Fractional control performance assessment of the nonlinear mechanical systems

Patryk Chaber* and **Paweł D. Domański****

Institute of Control and Computation Engineering, Warsaw University of Technology,
ul. Nowowiejska 15/19, 00-665 Warsaw, Poland
* *ORCID #0000-0003-0257-8255* ** *ORCID #0000-0003-4053-3330*

Abstract. There are many approaches to assess control quality, from classical mean-square error or variance, model-based and model-free approaches, to fractal or entropy measures. These indicators can be used for a variety of algorithms. Nonlinear industrial solutions pose new challenges for such solutions. Indicators must be robust, reliable and informative. They must work in the presence of disturbances and uncertainties. The complication of the process, its nonlinearities, mutual correlations, variable delays and outlying anomalies should not limit it. Additionally, human influence must not interfere with its robustness. One of the modern approaches that is gaining popularity is fractional calculus. It allows to consider complex and non-stationary processes. It is shown that Geweke-Porter-Hudak (GPH) fractional order estimator allows to assess control system quality. The method is validated using the laboratory mechanical servomechanism.

Introduction

Industry 4.0 transformation makes production versatile, flexible, sustainable, supporting vertical and horizontal integration. Such plants require stringent control system, which operates close to its technological constraints. Reliable control control performance assessment is a must. There are many approaches for the univariate PID loops [1]. Real non-linear processes exhibit internal correlations with varying delays at different time scales that reflect the long-range dependence or persistence properties. Modeling of such variables with regression models is not enough. Auto-Regressive Fractionally Integrated Moving Average (ARFIMA) models [2] constitute an alternative [3]. Our research follows above assumption. If the fractional model can be considered as the fundamental process behind control data, its coefficients, especially the fractional-order, could be used as its quality measure. This research uses GPH fractional order $-0.5 < d < 0.5$ estimator of the ARFIMA(p, d, q) process [4]. Once $d \in (-0.5, 0)$, the system is anti-persistent and exhibits long-range negative dependence. In case of $d \in (0, 0.5)$, the process is persistent and reflects long memory. Once $d = 0$, it is stationary independent process. Anti-persistent properties indicate aggressive tuning, persistent sluggish and $d = 0$ good control.

Results and discussion

The laboratory nonlinear servomechanism system (Fig. 1) is used to visualize the method. The system allows to measure the speed in two ways: using the tachometer and with the encoders. Each measurement has different characteristics. The first one is very noisy with the noise magnitude that depends on the speed, while the latter one is very smooth. The system is controlled by the PID controller with the anti-windup mechanism. They are tested with stationarity tests and as the results control error data are incremented to remove the non-stationarity.

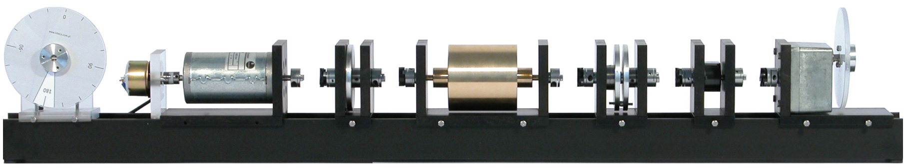

Figure 1: Laboratory servomechanism used during experiments

Table 1 shows sample experimental results that confirm initial assumptions. Fractional order does not depend on the sensor. Similar tuning is reflected by the similar values. The better control is observed close to the $d = 0$ value. Research addresses other issues, like the detailed impact of the PID parameters, the effect of the controller saturation and the anti-windup. The fractional order is compared with other statistical indexes.

Table 1: Fractional order estimates d; PID parameters: $\{k_p; k_I; k_D; k_H\}$; sensor used for feedback (E) - encoder, (T) - tachometer

	$\{0.1; 0.1; 0.1; 0.0\}$ (E)	$\{2.0; 2.0; 2.0; 10.0\}$ (E)	$\{10.0; 0.001; 0.001; 0.0\}$ (E)	$\{10.0; 0.001; 0.001; 0.0\}$ (T)	$\{10.0; 10.0; 0.0; 10.0\}$ (E)
encoder	-0.3906	-0.4157	-0.1005	-0.0998	-0.1475
tachometer	-0.3700	-0.4056	-0.1031	-0.0959	-0.1535

References

[1] Domański P.D. (2020) Control Performance Assessment: Theoretical Analyses and Industrial Practice. Springer International Publishing, Cham, Switzerland.

[2] Sheng H. Chen YQ and Qiu TS (2012) Fractional Processes and Fractional-Order Signal Processing, Techniques and Applications. Springer-Verlag London Limited, London, UK.

[3] Liu K., Chen YQ and Domański, P.D. (2020) Control Performance Assessment of the Disturbance with Fractional Order Dynamics. In W. Lacarbonara, B. Balachandran, J. Ma, J. A. Tenreiro Machado, and G. Stepan, editors, *Nonlinear Dynamics and Control* 255-264, Springer International Publishing, Cham, Switzerland.

[4] Geweke J. and Porter-Hudak S. (1983) The Estimation and Application of Long Memory Time Series Models. *Journal of Time Series Analysis* **4**(4):221–238.