Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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Annals of DAAAM International

CONTROLLER IMPLEMENTATION OF THE STEWART PLATFORM LINEAR ACTUATOR

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Abstract: *This article presents a simple and efficient approach to the control simulation, implementation and verification of a linear actuator which is a part of a Stewart platform. The proposed method is based on the state – space control with an input integrator. The controller itself combines structures of a position and a velocity control. Switching between the position and the velocity controller is realized according to desired and real position. The whole controller design is based on a linear state-space model of the actuator with the disturbance. The control system itself is implemented in NI LabVIEW software environment from where it is possible to control the constructed prototype through a real-time computer.*
Key words: *Stewart platform, parallel mechanism, controller implementation, linear actuator*

1. INTRODUCTION

The Stewart platform manipulator (Stewart, 1965) is a completely parallel kinematic mechanism that has major differences from typical serial link robots. During the recent years, a large variety of parallel mechanisms were introduced by research institutes and by industries (Gough & Whitehall, 1962; Gopalakrishnan et al., 2000; Merlet, 2005). This paper presents parallel mechanism which is suitable for testing of the backbone segments and hip joints, Fig. 1 (Brezina et al., 2009). The proposed mechanism makes possible to simulate the physiological movements of the human body and observe on long–term horizon how the cord implant affect the spinal element. The demand for fastening the spinal segments determines the size of particular segment of the device. Single layer of the device is created of couple of toroidal bodies (base and platform) linked to each other. Both plates are coupled with linear controlled actuators which simulate movement and load of specimen. Thus, the main aim of this article is to describe implementation of the linear actuator controller.

The linear actuator consist of a ball screw with a nut which transforms the rotational movement to the translational, a spur gearing, DC motor Maxon RE 35 with a planetary gearbox and IRC sensor. Therefore, the task of the linear actuator control is reduced to the task of control of a DC motor. DC motors are usually modeled as linear systems and then linear control approaches are implemented (Mao et al., 2003). Additionally, controllers for nonlinear DC motor models have been developed (Ahn & Truong, 2009). If the nonlinearities of the motor are known functions, then adaptive tracking control methods with the technique of input output linearization can be used (Horng, 1999).

Fig. 1. The Stewart platform mechanism

In this paper, a state-space controller was designed to regulate position and velocity with respect to the system dynamics and power consumption. The integrator block is added for the regulation quality improvement and the permanent regulation deviation elimination.

2. DESIGN METHODOLOGY

The constructed device represents fully mechatronic system according to the industrial guideline - VDI 2206. The intended design solution is divided into three main design stages, modeling, simulation and implementation. In this manner the paper extends the result of (Andrs & Brezina, 2010).

2.1 Modeling

A simplified linear state-space model of DC motor with additional disturbance input was used (1). The proposed method is common for both position and velocity controller design.

$$\mathbf{x}' = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u} + \mathbf{E}\mathbf{z} \ , \qquad \mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u} \ . \tag{1}$$

A, **B**, **C**, **D**, **E** are in sequence the state matrix, the input matrix, the output matrix, the feedforward matrix and the disturbance matrix. The state-space model of DC motor Maxon RE 35 (1) can be written as:

$$\begin{bmatrix} x_1' \\ x_2' \\ x_3' \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -k_f/J & k_m/J \\ 0 & -k_b/L & -R/L \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1/L \end{bmatrix} [u_M] + \begin{bmatrix} 0 \\ 1/J \\ 0 \end{bmatrix} [M_Z] \ ,$$
$$\begin{bmatrix} \varphi \\ \omega \\ i \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} [u_M] \ , \tag{2}$$

where k_f, k_m, k_b, R, L and J are the motor parameters. The state vector **x** represents angular displacement of the rotor φ, angular velocity ω and electrical current in the stator i, the vector of inputs **u** presents motor driving voltage u_M. The vector of model outputs **y** contains angular displacement of the rotor φ_M, angular velocity ω_M and electrical current in the rotor i_M. The disturbance vector **z** presents the DC motor loading torque M_Z. Implementation of the structure with the integrator on the input without loading disturbance leads to the following control law

$$\mathbf{u} = -\mathbf{R}\mathbf{x} + \mathbf{r}_i\mathbf{v} \ , \qquad \mathbf{v}' = \mathbf{w} - \mathbf{y} \ , \tag{3}$$

where $\mathbf{R} = [r_\varphi\ r_\omega\ r_i]$ is the vector of gains of the system's state vector, $\mathbf{r_i}$ presents gain of the integrator and $\mathbf{w}$ is reference value. Presented control law modifies the state-space model of the system to the state-space equation:

$$\begin{bmatrix} \mathbf{x}' \\ v' \end{bmatrix} = \left(\begin{bmatrix} \mathbf{A} & \mathbf{0} \\ -\mathbf{C} & 0 \end{bmatrix} - \begin{bmatrix} \mathbf{B} \\ -\mathbf{D} \end{bmatrix} \begin{bmatrix} \mathbf{R} & -\mathbf{r}_i \end{bmatrix} \right) \begin{bmatrix} \mathbf{x} \\ \mathbf{v} \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ 1 \end{bmatrix} [\mathbf{w}] . \qquad (4)$$

The controller gains $\mathbf{R}$ and the integrator gains $\mathbf{r_i}$ are adjusted in such a way that state matrix of the system with the integrator

$$\begin{bmatrix} \mathbf{A} & \mathbf{0} \\ -\mathbf{C} & 0 \end{bmatrix} - \begin{bmatrix} \mathbf{B} \\ -\mathbf{D} \end{bmatrix} \begin{bmatrix} \mathbf{R} & -\mathbf{r}_i \end{bmatrix} \qquad (5)$$

is solved for specified eigenvalues p_1, p_2, p_3 (and p_4), providing stability of the system for the sufficient position/velocity, in allowed control values range and with given power limitations. Note, that there is very capable to use MATLAB's function *place* and *c2d* (discrete version) to obtain real controller gains.

2.2 Simulation

A simulation model of the position/velocity controller with DC motor model was developed in software environment MATLAB/Simulink, Fig. 2. This model was used to observe the impact of the step change in M_z on the position/velocity response and to verify designed controller gains. The power converter, position and the electrical current sensor were modeled as first order systems.

2.3 Implementation

The control device was designed and implemented with respect to modularity and future expansion from one linear actuator to the whole machine. It was profitable to design the control device with hierarchic architecture. A personal computer (PC) communicating with a real-time PC NI PXIe-8130 complemented by a multifunctional card with field-programmable gate arrays (FPGA) are main hardware tools. The main advantage of this device is dividing of the control between the PC and the real-time PC which brings the advantage of user interface separation, thus increasing computational efficiency. High computational performance of the control unit NI PXIe-8130 predetermines it for the control algorithm implementation.

3. THE EXPERIMENT

A special test jig containing the linear actuator with a cart linked to the loading tackle was used for experimental purposes. The experiment was aimed to observe desired and real position of the cart loaded with a constant axis force, Fig. 3. The position of the cart was measured by IRC sensor mounted to the shaft of the DC motor.

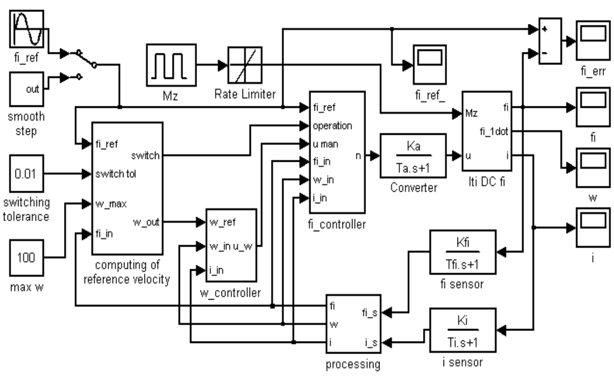

Fig. 2. The simulation model

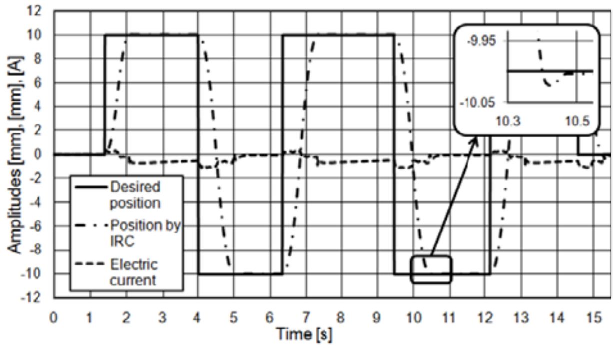

Fig. 3. An example of loading cycle with static axis loading force of 1500 N

4. CONCLUSION

The presented method is based on a state-space control structure with an input integrator. The simulation proved that the position/velocity controller is able to compensate the additional dynamics of the sensors and the converter. The experiment executed on the constructed test jig proves positioning of the cart with respect to input electrical current. The high accuracy of the positioning is guaranteed by the structure with the input integrator. Nowadays a control of the whole Stewart platform is implemented and tested.

5. ACKNOWLEDGEMENTS

This work is supported from research plan MSM 0021630518 Simulation modeling of mechatronic systems, Development of control and sensor system for unconventional mechatronic devices FSI-S-10-29 and CZ.1.07/2.3.00/09.0162.

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