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Predictive-delay control based on real-time feedback scheduling

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ABSTRACT

Usually in the context of integrated control and real-time scheduling, quality of control improvement is mainly based on the dynamic measurement process and the system task scheduling parameters (i.e., sampling period, execution time). In this paper, a new feedback controller based on delay prediction is proposed to overcome the degradation of quality for multi-controller systems due to scheduling delays. A statistical analysis is performed to highlight the correlation between scheduling artifacts (delays and jitters) and quality of the control. It is stated that the input–output latency has a significant influence on the quality of control. Hence, it is proposed to reduce control impairments by using a prediction of the response time to update the output. A case study consisting of the control of three servo-motors is used to practically illustrate our statement. The consistency and effectiveness of the improvement are checked through the case of the control of three inverted pendulums.

1. Introduction

Real-time control systems are generally composed of operational (operating equipment) and control parts. They usually consist of at least one control loop to fulfill three main functions: sampling measurement, ensuring the operating equipment stability through a controller algorithm and actuation. The desired performance, i.e., trade-off between accuracy and rapidity of a control loop, is determined by the damping ratio ξ, the closed-loop system bandwidth ω_c, the sampling period h and the phase margin φ_m (all these control parameters are interrelated, see Table 1 for details). Several methods in control theory are used (lag/lead compensator, frequency response methods, etc.), and several trials are performed until all transient and steady state requirements (fast dynamic and good precision) are met. The associated parameters (T_{rise}, T_{set}, T_{peak}) are shown in Fig. 1.

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Table 1
Control parameters description.

Parameter	Description	Used formula
ω_c	Closed-loop system bandwidth	First frequency where the DC gain drops below 70.79% (−3 dB)
h_i^{nom}	Nominal period	The rule of thumb in [1], $0.2 < \omega_c h_i^{\text{nom}} < 0.6$
%os	Over shoot	$\frac{y_{max}-y_{final}}{y_{final}}$, ($y_{max}$ and y_{final} are defined in Fig. 1)
ξ	Damping ratio	$\frac{ln(\%os/100)}{\sqrt{\pi^2+ln^2(\%os/100)}}$, (defined in [2])
φ_m	Phase margin	$arctan(\frac{2\xi}{\omega_c\sqrt{-2\xi^2+\sqrt{1+4\xi^4}}})$, (defined in [2])
T$_{rise}$	Rise time required for the output response to reach 90% of its input value from the start	Presented in Fig. 1
T$_{set}$	Settling time required for the output response to approach and stay within a certain range of the input value (usually 2%)	Presented in Fig. 1.

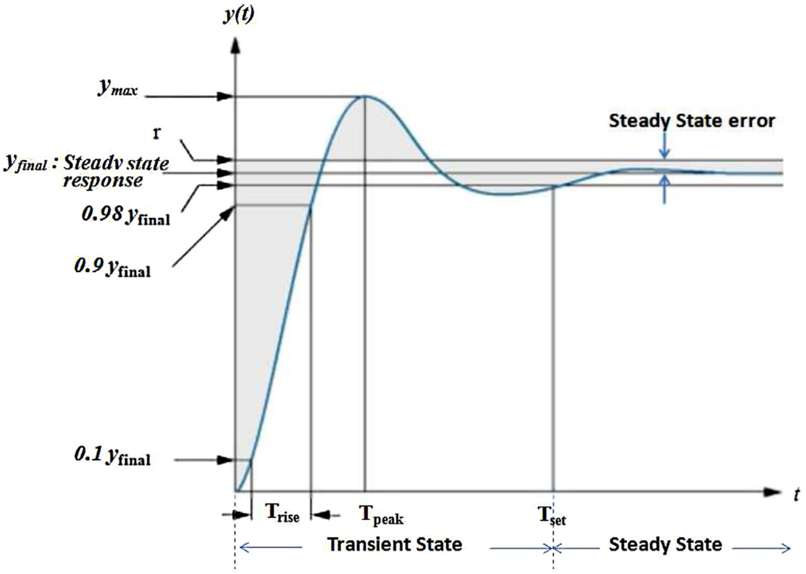

Fig. 1. Second order system response specification.

In most real-time operating systems, the controller part is considered and implemented as a periodic task. In such setting, the first constraint is how to choose task periods. It is known that a very low period may lead to a redundant or a useless control, while a large period may deteriorate the stability of the system. A common way to choose appropriate sampling period (nominal period h^{nom}) is to use the rule of thumb, defined in [1] as

$$0.2 < \omega_c h^{\text{nom}} < 0.6. \tag{1}$$

It is worth noting that this rule is defined for systems with a constant sampling time. Limitation on computing resources imposes temporal constraints. Control tasks are urged to start the sampling measurement at nominal periods and their processing has to end within the specified deadlines, otherwise the system fails. To deal with this issue, real-time scheduling theory where a task-set is considered to be feasible if it is schedulable by a scheduling algorithm, is often used. Yet, matching the condition of the empirical rule 1, even if some deadlines are violated, the system continues evolving correctly [3]. The second constraint is the controller execution time, stipulating that only a margin of φ_m/ω_c is tolerated for the delay on the computing time. These constraints are referred to as scheduling-control codesign constraints. Henceforth, ensuring schedulability or opting for suitable control may not suffice, and subsequently interrelationships between schedulability and control design must be considered.

In this work, codesign constraints related to scheduling artifacts (i.e., delays and jitters) due to interference between tasks according to scheduling policy are studied.

It is well known, that for near a decade, previous works have focused on the real-time scheduling/control codesign. At the start, researchers used to integrate changes in the state variables of the scheduler (processor bound, periods, execution time, etc.) into the control loop, this is referred to as feedback scheduling. However, in such models, interdependencies between the system variables are still somewhat ambiguous. For instance, in [3] a Feedback Scheduler (FBS) is defined where each time it is released, the task periods are readapted dynamically under the condition that while the observed task execution time varies, the processor load remains less or equal to the feasibility bound of Liu and Layland (L&L) [4]. It is concluded in [3] that when the product $\omega_c h^{\text{nom}}$ is small for all control tasks, the quality of control (QC) will be less sensitive to the