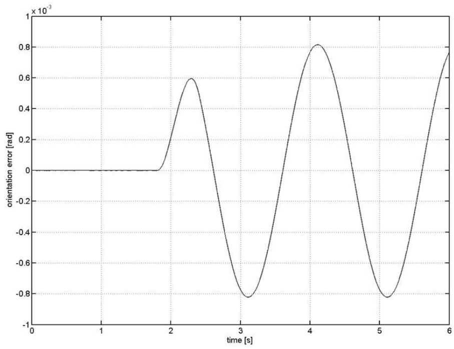

Fig. 14. Orientation errors (X, Y, Z axis)

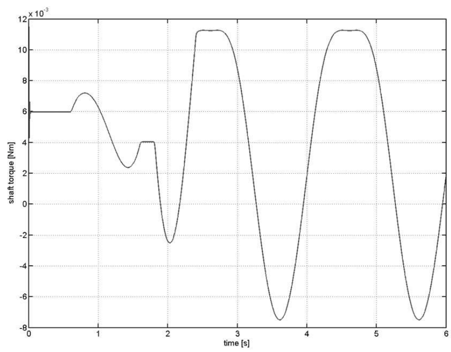

Fig. 15. Shaft torque (single actuator)

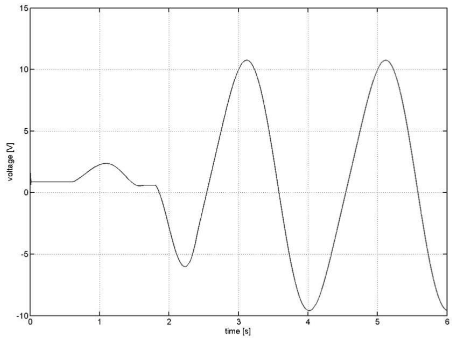

Fig. 16. Driving voltage (single actuator)

5. NI LabView implementation

The presented control design was remade in NI LabView where is guaranteed communication with a real-time machine for the linear actuator motion control. The real-time machine contains FPGA chipset which can be configured directly from the NI LabView environment. The main advantage of the device is saving of computational time and reliable timing. The linear model for the control design was exported from Matlab to NI LabView. Experiments with real linear actuator for the model verification and feedback correction of the SimMechanics model of dynamics are planned to the near future.

6. Conclusion

The presented approach may be used for the designing of dynamic models of complicated mechatronic systems and for designing of their control. The approach was applied on the example of the Stewart platform which is a six degrees of freedom parallel mechanism. Simulation results proved that control designed with use of the linear state space machine model is able to work with better than 4.2 % positioning error. Now the verification on the real machine is planned. Matlab SimMechanics and NI LabView were used for the different phases of the design and also some general advantages of working with these environments were mentioned.

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References

[1] T. Březina, Simulation modelling of mechatronics systems II, Brno University of Technology, Brno, 2006.

[2] T. Březina, L. Březina, The device for implants testing: The control, Proceedings of the Engineering mechanics 2008, Svratka, Institute of Thermomechanics, Academy of Sciences of the Czech Republic, 2008, pp. 84–89.

[3] B. Dasgupta, T. S. Mruthyunjaya, Closed form dynamic equations of the general Stewart platform through the Newton-Euler approach, Mechanism and machine theory 34 (7) (1998) 993–1 012.

[4] J. Gallardo, J. M. Rico, A. Frisoli, D. Checcacci, M. Bergamasco, Dynamics of parallel manipulators by means of screw theory, Mechanism and machine theory 38 (11) (2003) 1 113–1 131.

[5] V. E. Gough, S. G. Whitehall, Universal tire test machine, Proceedings of the 9th International Technical Congress of International Federation of Automotive Engineering Societes, London, Institution of Mechanical Engineers, 1962, pp. 117–135.

[6] S. H. Lee, J. B. Choi, Song, D. W. Ch. Hong, Position control of a Stewart platform using inverse dynamics control with approximate dynamics, Mechatronics 13 (6) (2003) 605–619.

[7] J. Wang, J. Wu, L. Wang, T. Li, Simplified strategy of the dynamic model of a 6-UPS parallel kinematic machine for real time control, Mechanism and machine theory 42 (9) (2007) 1 119–1 140.