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Application of SSOD-PI and PI-SSOD event-based controllers to greenhouse climatic control

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ABSTRACT

In this work, an application of the Symmetric Send-On-Delta (SSOD) event-based controllers to the inside air temperature control of the greenhouse production process is presented. The control technique analysis is split into two stages. The first stage is devoted to determine the proper controller parameters and to check the influence of the Send-On-Delta (SOD) threshold value through simulation study. At the second stage, experimental tests on the real greenhouse facilities are performed. The obtained results show that the analyzed control techniques handle the control task with desired accuracy and performance. In particular, the proposed control system saves costs related with energy consumption and wear minimization, by achieving a satisfactory performance at the same time.

1. Introduction

Nowadays data networks are often included in the development and in the deployment of industrial control systems and this requires a change in the classical approach of control system design. Indeed, closed-loop control systems using field buses, local area networks or even Internet make the adoption of the classic time-driven paradigm difficult. For these reasons, the introduction of the field bus technology represents a milestone in industrial control systems [1–6]. Furthermore, the event-based approach can be exploited in many other aspects. Despite the obvious benefits for networked systems, the event-based control systems can also be used to decrease a control effort required to carry out control tasks. This feature of event-based control systems can be used to establish a tradeoff between control performance (control accuracy) and control effort (resources used for control purposes). In such a way, event-based control systems could reduce usage of resources (reducing economical costs) at the expense of negligible performance degradation. This is the case of the greenhouse temperature control problem, where it is important to reduce the number of actuator movements (to reduce energy consumption and to save actuator lifetime) but keeping acceptable performance results (temperature within certain limits).

Actually, this is the case of many biological systems. These processes are characterized for being in an equilibrium state and changes come in a sporadic way because of external stimuli (disturbances). Therefore, the control system reacts against sporadic changes, which perfectly fit to event-driven approach. Furthermore, the event-based control scheme reduces control system attention reacting only when it is strictly necessary. Due to this working principle, the overall control effort can be decreased, for instance, reducing demands of electrical energy or other resources used for control purposes. Some recent works show that event-driven approaches are able to modulate the execution of the control task adapting it to the proper system dynamics and in result they provide several benefits [7–9]. This is an important feature, since the bioprocesses control system usually focuses on external disturbance compensation. In [10] it was shown that the application of the event-based controller with sensor deadband allows a significant reduction of CO_2 losses in microalgae culture process. This reduction was obtained at expense of an insignificant control performance degradation. On the other hand, in [11] the event-based approach was used for effective utilization of flue gases in raceway reactor. In that work, the event-based approach

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enabled the control system design flexibility to achieve desired tradeoff between control performance and control effort. The developed algorithm provides only the necessary amount of gas, reducing the gas usage when compared to classical control scheme. Moreover, in [9], an event-based GPC control strategy is proposed for controlling greenhouses temperature. In such a case, it was demonstrated that the application of the event-based control technique reduces the amount of information exchanged between control system nodes. Considering the aforementioned aspects, event-based techniques, among others applications, become an interesting solution for the industrial bioprocess control systems. In fact, those processes have a hierarchical structure and for low level control loops the Proportional-Integral-Derivative (PID) controllers are frequently used. However, there are only a few implementations using an event-based approach. For this reason, the application of event-based control systems should be more disseminated in industrial environments highlighting their features.

Event-driven systems require an event detection technique that indicates a time instant when control action should be carried out. For this purpose, numerous event-based sampling techniques were introduced and evaluated. When the event-based sampling technique is used, the sampling time is aperiodic and thus it becomes necessary to study and to analyze how the control techniques should be modified to account for that aspect. Considering this feature, it is necessary to develop a new control system methodology able to deal with nonuniform sampling. One of the most promising event-based sampling strategies is the SOD sampling (also denoted as level crossing sampling [12]), where node samples (and sends) the signal only when it changes a fixed quantity with respect to the last sampled value [13,14].

The SOD sampling is often combined with event-based PID controllers [15–24]. This is because PID controllers are widely known and used in industry and, as a consequence, attract the research effort to adapt such control technique to event-based operation mode. The modified version of the SOD technique, called symmetric send-on-delta (SSOD) sampling (where the thresholds are fixed and the presence of the zero-threshold is guaranteed [12]) was used in [7] to avoid the dependence on the initial conditions and to guarantee the existence of a (unique) equilibrium point [25]. Furthermore, sufficient conditions on system stability and necessary and sufficient conditions on the controller parameters for the existence of equilibrium points without limit cycles for First-Order-Plus-Dead-Time (FOPDT) processes using SSOD technique were analyzed in [7]. On the other hand, in [26], *ad-hoc* tuning rules are proposed and compared with two well-known tuning rules (namely, the AMIGO (Approximate M-constrained Integral Gain Optimization) rules [27] and the SIMC (Skogestad Internal Model Controller) rules [28]), highlighting the similar behavior of the proposed controller with the standard ones. It should be mentioned that heuristic tuning methods (such AMIGO or SIMC) are frequently used by the practitioners. Despite its significant potential, the event-based controllers are rarely used in practical applications [29–31]. Indeed, in order for this methodology to be widely accepted in the process control community, it is necessary that its design issues are fully characterized and its effectiveness is proven in different application fields. This is even more important in PI(D) control technique, which is dominant in the vast majority of industrial control loops. The development and application of the event-based PID variants should be promoted since could reduce several issues in industrial control systems.

Taking into account the properties commented above and the relatively small number of practical applications of event-driven controllers, in this work, two event-based PI approaches are implemented for the greenhouse production process. The SSOD-based PI (Proportional-Integral) controllers are applied to the greenhouse production process, to handle the inside air temperature control task. The event-based approaches are evaluated in two stages. The first one focuses on a simulation study, where an exhaustive analysis is provided based on a preliminary simulation study for inside temperature presented in [8]. Additionally, the event-based configurations are compared to the classical PI controller, which is commonly used for greenhouse inside temperature control. Performed tests were oriented to show the influence of event-based PI parameters on the overall control performance. Subsequently, several controller configurations are verified in order to determine the desired performance as function of the SSOD threshold value. In this way, the compromise between control performance and control effort can be established. Moreover, the communication issues are also measured considering input and output events of the process. The second stage focuses on the experimental analysis of the event-based approaches. For this purpose, only the selected configurations from the simulation study were implemented and tested on the real greenhouse facilities. The analysis of the tested control technique was performed using several indexes, that measure control accuracy, control effort and number of communications. The results show that event-based PI controller configurations provide promising results. The tested control systems preserve all benefits of the event-based systems, as well as introducing the possibility to adjust the tradeoff between control performance and control effort. The obtained results demonstrate that this type of controllers is a suitable alternative to the event-based predictive control strategy, previously tested on the same process. Indeed, SSOD controllers are as effective as the previous approach, being at the same time simpler in implementation and requiring less computational/communication efforts to achieve similar control performance.

With the study presented in this work, it is shown that event-based controller is feasible for handling a complex system such as the greenhouse production process. In such a case, the controlled process is managed efficiently taking into consideration the efficient use of energy. The use of event-based approaches in greenhouses is especially relevant since the actuation system in these cases is usually composed by mechanical devices controlled by relays. Thus, it is desirable to reduce the number of commutations of the control signals in order to increase the life-span of the components.

The paper is organized as follows. The overall control scheme is summarized in Section 2, including description of the event-triggering technique and characterization of the event-based control approach. Subsequently, the greenhouse production process as well as the used modelling approaches are introduced in Section 3. The results and discussion for the simulation study and the experimental validation are given in Section 4. Finally, conclusions are drawn in Section 5.

2. Control architecture

This section is devoted to describe the key techniques and their properties used to built the event-based control approach. This includes a brief introduction to the symmetric send-on-delta sampling method, and its application to the PI control technique. Moreover, the resulting control architectures are introduced considering PI-SSOD and SSOD-PI configurations.

2.1. Symmetric send-on-delta triggering

The evaluated event-based controller uses the event-triggered data exchanging method applying a special case of the send-on-delta sampling scheme [13,16] and it is called symmetric-send-on-delta, which can also be seen as a generalization of a relay with hysteresis.

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