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Generalized Pattern Search Methods for control of stable, unstable and integrating systems with unknown delay under step input

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Abstract

A number of different analytical and numerical methods have previously been proposed to identify and control systems with unknown delay. The methods have been based on the Smith Predictor for the stable case and on modified Smith predictor, for the unstable and integrating case. Among the proposed optimization techniques, the pattern-search-based method besides its computational advantage, provides better accuracy compared to other methods. However, the response of the methods under step input in some case is deficient. This paper presents an improved Generalized Pattern Search Method (GPSM) based optimization technique, where new updates ways are proposed. The proposed GPSM algorithm uses a simple structure based on the feedback of fitness value in the process. It provides better performance for delay identification and a reference tracking. Comparisons with existing methods for delay estimation are presented using both synthetic and experimental data under various conditions. The proposed scheme offers higher accuracy, and also eliminates the need for users to manually tune the control parameters of Pattern Search Methods.

Keywords: Time delay; Unstable systems; Modified Smith predictor; Intelligent control; Pattern Search Method

1. Introduction

Delay is a physical phenomenon present in all dynamical systems. In some cases, the effect of the delay can be seen with the naked eye, while in other circumstances its effect is almost imperceptible. Delay can be divided into four categories: (i) Distributive delay which is represented by a signal that depends on the value of this signal in a previous

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time (which can be finite or infinite in duration). (ii) Point delay, is a signal that has a previous time value, where the time distance is measured between the actual and previous moments. (iii) External delay is a delay to the input or/and output of the system. (iv) Internal delay is a delay in the system state. Of all these delays, maybe the internal delay is the most difficult to control, since, while the external delay affects the numerator of the transfer function, or what is the same, the zeros of the system, the internal delay affects the denominator, modifies the poles of the transfer function, and, therefore, conditioning in this way the system stability. It is to highlight, that the external delay becomes an internal delay in closed-loop configuration.

The external delay in a process causes the output signal being delayed with respect to the input. Thus, if a control strategy has to be designed for this system, the presence of the delay makes it a more difficult task. External delay is present in many system models, due to different reasons, specially: (i) The network delays, generally small, which are due to the transport of the information (control law, measures, etc.) between the process and the controller [29]. (ii) The mass transport delay, whose size is related with the physical properties of the systems [11,31].

Control strategies for delayed systems can be implemented in different ways. On one hand, if the delay is small and known, it is possible to apply classical techniques of closed-loop control, obtaining an acceptable performance of the controller. In [2,31] different tuning rules for stable/unstable first order plus dead time (FOPDT) and second order plus dead time (SOPDT) systems can be found. The disadvantage of such techniques is that they only work well when the delay is small compared with the time constant of the system [34]. On the other hand, if the delay is long, it is necessary to use a delay compensation scheme, being the Smith Predictor (SP) the most extended one. This topology was proposed in the 1950s. Since then, it has been extended to include robustness issues or the possibility of dealing with unstable processes [25]. The use of the Smith Predictor facilitates the controller design because it allows to disregard the delay as long as it is perfectly known. However, in practice there is always some mismatch between the assumed and real delays. This error degrades the final performance and can even result in instability [21]. The SP has been extended to stable, unstable and integrating systems in [25], where a perfectly known delay is also necessary. Nevertheless, this restriction reduces the commercial use of these controllers.

The approaches mentioned above, can be used where the delay is known, but if the model has an uncertainty in the delay, the response of the controller is strongly affected. For it is commonly to find some approaches that taken into account an uncertainty in the model delay. As an example, in [35] a modification of the Smith predictor is made, and a scheme of two degrees of freedom is formulated and the response to the reference decouples from the disturbance rejection. In [28] an analysis of a robust control for the Smith predictor, is made. Additionally, iterative learning control [20,33], two-degree-of-freedom (2DOF) controllers [23], $L_2 - L_\infty$ fuzzy control [14] and Lyapunov–Krasovskii functional methods [12,13], have been proposed for this purpose.

Recently, a framework focused on the identification and control of systems with delay uncertainty, has been proposed for both stable [1,15,17] and unstable cases [18]. The approach presented in [1,15,17] is based on the classical SP and a multi-model scheme. The multi-model scheme contains a battery of time-varying models which are updated using a modification rule. Each model possesses the same rational component but a different delay value. The algorithm compares the mismatch between the actual system and each model and selects, at each time interval, the one that best describes the behavior of the actual system, providing online identification of the delay while simultaneously ensuring the closed-loop stability. The way in that the delay varies is determined by a heuristic optimization; this allows the delay identification and the system control simultaneously. Additionally, this approach leads to a robustly stable closed-loop system while achieving a great performance for systems with unknown long delays. This work was extended to stable, unstable and integrating systems in [18]. The approach has the same framework but, in this case, the scheme is based on the modified Smith Predictor (MoSP) introduced in [25] and the optimization is framed into a Pattern Search Method (PSM) [32]. Maybe, the principal shortcoming of all these approaches is that the delay identification cannot be guaranteed for a step signal since a non-periodic input signal is a requirement to guarantee the delay identification, reducing its scope in the process control industry where step signals are used predominantly.

Following the same line as [18], this paper is focused on the estimation of the delay in an on-line manner. For it, we use a multi-model scheme with time-varying models to define a time-varying nominal delay, which is used in the control law. The proposed approach can be used in stable, unstable and integrating systems. The principal advantage with respect to [18] is that the estimation can be made with a step signal. In this way, the approach has a great scope in the process industry. Furthermore, the convergence time of the nominal delay to the actual one is reduced considerably in comparison with [18], allowing a settling time reduction.