Preprints of the 19th World Congress
The International Federation of Automatic Control
Cape Town, South Africa. August 24-29, 2014

Symmetric send-on-delta PI control of a greenhouse system ⋆

Manuel Beschi * **Andrzej Pawlowski** ** **José Luis Guzmán** ***
Manuel Berenguel *** **Antonio Visioli** ****

* *Dipartimento di Ingegneria dell'Informazione, University of Brescia, Italy (e-mail: manuel.beschi@ing.unibs.it)*
** *Departamento de Informática y Automática, ETSI Informática, UNED, 28040 Madrid, Spain (e-mail:a.pawlowski@dia.uned.es)*
*** *Departamento de Informática, Universidad de Almería, Almería, Spain (e-mail: {beren,joseluis.guzman,a.pawlowski}@ual.es)*
**** *Dipartimento di Ingegneria Meccanica e Industriale, University of Brescia, Italy (e-mail: antonio.visioli@ing.unibs.it)*

Abstract: This paper deals with a symmetric send-on-delta PI control strategy for controlling the internal temperature of a greenhouse. It is shown that, by properly designing the control system, the disturbances represented by the soil temperature, the solar radiation, the wind velocity, and the outside temperature can be effectively compensated with a limited number of events. The role of the design parameters is outlined and simulation results demonstrate the efficacy of the methodology by comparing it with previously proposed techniques.

Keywords: Event-based control, PID control, Greenhouses.

1. INTRODUCTION

The reduction of the installation cost and of the set-up time of an industrial control system are key issues to improve the return of investment. Moreover, a simple and cheap reconfigurability is required. For these reasons, the introduction of the field bus technology represented a milestone in the industrial control systems.

In the last decades, thanks to the wireless communication improvements, the wireless control systems are becoming a suitable solution because they allow the designer to reduce the use of the wires (and their installation cost) and to easily reconfigure the layout of the plant. The principal drawbacks of this technology are the limited network bandwidth and the (possible) presence of batteries to power up a part of the communication nodes.

One way to reduce the network use and save the batteries energy is to implement an event-based control strategy (Blevins, 2012). For this reason, this control field has been the subject of a lot of research effort in the last few years (see, for example, (Åström, 2008; Heemels et al., 2008; Heemels and Donkers, 2013; Otanez et al., 2002; Chacón et al., 2013))

One of the most promising event-based sampling strategies is surely the send-on-delta (SOD) sampling (also denote level crossing sampling (Kofman and Braslavsky, 2006)), where a node samples (and sends) a signal only when it changes of a fixed quantity with respect to the last sampled value (Miskowicz, 2006; Sánchez et al., 2009).

The SOD sampling is often combined with an event-based Proportional-Integral-Derivative (PID) controllers (Årzèn, 1999; Vasyutynskyy and Kabitzsh, 2006; Rabi and Johansson, 2008; Durand and Marchand, 2009; Vasyutynskyy and Kabitzsh, 2009, 2010; Sánchez et al., 2011, 2012), which are widely known and used by the industry. The stability issues of this control family has been recently investigated (see, for example, (Leva and Papadopoulos, 2013; Tiberi et al., 2012)).

In (Beschi et al., 2012), a 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) is used to avoid the dependence by the initial conditions and to guarantee the existance of a (unique) equilibrium point (Beschi et al., 2011). In (Beschi et al., 2012), sufficient conditions on system stability and necessary and sufficient conditions on the controller parameters for the existence of equilibrium points without limit cycles have been found for first-order-plus-dead-time (FOPDT) processes, while in (Beschi et al., 2014a), *ad-hoc* tuning rules are proposed and compared with two well-know tuning rules (namely, the AMIGO rules (Åström and Hägglund, 2002) and the SIMC rules (Skogestad, 2003)), highlighting the similar behavior of the proposed controller with the standard ones.

Because of their recent introduction, the event-based PI(D) controllers for industrial wide-scale plants have been implemented in few applications (Beschi et al., 2014b; Witrant et al., 2010). In (Pawlowski et al., 2012), an event-based GPC control strategy is proposed for controlling

⋆ This work has been partially funded by the following projects: DPI2011-27818-C02-01 (financed by the Spanish Ministry of Economy and Competitiveness and ERDF funds) and Controlcrop PIO-TEP-6174 (financed by the Consejería de Economía, Innovación y Ciencia de la Junta de Andalucía)

greenhouses plant. In fact, an event-based control could be an interesting improvement in this sector, because the greenhouses are often great facilities, where the layout can change from a harvest to another, therefore a high reconfigurability of the sensor nodes is required.

In this paper, the SSOD-based PI control is applied to the greenhouse in order to demonstrate that this type of controllers could be a suitable (and simpler) alternative to event-based GPC control strategy, requiring less computational and communication efforts to the detriment of the achievable control performance.

The paper is organized as follows. The overall control scheme is described in Section 2, while the control of greenhouses temperature is addressed in Section 3. Simulation results are presented and discussed in Section 4. Finally, conclusions are drawn in Section 5.

2. CONTROL ARCHITECTURES

As already mentioned, the symmetric send-on-delta triggering technique can be considered as a modified case of the send-on-delta sampling method (see (Miskowicz, 2006; Vasyutynskyy and Kabitzsh, 2006; Kofman and Braslavsky, 2006)).

The sampling algorithm can be seen as an automaton which receives an input signal $v(t)$ (which can be, for example, the controlled signal or the control action), and generates a sampled output signal $v^*(t)$. The automaton has an internal state variable $i(t) \in \mathbb{Z}$, which denotes the actual activated state. For each $i(t)$, the output of the block is set equal to $i(t)\Delta$ (which could be multiplied by a scaling factor $\beta \in \mathbb{R}$), where $\Delta > 0$ is the threshold amplitude. In fact, the state variable changes its value when the input signal $v(t)$ crosses *one of the two thresholds* $(i(t) - 1)\Delta$ and $(i(t) + 1)\Delta$ values. When $v(t)$ crosses the first one, $i(t)$ is decreased by a unit, while when $v(t)$ reaches the second threshold an unitary increment of $i(t)$ is done. Thus, the behaviuor of the system can be described as a hybrid system (Goebel et al., 2009) in the following way:

$$i(t) = \begin{cases} (i(t^-) - 1) & \text{if } v(t) < (i(t^-) - 1)\Delta \\ i(t^-) & \text{if } \frac{v(t)}{\Delta} \in [(i(t^-) - 1), (i(t^-) + 1)] \\ (i(t^-) + 1) & \text{if } v(t) > (i(t^-) + 1)\Delta \end{cases}$$
$$v^*(t) = \Delta\beta i(t). \tag{1}$$

In (Beschi et al., 2012), two control structures, denoted SSOD-PI and PI-SSOD, are presented (see Figure 1). The two different cases depend on whether the triggering function is applied to the control error or to the control variable respectively. In fact, as shown in the top of Figure 1, in the SSOD-PI control scheme, the SSOD sampling block is located in the sensor unit (SU), while the control unit (CU) and the actuator unit (AU) communicate at a regular sampling period (if the signal $u(t)$ changes). This scheme is particularly suitable when the control and the actuator units are located in the same entity (thus, no wireless communications are required).

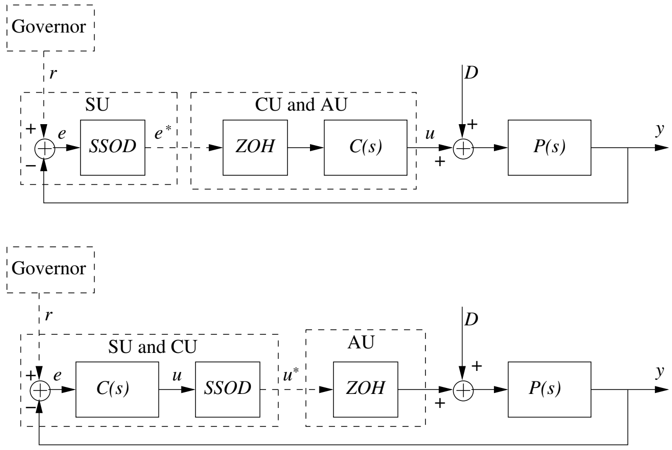

Fig. 1. Control scheme of the SSOD-PI controlled system (top) and of the PI-SSOD controlled system (bottom). The dashed arrows indicate data sending via the communication means.

Remark 1. Because of the SSOD-PI control architecture the control action $u(t)$ is a piecewise-straight line, if the control and the actuator units are located in different places, it is possible to send the straight line profile by sending only its coefficient if the actuator (thanks to its on-board intelligence) has the possibility of following a predefined path.

In the dual architecture, shown at the bottom of Figure 1, the sensor and controller units communicate at a regular sampling period (for instance, because they are located in the same machine), while the SSOD-based sampling is used to send information to the actuator. Note that the ZOH blocks have been used in order to highlight that the output value of this block is held until a new event occurs.

In both cases the controller is a (discretized version of a) continuous-time PI controller, namely:

$$C(s) = K_p + \frac{K_i}{s} \tag{2}$$

where K_p is the proportional gain and K_i is the integral gain. In particular, the controller is dicretized by using the backward Euler method obtaining the following discrete system (with sampling period h):

$$C(z^{-1}) = \frac{(K_i h + K_p) - K_p z^{-1}}{1 - z^{-1}} \tag{3}$$

The stability properties of these control schemes are stated in (Beschi et al., 2012), where the controlled system can be described by a first-order-plus-dead-time (FOPDT) transfer function, which is well-known to be capable of accurately modelling many overdamped self-regulating industrial processes (Åström and Hägglund, 2006; Visioli, 2006), while in (Beschi et al., 2013), the stability study is extended to high-order systems.

Remark 2. Note that the SSOD gain β can be included in the process gain K and therefore it does not represent a critical issue. Thus, as in (Beschi et al., 2012), the value $\beta = 1$ will be considered hereafter, without losses of generality.

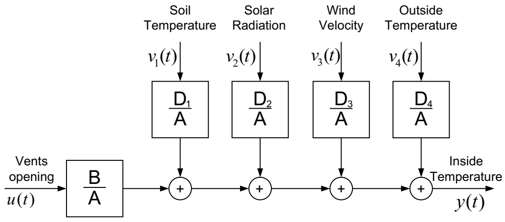

Fig. 2. Greenhouse process model with disturbances for diurnal temperature control.

Remark 3. Because of the integral action is updated each sampling time, no sticking effects are presents. For this reason, it is not necessary to set a maximum time interval between two events. Obviously, it is possible to add this feature if it is required by the transmission protocol.

Remark 4. It is important to note that, in the proposed event-based control strategies, the communications from SU to CU and from CU to AU are not related, while other control strategies (for example, the event-based GPC controller proposed in (Pawlowski et al., 2012)) require, in any case, two communications for each event (from SU to CU and from CU to AU).

3. GREENHOUSE PROCESS DESCRIPTION AND SYSTEM MODELS

The goal of the presented control structure is to regulate the internal temperature $y(t)$ of a greenhouse (see Figure 2). The evolution of this quantity can be modeled using a MISO (multi-input single-output) system (Pawlowski et al., 2012) and it is mainly influenced by the following disturbance variables: $v_1(t)$: soil temperature, $v_2(t)$: solar radiation, $v_3(t)$: wind velocity, and $v_4(t)$: outside temperature. The controller acts to the system by changing the vents opening percentage $u(t)$.

The disturbances can be divided in two categories: the fast-varying ones, namely, the solar radiation changes due to passing clouds and the wind velocity (which is also characterized by significant noise) and the low-varying signals, namely, the solar radiation changes due to daily solar cycles, the soil temperature, and the outside temperature.

The experimental data used for simulation purposes have been obtained from an industrial greenhouse placed at the Experimental Station of the CAJAMAR Foundation “Las Palmerillas” in Almería, Spain [1]. The main constructive data are: average height of 3.6 m and covered surface of 877 m^2. The main actuator is the natural ventilation and it is equipped with a SCADA system able to perform experiments both for system identification and control. The sampling period is set equal to 1 minute.

Considering the previous description, the CARIMA model for this system is given by (Pawlowski et al., 2012)

$$A(z^{-1})y(t) = z^{-d}B(z^{-1})u(t-1) + \sum_{i=1}^{4} z^{-d_{D_i}} D_i(z^{-1})v_i(t) + \frac{\varepsilon(t)}{\Delta} \quad (4)$$

[1] http://aer.ual.es/CJPROS/engindex.php

where $z^{-d_{D_i}}$ and $D_i(z^{-1})$ are time delays and polynomials used to describe the dynamics between the disturbances and the process output, respectively.

Many different experiments were performed during several days applying a combination of pseudo-random binary sequences (PRBS) and step-based input signals at different operating points. It was observed that the Auto Regressive with External Input (ARX) model using Akaike's Information Criterion (AIC) model provides the best fit to the dynamic behavior of the real system. This fact was confirmed by cross correlation and residuals analysis, obtaining models' best fit of 92.53 %. The following discrete time polynomials (with sampling period equal to h =60 [s]) were obtained as the results of estimation around 25°C (Pawlowski et al., 2012) (see Figure 2):

$$\begin{aligned}
A(z^{-1}) &= 1 - 0.3682z^{-1} + 0.0001z^{-2} \\
B(z^{-1})z^{-d} &= (-0.0402 - 0.0027z^{-1})z^{-1} \\
D_1(z^{-1})z^{-d_{D_1}} &= (0.1989 + 0.0924z^{-1} + 0.1614z^{-2})z^{-2} \\
D_2(z^{-1})z^{-d_{D_2}} &= (0.0001 + 0.0067z^{-1} + 0.0002z^{-2})z^{-1} \\
D_3(z^{-1})z^{-d_{D_3}} &= (-0.0002 - 0.3618z^{-1} + 0.0175z^{-2})z^{-1} \\
D_4(z^{-1})z^{-d_{D_4}} &= (0.0525 + 0.3306z^{-1} + 0.0058z^{-2})z^{-1}
\end{aligned}$$

4. SIMULATION RESULTS

This section describes simulation results obtained using the proposed algorithm applied to the diurnal greenhouse temperature control problem summarized in the previous section. The simulations use real data measured in the experimental greenhouse during 19 days (Pawlowski et al., 2012).

The discrete controller (3) is designed to have a gain crossover frequency equal to $300^{-1}\pi$ [rad/s] and a phase margin equal to 75°, obtaining the following controller gains: $K_p = -6.83$ [%/°C] and $K_i = 0.0890$ [%/(s°C)]. In order to highlight its influence in the system performance, different values of the threshold Δ are selected (see Tables 1-2 for numerical values).

The obtained performance are presented in Table 1 for the SSOD-PI case and Table 2 for the PI-SSOD controller (which have been considered separately).

The considered performance indexes are:

- the integrated absolute error $IAE = \sum_k |(r - y_k)|$ where r is the reference signal and y_k is value of the actual temperature;
- the number of events E_y generated by the SU;
- the number of events E_u generated by the CU.

The performance indexes are calculated during the diurnal hours. The SSOD-based controllers are compared with the discrete time (DT) controller.

Figures 3-4 show, for sake of clarity, the zoom of the simulation results during two hours. Note that, in the plots where the events are shown, the events E_u are represented by positive bars, while the event E_y are represented by negative bars.

As expected, when small values of the threshold parameters are selected, the performance indexes are closed to the standard DT controller, while by increasing the threshold

Table 1. Performance indexes obtained with the SSOD-PI controlled system. IAE integrated absolute error, E_y number of events from SU to CU, and E_u number of events from CU to AU.

Day	DT			$\Delta = 0.10$			$\Delta = 0.20$			$\Delta = 0.50$			$\Delta = 1.00$		
	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u
1	91	144	144	91	116	132	92	85	122	100	49	115	114	23	81
2	159	234	234	157	198	232	157	175	213	164	105	179	184	54	114
3	108	284	284	109	216	275	112	157	260	129	73	214	133	25	43
4	117	291	291	119	228	280	118	161	263	141	78	187	182	44	128
5	92	103	103	91	94	101	90	88	97	90	56	66	87	37	24
6	274	423	423	274	361	420	279	307	410	293	176	338	320	87	227
7	148	326	326	154	255	319	155	211	309	166	105	225	197	34	116
8	96	201	201	95	157	197	95	129	188	96	64	129	122	22	73
9	215	362	362	216	304	352	214	238	331	214	127	233	237	63	135
10	179	315	315	178	267	310	180	233	285	180	133	216	208	69	117
11	134	331	331	135	254	321	136	198	295	140	86	191	181	30	92
12	111	197	197	110	167	194	111	134	185	127	83	151	140	43	103
13	185	322	322	186	276	319	188	226	297	198	127	264	179	59	87
14	119	381	381	118	291	366	116	208	332	126	89	205	176	30	55
15	190	213	213	190	188	205	191	176	209	189	122	170	207	74	126
16	202	166	166	201	158	164	201	148	162	199	112	143	195	69	100
17	188	295	295	188	258	285	190	225	277	196	147	238	213	61	153
18	207	290	290	207	266	287	207	223	278	205	139	236	222	68	146
19	173	457	457	178	356	451	186	250	408	197	96	276	282	39	193
1-19	2988	5335	5335	2997	4410	5210	3018	3572	4921	3150	1967	3776	3579	931	2113

Table 2. Performance indexes obtained with the PI-SSOD controlled system. IAE integrated absolute error, E_y number of events from SU to CU, and E_u number of events from CU to AU.

Day	DT			$\Delta = 1.0$			$\Delta = 2.0$			$\Delta = 5.0$			$\Delta = 10.0$		
	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u	IAE	E_y	E_u
1	91	144	144	90	143	110	91	144	85	95	144	54	103	142	27
2	159	234	234	159	234	207	157	234	171	155	234	79	168	233	25
3	108	284	284	109	283	226	111	282	171	111	283	77	109	283	22
4	117	291	291	117	291	232	123	289	199	132	290	105	144	291	41
5	92	103	103	92	103	90	93	103	70	97	103	26	111	103	2
6	274	423	423	275	422	377	277	422	317	286	423	199	310	422	118
7	148	326	326	153	324	265	152	326	215	161	326	124	158	326	46
8	96	201	201	97	201	169	99	201	134	97	201	64	103	201	24
9	215	362	362	218	361	305	220	362	260	219	362	139	235	362	49
10	179	315	315	179	314	268	181	314	220	181	315	122	200	315	44
11	134	331	331	133	331	258	133	328	215	134	328	109	152	329	44
12	111	197	197	110	197	173	110	197	137	117	196	73	119	197	29
13	185	322	322	186	322	278	186	322	231	196	322	144	181	322	55
14	119	381	381	119	380	289	115	380	207	129	381	108	125	381	25
15	190	213	213	191	213	197	191	213	168	199	213	101	202	213	46
16	202	166	166	202	166	148	200	166	132	201	166	97	195	166	47
17	188	295	295	189	295	258	189	295	219	192	295	133	213	294	65
18	207	290	290	207	290	262	207	290	230	208	290	141	218	290	55
19	173	457	457	176	456	369	180	457	294	198	456	177	207	456	71
1-19	2988	5335	5335	3002	5326	4481	3015	5325	3675	3108	5328	2072	3253	5326	835

values the number of events decreases and the disturbance rejection performance increases. It is important to remark that, if the DT controller is able to reduce the effect of the noises on the output into an error band, selecting a value of Δ smaller that this value causes a high number of event (see, for example the SSO-PI case with $\Delta = 0.10$).

From the disturbance rejection performance point of view, by using small thresholds it is possible to obtain almost the same performance of a discrete-time controller PID controller. This confirms that it is necessary to take into account the trade-off between the precision and the number of events when the threshold Δ is selected (Beschi et al., 2014a).

Comparing these strategies with more complex control strategies (see (Pawlowski et al., 2012)), it possible to note that with high values of the threshold they provide similar performance but with a lower number of required communications (see Remark 3).On the contrary, by using smaller values of the thresholds, the effectiveness of the GPC strategy to reject disturbances is more evident (at the expense of a slight increase of the number of the events). Note that, if AU and CU (CU and SU) are located in same physical entity, only the events E_y (E_u) require communication effort by using the SSOD-PI (PI-SSOD) control strategy. Otherwise, the SSOD-PI controller has a lower number of events with respect to the PI-SSOD case because its control signal is constant when the system output is close to the set-point signal.

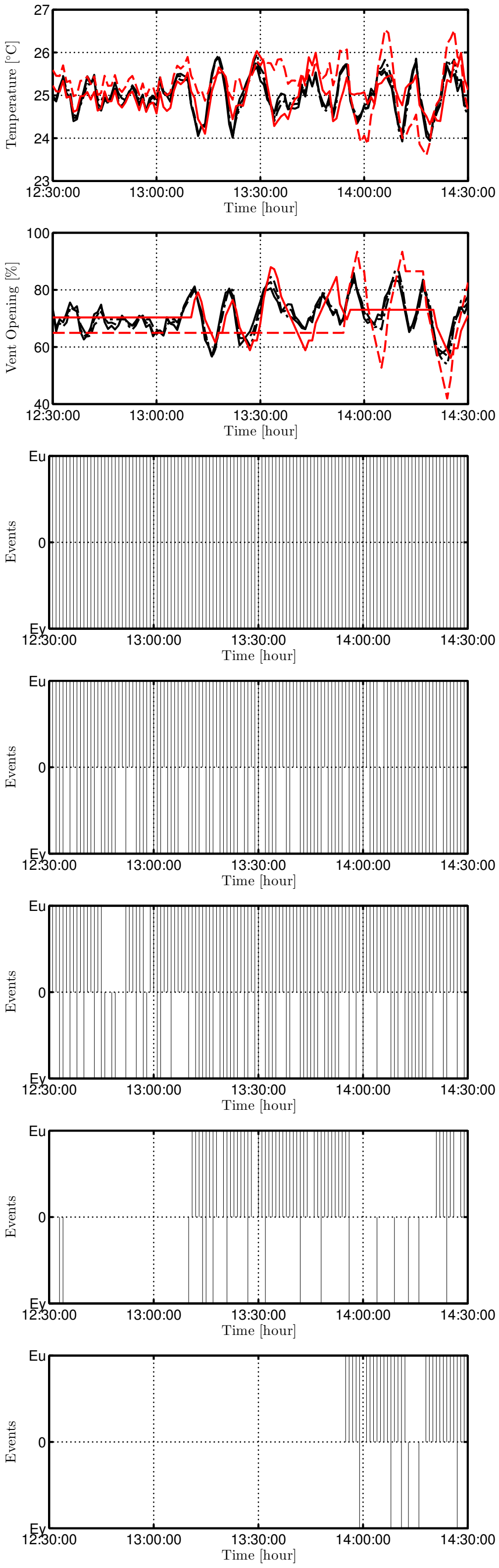

Fig. 3. Zoom of simulation results obtained by using a SSOD-PI controller. (Discrete time controller: black solid line, $\Delta = 0.1$: black dashed line, $\Delta = 0.2$: black dash-dot line, $\Delta = 0.5$: red solid line, $\Delta = 1.0$: red dashed line). First plot (from the top): process variable. Second plot: control variable. Third to seventh plots: events with the discrete time case, $\Delta = 0.1$, $\Delta = 0.2$, $\Delta = 0.5$, and $\Delta = 1.0$.

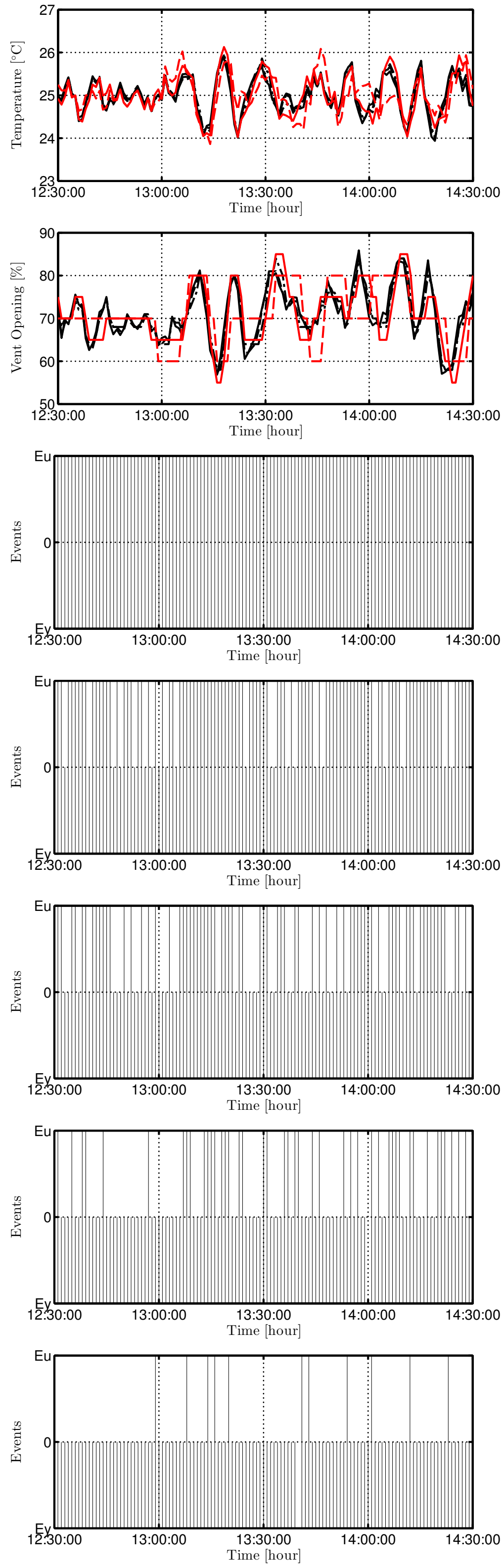

Fig. 4. Zoom of simulation results obtained by using a PI-SSOD controller. (Discrete time controller: black solid line, $\Delta = 1.0$: black dashed line, $\Delta = 2.0$: black dash-dot line, $\Delta = 5.0$: red solid line, $\Delta = 10$: red dashed line). First plot (from the top): process variable. Second plot: control variable. Third to seventh plots: events with the discrete time case, $\Delta = 1.0$, $\Delta = 2.0$, $\Delta = 5.0$, and $\Delta = 10$.

5. CONCLUSIONS

In this paper, the SSOD-PI and the PI-SSOD control strategies are used to control the internal greenhouse temperature.

These strategies allow the user to reduce the number of communications with respect to standard PI controller without significantly reduce the rejection perfomance. Moreover, they provide flexibility in the design as a nice freature, because when great values of the threshold parameter are selected, they present similar performance with respect to more complicated control strategies.

REFERENCES

Årzèn, K. (1999). A simple event-based PID controller. In *Proceedings of 14th World Congress*. Bejiing (China).

Åström, K. (2008). Event based control. In A. Astolfi and L. Marconi (eds.), *Analysis and Design of Nonlinear Control Systems*, 127–147. Springer Berlin Heidelberg.

Åström, K. and Hägglund, T. (2002). Revisiting the Ziegler-Nichols tuning rules for PI control. *Asian Journal of Control*, 4(4), 364–380.

Åström, K. and Hägglund, T. (2006). *Advanced PID Control*. ISA Press, Research Triangle Park (USA).

Beschi, M., Dormido, S., J., Sánchez, and Visioli, A. (2012). Characterization of symmetric send-on-delta PI controllers. *J. Process Contr*, 22(10), 1930–1945.

Beschi, M., Dormido, S., Sánchez, J., and Visioli, A. (2013). Stability analysis of symmetric send-on-delta event-based control systems. In *Preprints of American Control Conference*, 1771–1776. Washington (USA).

Beschi, M., Dormido, S., Sánchez, J., and Visioli, A. (2014a). Tuning of symmetric send-on-delta PI controllers. *IET Control Theory & Applications*.

Beschi, M., Dormido, S., Sánchez, J., Visioli, A., and Yebra, L. (2014b). Event-based PI plus feedforward control strategies for a distributed solar collector field. *IEEE Transactions on Control Systems Technology*.

Beschi, M., Visioli, A., Dormido, S., and Sánchez, J. (2011). On the presence of equilibrium points in PI control systems with send-on-delta sampling. In *Proceedings of 50th Int. Conference on Decision and Control and European Control Conference*. Orlando (USA).

Blevins, T. (2012). PID advances in industrial control. In *Proceedings of IFAC Conference on Advances in PID Control*. Brescia (Italy).

Chacón, J., Sánchez, J., Visioli, A., Yebra, L., and Dormido, S. (2013). Characterization of limit cycles for self-regulating and integral processes with PI control and send-on-delta sampling. *Journal of Process Control*, 23(6), 826 – 838.

Durand, S. and Marchand, N. (2009). Further results on event-based PID controller. In *Proceedings of 10th European Control Conference*. Budapest (Hungary).

Goebel, R., Sanfelice, R., and Teel, A. (2009). Hybrid dynamical systems. *IEEE Control Systems Magazine*, 29(2), 28–93.

Heemels, W.P.M.H. and Donkers, M.C.F. (2013). Model-based periodic event-triggered control for linear systems. *Automatica*, 49(3), 698 – 711.

Heemels, W., Sandee, J., and Van Den Bosch, P. (2008). Analysis of event-driven controllers for linear systems. *International Journal of Control*, 81(4), 571–590.

Kofman, E. and Braslavsky, J. (2006). Level crossing sampling in feedback stabilization under data rate constraints. In *Proceedings of 45th International Conference on Decision and Control*. San Diego (USA).

Leva, A. and Papadopoulos, A.V. (2013). Tuning of event-based industrial controllers with simple stability guarantees. *J.Process Contr*, 23(9), 1251 – 1260.

Miskowicz, M. (2006). Send-on-delta: An event-based data reporting strategy. *Sensors*, 6, 49–63.

Otanez, P., Moyne, J., and Tilbury, D. (2002). Using deadbands to reduce communication in networked control systems. In *Proceedings of American Control Conference*. Anchorage (USA).

Pawlowski, A., Guzmán, J.L., Normey-Rico, J.E., and Berenguel, M. (2012). A practical approach for generalized predictive control within an event-based framework. *Computers & Chemical Engineering*, 41, 52–66.

Rabi, M. and Johansson, K.H. (2008). Event-triggered strategies for industrial control over wireless networks. In *Proceedings of 4th Annual International Conference on Wireless Internet*. Maui (USA).

Sánchez, J., Guarnes, M.A., Dormido, S., and Visioli, A. (2009). Comparative study of event-based control strategies: An experimental approach on a simple tank. In *Proceedings of European Control Conference*. Budapest (Hungary).

Sánchez, J., Visioli, A., and Dormido, S. (2011). A two-degree-of-freedom PI controller based on events. *Journal of Process Control*, 21, 639–651.

Sánchez, J., Visioli, A., and Dormido, S. (2012). *PID Control in the Third Millennium (R. Vilanova and A. Visioli (eds.))*, chapter Event-based PID control, 495–526. Springer.

Skogestad, S. (2003). Simple analytic rules for model reduction and PID controller tuning. *Journal of Process Control*, 13(4), 291 – 309.

Tiberi, U., Araujo, J., and Johansson, K. (2012). On event-based PI control of first-order processes. In *Proceedings of IFAC Conference on Advances in PID Control*. Brescia (Italy).

Vasyutynskyy, V. and Kabitzsh, K. (2006). Implementation of PID controller with send-on-delta sampling. In *Proceedings of International Control Conference*. Glasgow (Scotland).

Vasyutynskyy, V. and Kabitzsh, K. (2009). First order observers in event-based PID controls. In *Proceedings of IEEE Conference on Emerging Technologies & Factory Automation*. Mallorca (Spain).

Vasyutynskyy, V. and Kabitzsh, K. (2010). A comparative study of PID control algorithms adapted to send-on-delta sampling. In *Proceedings of IEEE International Symposium on Industrial Electronics*. Bari (Italy).

Visioli, A. (2006). *Practical PID Control*. Springer, London, UK.

Witrant, E., and. G. Sandou and. F. Santucci and. M.D. Di Benedetto, A.D., Isaksson, A., Johansson, K., Niculescu, S., Olaru, S., Serra, E., Tennina, S., and Tiberi, U. (2010). Wireless ventilation control for large-scale systems: the mining industrial case. *International Journal of Robust and Nonlinear Control*, 20, 226 – 251.