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A case of mitigating non-autonomous time-delayed system with cubic order feedback

Chi-Wei Kuo, C. Steve Suh*

Nonlinear Engineering and Control Lab, Mechanical Engineering Department, Texas A&M University, College Station, TX 77843-3123, USA

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Abstract

Time-delayed feedback of a small magnitude can perturb a system to exhibit complex dynamical responses including route-to-chaos. Such motions are harmful as they negatively impact the stability and thus output quality. A non-autonomous time-delayed oscillator having several higher order nonlinear feedback terms is investigated using a novel concept featuring simultaneous control of displacement in the time-domain and spectral response in the frequency-domain. The concept is explored to formulate a control methodology feasible for the mitigation of the non-autonomous time-delayed feedback system. Because the control concept does not require linearization, the true dynamics of the non-autonomous delayed feedback system is faithfully preserved and properly construed in the control action. The validity of the controller design is demonstrated by evaluating its performance against PID and fuzzy logic in controlling displacement and frequency responses with the most chaotic dynamic response time-delay parameters.

1. Introduction

Time-delayed systems are ubiquitous in science and engineering. They are found governing a broad set of physical processes ranging from quantum dot laser [1] to electrical power

* Corresponding author.
E-mail address: ssuh@tamu.edu (C.S. Suh).

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Nomenclatures

x	excitation sequence
$\alpha_1, \alpha_2, \beta_1, \beta_2, k$	parameters of non-autonomous time-delayed feedback system
ω_f	external driving frequency
τ	time-delay parameter
t	time
$W(z)$	adaptive filter
n	time step
$e(n)$	error
$y(n)$	system output
$d(n)$	desired response
J	performance function
$\mathbf{w}$	adaptive filter coefficient vector
$P(z)$	unknown plant
$S(z)$	transfer function associated with control mechanism
ω_c	unobservable control frequency
N	length of input sequence
T	wavelet transformation matrix
$W_1(n), W_2(n)$	adaptive filters
$U(n)$	input control signal vector
$X'(n)$	compensated output signal vector
$\bar{y}(n)$	reconstructed signal
$\bar{e}(n)$	error between the desired signal and the reconstructed signal
$f(n)$	difference between $e(n)$ and $\bar{e}(n)$
μ_1, μ_2	optimization step sizes
k_p, k_i, k_d	PID control parameters

transmission [2] to manufacturing chatter. Early interests were in characterizing time-delayed systems subject to the combined action of the time-delay and feedback parameters. Phase portrait and Poincaré section were commonly adopted for the task. For example phase portraits were employed for the reconstruction of the chaotic data from an experiment performed on the Belousov–Zhabotinskii reaction [3] and the study of an autonomous rotary system [4]. Poincaré sections on the other hand were employed in the control of nonlinear ionization waves using time-delayed auto-synchronization [5] and for locating the periodic orbits of a time-delayed system [6]. Other characterization tools were also explored including the determination of the largest Lyapunov exponents for continuous as well as discrete systems [7,8], the calculation of the proper delay time for chaotic time series [9], and the use of fractal dimension for searching for the proper embedding dimension that is also one of the parameters of the Method of Delays [10]. While being widely applied, nonetheless, the tools above are not without limitations. Phase portrait and Poincaré section are not feasible for erratic responses that are innately chaotic [11]. Lyapunov exponents or fractal dimensions are oftentimes insufficient for resolving chaotic responses because different attractors may generate the same Lyapunov numbers [12].