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Identification of the Servo Motor Used in the Walking Robot

1. Introduction

The hexapod walking robot equipped with a construction plate is considered. The robot consists of six identical legs. The three-link legs are driven by three servo motors. The servo motor has a position range from –60 to +60 degrees. The leg construction is similar to the biological construction of the cockroach leg. Thanks to this fact the analysis of natural gaits of insects will be used during the control process design [9]. The robot is shown in Figure 1.

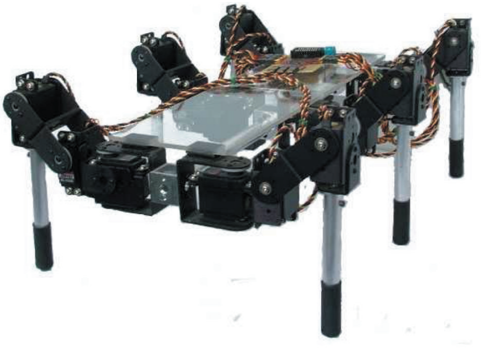

Fig. 1. Photo of the hexapod – six-legged walking robot

Hitec HS-475HB servo motors are used. The servo motor is controlled by a semi-PWM signal: it is a square signal and the width of its "high" level corresponds the desired servo motor position.

Figure 2 shows the control signal with the expected time and voltage values. The position of the servo motor is measured by the built-in potentiometer. A voltage drop on the potentiometer gives a direct information about the motor position.

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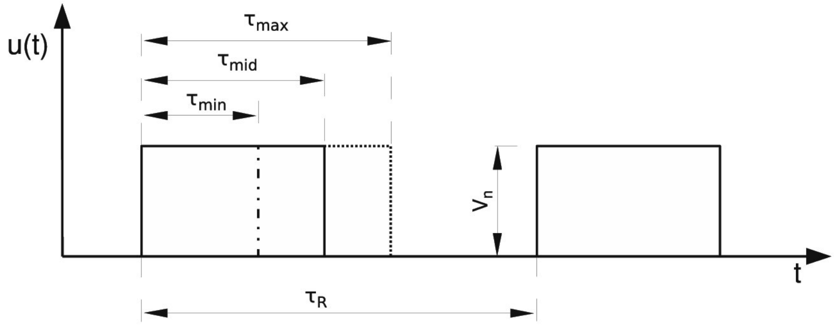

Fig. 2. The servo motor control signal: V_n = 3–4 V, τ_{max} = 2.1 ms is the servo motor at the right boundary position, τ_{mid} = 1.5 ms is the servo motor at the mid-position, τ_{min} = 0.9 ms is the servo motor at the left boundary position, τ_R = 20 ms is the square pulse refresh time

The direct control layer with the pre-set controller in the feedback loop of the servo motor has been implemented by a manufacturer. The structure and the parameters of the built-in controller are unknown. The whole system consists of 18 servo motors.

A development environment has been recently prepared for a plant identification and a control system design purposes [7]. It consists of two layers: an FPGA circuit and a PC computer with the Xenomai real-time operating system [6]. The FPGA circuit is responsible for the semi-PWM control signal generation and analogue to digital (AD) converters service. Desired experiments are executed by the PC with the real-time operating system (see Fig. 3).

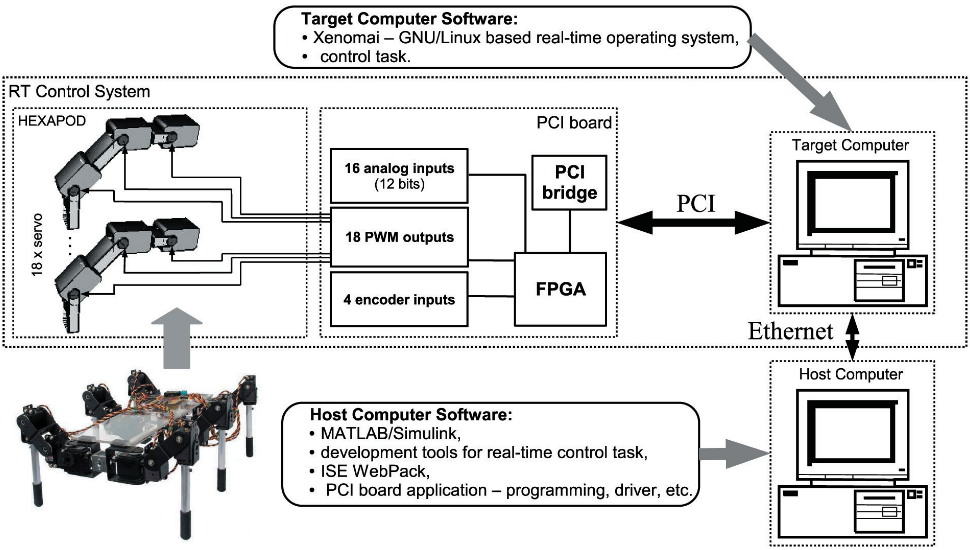

Fig. 3. The scheme of the development environment architecture

The other PC (the host) is also used for the FPGA logic and the software development, data preparation and analysis of the results. The system architecture is presented in Figure 3. Specially for the experiments described in this paper the development environment is enhanced with an incremental encoder service procedure in the FPGA circuit and in the PC [3].

2. Static analysis

At the beginning the static analysis is done. The servo motor is connected to the constructed system. The following signals are considered:

- servo motor angular position with the incremental encoder
- servo motor potentiometer voltage drop with the voltmeter
- servo motor potentiometer voltage drop with the AD converter.

Table 1

Fitted input and output scaling functions: α_s – desired angular position, p – corresponding servo motor units, x – ticks measured with AD converter, α_r – corresponding servo motor angular position

	Input relation	Max. error	Output relation	Max. error
Servo 1	$p = 396\alpha_s + 24053$	0.19%	$\alpha_r = -0.1647x+120.7564$	0.53%
Servo 2	$p = 386\alpha_s + 24111$	1.02%	$\alpha_r = -0.1695x+121.8836$	0.67%
Servo 3	$p = 395\alpha_s + 23983$	0.29%	$\alpha_r = -0.1640x+118.2398$	0.7%
Servo 4	$p = 384\alpha_s + 23943$	0.79%	$\alpha_r = -0.1703x+122.9180$	0.68%

During the experiment 49 successive values are set to semi-PWM signal generator and all the listed values are read. This experiment has been repeated for 4 different servo motors. Two main functions are analysed for each servo motor. These are relationship between:

- the servo motor units and corresponding angular position
- the angular position of the servo motor and measured ticks.

Both of them appear to be linear. Using the linear regression method the linear functions have been fitted to the measured points [1]. The biggest identified difference between fitted linear function and measured data relative to the range has been evaluated. The error values and the list of fitted functions for every tested servo motor are shown in Table 1. The second servo motor demonstrates the biggest difference. It is slightly bigger then 1%. The collected experimental points and fitted functions for the first tested servo motor are shown in Figure 4.

The identified relations are going to be used during successive experiments as input and output scaling functions. These experiments demonstrate that the biggest identified error resulting from linearization is sufficiently small for the considered application. However, if an arbitrary set of scaling functions were used for every servo motor the biggest identified error would be equal to 3.4% of the range that is equivalent to 4.0814°. Therefore every servo motor scaling functions have to be identified separately. On the other hand thanks to its use the experimentally detected variation in static behaviour of different servo motors are transparent to the control system [7].

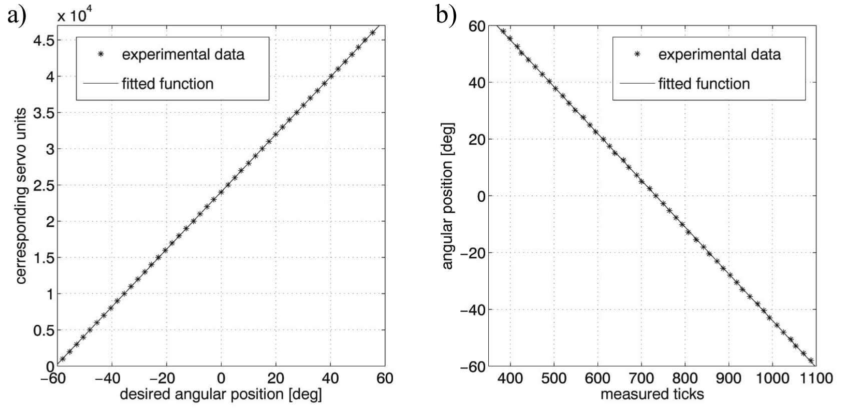

Fig. 4. Experimental data points and corresponding fitted linear scaling functions of the first servo motor: a) input; b) output

3. Dynamic analysis

The servo motor dynamics analysis is performed. For each servo motor the several experiments are executed. Three different input sequences are set to the servo motor. Every sequence lasts 30 seconds. Figure 5 shows the sequence that is used during the dynamics identification process. A shape of the identification sequence is relevant to planned servo motor applications.

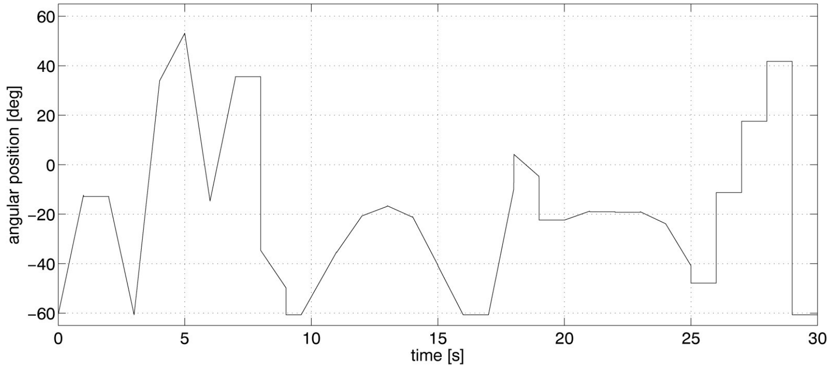

Fig. 5. The servo motor input – the identification sequence

Figures 6 and 7 show the verification sequences. The first one contains slow signal changes like different slopes and the second consists of peaks and steps. Figures 8, 9 and 10 show the servo motor responses to these sequences. The measured signal contains noise. As far as the identification is concerned the noise is neglected.

The sample time in all experiments is equal to 1 ms.

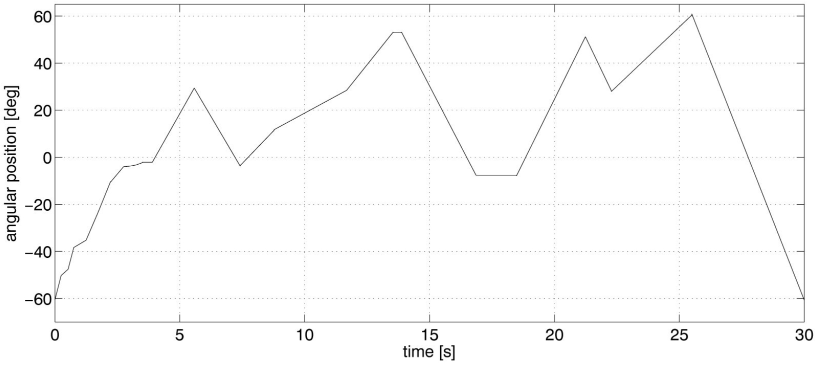

Fig. 6. The servo motor input – the "slow" verification sequence

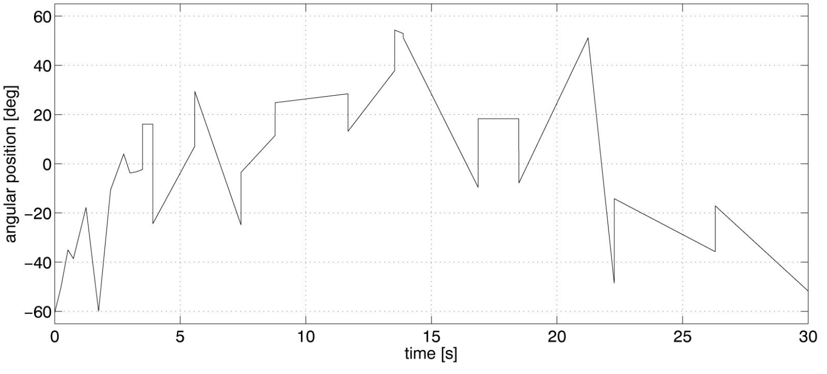

Fig. 7. The servo motor input – the "fast" identification sequence

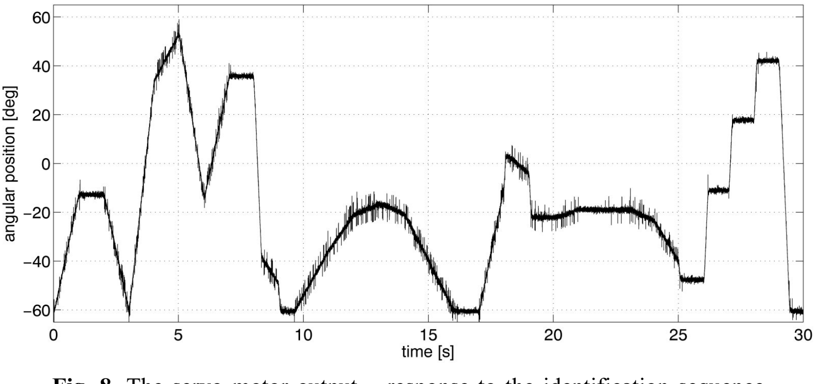

Fig. 8. The servo motor output – response to the identification sequence

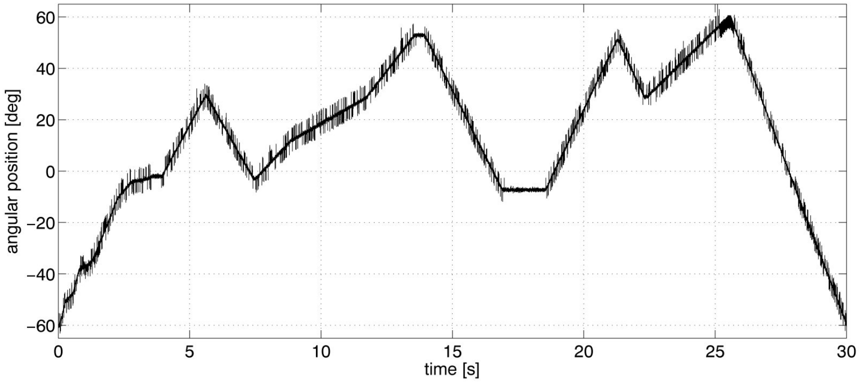

Fig. 9. The servo motor output – response to the "slow" verification sequence

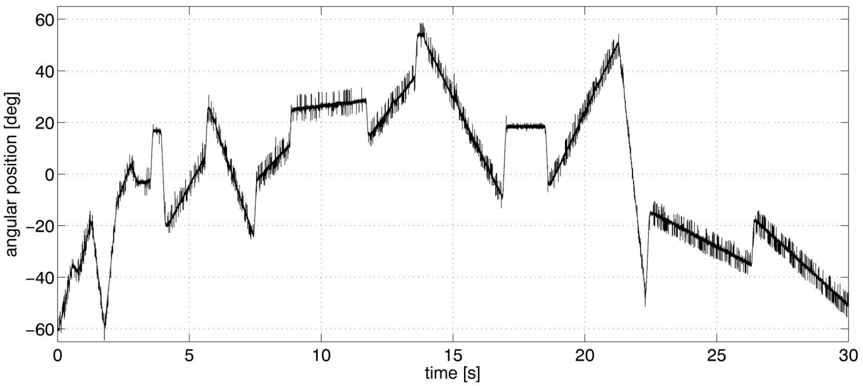

Fig. 10. The servo motor output – response to the "fast" identification sequence

3.1. Linear model

The linear model is identified with MATLAB System Identification Toolbox [2, 5]. A number of different linear models is taken into account. Models have been compared one to another with performance index:

$$J = \sum_{k=0}^{N} \left(y(k) - y_m(k) \right)^2$$

where $N = 30000$, $y(k)$ is a plant and $y_m(k)$ is a model response for the same control sequence.

The best (as far as the performance index is concerned) result is achieved with fourth-order discrete linear model given below:

$$x(k+1)=\begin{bmatrix} 0.9963 & -0.0058904 & 0.0018008 & 0.029778 \\ 0.007089 & 0.97588 & 0.026402 & -0.27325 \\ 0.00083659 & 0.0029237 & -0.99034 & -0.23068 \\ 0.0017501 & -0.031085 & 0.045057 & -0.45195 \end{bmatrix} x(k)+$$

$$+\begin{bmatrix} -5.6112\cdot 10^{-6} \\ 8.8037\cdot 10^{-5} \\ -0.000286 \\ 0.00045491 \end{bmatrix} u(k)$$

$$y(k)=\begin{bmatrix}1615.6 & 279.94 & -22.375 & 33.2\end{bmatrix} x(k)$$

The value of the performance index for the best linear model is equal to: 700.7 for the identification sequence, 137.2 for the "slow" verification sequence and 377.4 for the "fast" verification sequence.

3.2. Non-linear model

There is some indication that control signal constraints have impact on the servo motor dynamics. In Figure 11 we can easily observe two phases of the servo motor step response signal change. At the beginning it is the phase of signal growth with a constant angular velocity of the DC motor. Next, it is a typical phase of the first-order inertial object [4]. The first phase is a result of the control signal constraint; a constant control signal results in a constant DC motor velocity. In a neighbourhood of a steady state the control signal value falls below the constraint and the DC motor behaves like an inertial plant.

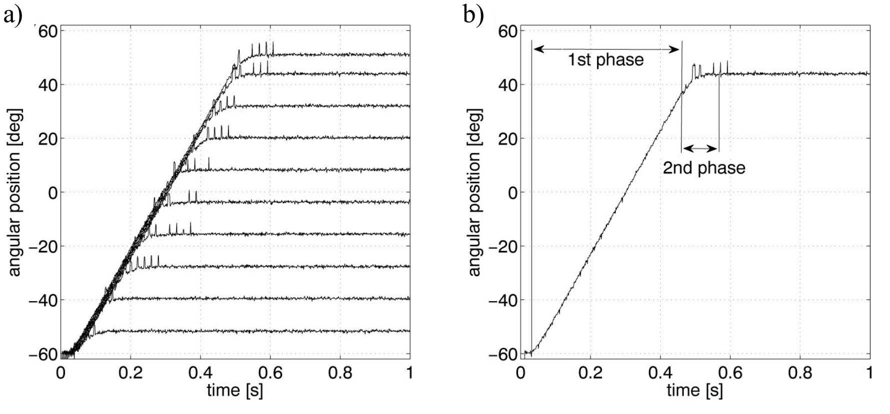

Fig. 11. The servo motor step response: a) comparison of 10 different step responses; b) step response with two indicated phases

The model of the servo motor equipped with this constraint is built in the Simulink software.

The following list of the parameters have to be determined:

T_i – DC motor inertia
k_i – DC motor gain
k_p – proportional controller coefficient
$S_{\min}$ – control signal lower constraint
$S_{\max}$ – control signal upper constraint

The model assumes that DC motor is controlled with a proportional controller in a feedback loop and its dynamics can be approximated with a first-order inertial model. Figure 12 presents the structure of the model. The numerical optimisation methods can be used to identify parameters values [8]. Unfortunately, the model is parametrically redundant and optimal solution is not unique.

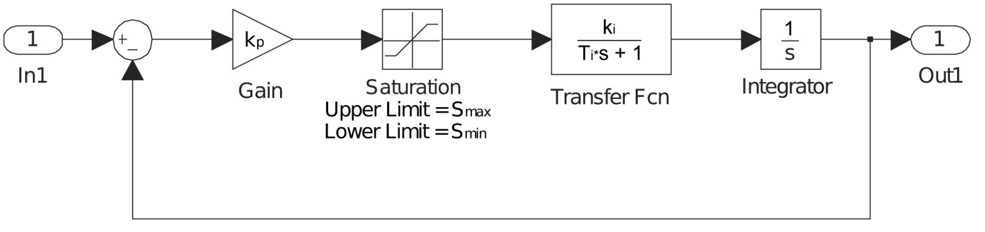

Fig. 12. Structure of the servo motor non-linear model

To avoid this problem one of the parameters: k_i is set to 1. Assuming that:

$$k = k_p k_i$$

$$\overline{S} = S_{\max} k_i$$

$$\underline{S} = S_{\min} k_i$$

the new model (Fig. 13) equivalent to the old one is obtained.

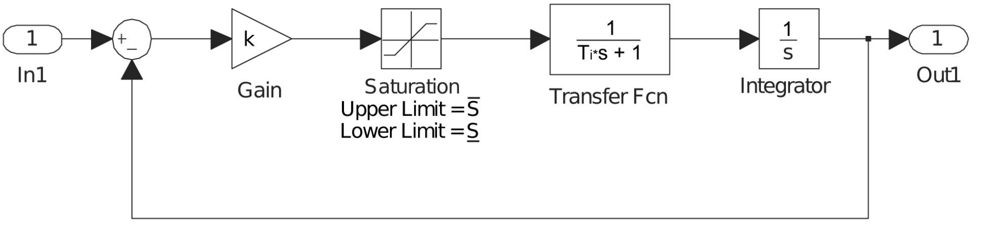

Fig. 13. Modified structure of the servo motor non-linear model

The parameters of this model are identified with the least squares optimisation method (trust region method). The Simulink Design Optimization tool is used. The obtained values are listed in Table 2.

Table 2
The non-linear model parameters

Parametr Name	Symbol	Value
DC motor inertia	T_i	0.0181
Proportional controller coefficient	k	20.8279
Upper control signal constraint	$\overline{S}$	220.9851
Lower control signal constraint	$\underline{S}$	–220.854

The values of the performance index defined in 3.1 are equal to: 38.5 for the identification sequence, 27.35 for the “slow” verification sequence and 38.2 for the “fast” verification sequence.

4. Summary

The experiments show that in the case of Hitec HS-475HB servo motor the non-linear model with the proposed architecture gives better results then a linear one. The values of performance index in both cases are compared in Table 3. The performance index value for the non-linear model significantly outperforms the linear one. Figures 14, 15 and 16 show the linear model, the non-linear model and the plant dynamics. The proposed non-linear model is a sufficiently good approximation of the servo motor dynamics dedicated to future experiments.

The servo motor simulation already performed will help a lot in overall hexapod legs motion simulation and control design.

Table 3
Performance index for the linear and non-linear models

Sequence	Linear model	Non-linear model
Identification	700.7	38.5
“Slow” verification	137.2	27.35
“Fast” verification	377.4	38.2

However, experiments with the static servo motor behaviour show that the scaling functions for every single servo motor have to be identified separately. In the case when eighteen servo motors are used the control becomes a very complex and time consuming task.

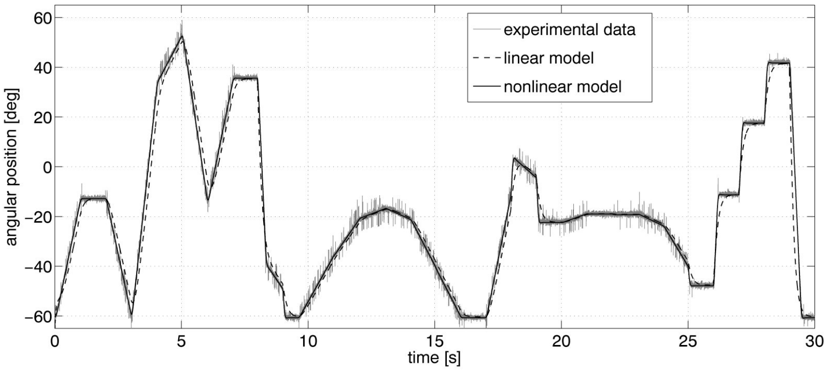

Fig. 14. Response to the identification sequence – linear and non-linear models compared to the real plant response

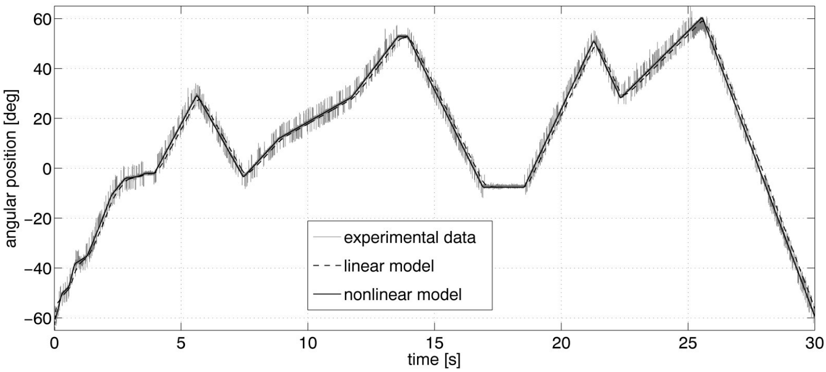

Fig. 15. Response to the "slow" verification sequence – linear and non-linear models compared to the real plant response

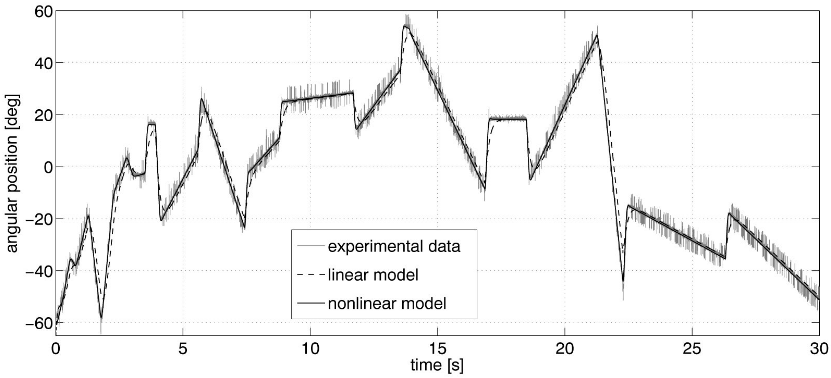

Fig. 16. Response to the "fast" verification sequence – linear and non-linear models compared to the real plant response

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