Modeling and Simulation of a Temperature Robust Control in Grain Drying Systems for Thermal Damage Reduction

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Abstract: Informatics plays an imperative role in the designing and tuning of new control systems strategies, since the computational simulation of such systems is part of the entire process of applying an algorithm on a real environment. This paper presents an alternative to the Proportional-Integrative-Derivative (PID) controller for temperature control in grain drying systems. The PID controller may present undesirable oscillations in the presence of external disturbances associated with agroindustrial facilities, thus demanding a precise and automatic tuning during the entire process. Robust controllers are suitable and recommended for the drying final quality, since the grains are offered a thermal damage reduction when submitted to abrupt temperature variations, as fragility and even crack during processing. Simulation results on an experimental model of a nonlinear robust controller, named Shunt Indirect Variable Structure Model Reference Adaptive Controller (SIVS-MRAC) are shown. Performance results before disturbances and parametric variations are compared with the PID behaviour.

1 INTRODUCTION

Drying is an important unit operation applied in a wide variety of processes such as in food, pharmaceuticals and chemicals. This importance, given specifically to the drying of grains, is a well known phenomenon, since they represent a worldwide source of food. Harvest, handling, storage and appropriate drying must be carried out properly in order to guarantee the quality and the use of the grains production. To achieve this purpose, many researches on applied software and hardware have been carried out (Kemp, 2007). Grains are biological entities extremely sensible to heat and temperature effects, which may cause severe damage to the expected final characteristics. Some quality attributes may be seriously affected, such as the amount and level of cracks, tissues integrity, acidity, protein levels, germination and appearance. Rice, for instance, is a grain susceptible to thermal damages and, therefore, it needs special attention regarding the temperature of the drying air, so that no problems might arise during the processing. Additionally, the percentage of entire perfect grains is related to the drying method. Therefore, it is recommended the choice of control techniques that offer the guarantee of insensibility to possible abrupt temperature variations generated from external disturbances and/or physical parameters variations as well, reflected on the mathematical model of the system. These variations may arise from worn components (resistances, capacitances, inductors and so on) and their range of tolerance. The most common agroindustrial control systems are based on the Proportional-Integrative-Derivative (PID) controller. However, fixed parameters controllers – which do not take into account the uncertainties in the physical parameters – as PID, tend to behave slower and in an oscillatory way when submitted to eventual disturbances which may occur. Works which compare PID to other model based control strategies, when applied to grain drying systems, were always of interest (Forbes et al., 1984) and still are (Agnew, 2012). A possible solution is the aggregation of online parametric adaptation based on estimators such as gradient or least squares, however instability and lack of robustness in the original algorithms were detected in Rohrs et al.

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(1985). A possibility is the union of an adaptive scheme, as the Model Reference Adaptive Control (MRAC), which determines the desired closed loop performance, with the nonlinear control technique, called Variable Structure Systems (VSS), based on the relay theory (Utkin, 1978). This technique was named Variable Structure Model Reference Adaptive Control (VS-MRAC) (Hsu and Costa, 1989) and it guarantees a fast and non oscillatory transient. Robustness to external disturbances and unmodeled dynamics was also achieved. Although, originally, its control signal was switched and with high frequency, further works were concerned about its smoothness (Hsu, 1997). Oliveira and Araujo (2008) developed a VS-MRAC version for the unitary relative degree based on the indirect approach of the adaptive control, named IVS-MRAC, without performance losses and that turns the controller project itself more intuitive, since the controller parameters are directly related to the plant model parameters. Its application on an industrial environment can be seen in Oliveira et al. (2010). The general case for the IVS-MRAC was presented in Fernandes et al. (2010) and it was named Shunt IVS-MRAC (SIVS-MRAC). It introduces a parallel compensator to the original plant, and, by this strategy, the entire system (plant + shunt compensator) becomes of unitary relative degree, thus allowing the use of the original IVS-MRAC in series with a PI controller. In this work, the SIVS-MRAC is applied (through simulations) on the temperature control of a mathematical model obtained from an educational drying grains prototype. Simulation results in adverse conditions of external disturbances and parameter variation are presented and compared to the results of a PID, tuned to behave as good as possible.

2 PID AND IVS-MRAC CONTROLLERS

The PID controller provides a control signal to be applied on the plant from the combination of three actions, namely, the proportional, integrative and derivative. Therefore, the project consists in choosing three tuning parameters: the proportional gain k_p, the integral time T_i and the derivative time T_d. To adjust these parameters, many methods may be used, all based on an available model for the plant and performance requirements, such as settle time or overshoot. The SIVS-MRAC project makes the assumption that the plant model has known and limited uncertainties and it uses switched adaptive laws which act on these same uncertainties (Fernandes et al., 2010). A complete theoretical description and the stability analysis may be found in Oliveira and Araujo (2008), being the main objective of this work the computer simulation of the SIVS-MRAC, when applied to the temperature control of a drying system.

3 MATERIALS AND METHODS

The drying grains system used in this work (Figure 1) is compound by a garner, a heater and a fan which blows the air through the garner, where exists a screened drawer, like a strainer, in which the grains are deposited, characterizing a fixed-bed drying. The temperature adjustment is made by an industrial PID controller, being the temperature on the input and on the top of the garner obtained from two Pt100 sensors.

Figure 1: Educational kit for drying grains control.

The air flow control is made by a potentiometer, that acts on the PWM signal generator. The PID output signal is applied on a Solid State Relay (SSR), which, by its turn, acts on the electrical resistance of the heater. Using the graphical method of step response to get the mathematical model that better describes the practical system, the air flow was fixed in 10% and the system was modelled by a first order transfer function with delay (1), with K=55, T=27 and L=6. For simulation purposes, the delay was added to (1) and the Pade's approximation for exponentials was used in (1), generating $G_1(s)$ (2).

$$G(s)=\frac{K}{Ts+1}e^{-Ls}=\frac{55}{27s+1}e^{-6s}=$$

$$G(s)=\frac{55/27}{27/27s+1/27}e^{-6s}=\frac{2.03}{s+0.037}e^{-6s}.$$

Equation (1) may be written in the parameterized form (Oliveira and Araujo, 2008):

$$G(s)=\frac{k_p}{s+\alpha_1}e^{-Ls}, \tag{1}$$

where $k_p = 2.03$ is the high frequency gain and $\alpha_1 = 0.037$ is the pole. For (1), the original IVS-MRAC may be applied. After the algebraic manipulations involved in using Pade's approximation, the new transfer function is of relative degree three (2) and, therefore, the generalized IVS-MRAC, the SIVS-MRAC must be chosen.

$$G_1(s)=\frac{3{,}025}{27s^3+9{,}91s^2+1{,}815s+0{,}055} \tag{2}$$

To get (2) it was used the second order Pade's approximation, according to:

$$e^{-sT}=\frac{1}{1+sT+\frac{1}{2!}(sT)^2}$$

where T is the delay. Table 1 shows all used parameters and auxiliary polynomials.

Table 1: PID and SIVS-MRAC parameters used in the computational simulation.

PID	$k_p = 0.1; T_i = 10; T_d = 10$
SIVS-MRAC	$\alpha = 1.05; \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0.005$ $\alpha_1 = 0.05; \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0.01$ $A_m(s) = s^3 + 0.008s^2 + 0.12s + 0.6$ $\Lambda(s) = s^4 + 0.05s^3 + 0.5s^2 + s + 2$ $W_c(s) = 0.2\frac{s+1}{(s+0.2)^2}$ $PI: \quad k_p = 0.5; T_i = 10$

where $A_m(s)$ is the characteristic polynomial, $\Lambda(s)$ is the filter, $W_c(s)$ is the proposed shunt compensator. The detailed description of the parameters of the SIVS-MRAC may be found in Fernandes et al. (2010). The method used to tune the PID was the first method of Ziegler-Nichols.

4 SIMULATION RESULTS

The graphics present ideal situations (without disturbances) and with the presence of common ones in the industrial facilities, such as air humidity, environmental temperature, air flow variations etc., that may affect the drying process and the product final quality. These disturbances are modelled through the addition of signals in the plant input and by parameter variations in (1) and, consequently, in (2). According to (1) and Oliveira and Araujo (2008), the IVS-MRAC has three parameters to be adjusted, related to the plant parameters: $k_{pNOM} = 2; \bar{k}_p = 0.5; \bar{\alpha}_1 = 1.$ The reference model (desired dynamics) is:

$$M(s)=\frac{y_m}{r}=\frac{k_m}{s+\alpha_{m1}}=\frac{0.1}{s+0.1} \tag{3}$$

The simulation step is h=10^{-2} and the initial reference is 45ºC. All simulations run during 400 seconds, except the step response (Figure 2). Between t=50s (dON) and t=200s (dOFF) a step disturbance of 2 Volts is introduced in (2). From t=150s on, a parametric variation (vpON) is introduced, in such a way that (1) becomes 55.5/(26.5s+0.5). At t=150s the reference signal is changed to 55ºC and at t=250s it is changed to 35ºC. Figure 2 presents the open loop response, showing a convergence at about t=150s. So, a performance requirement for the controllers was the reduction of that time. Figure 3 shows the behaviour of the PID acting on ideal conditions. It is possible to note the convergence at t=100s. Figure 4 shows the performance of the PID when external disturbances and model parametric variations are present. It is very noticeable the effect at the moment of their application. The IVS-MRAC applied to (2) neglecting the delay (L=0) may be seen in Figure 5 and perfect tracking is achieved. In introducing the delay, the SIVS-MRAC must be applied (Figure 6). Figures 6 and 7 show the SIVS-MRAC with and without disturbances. It is noteworthy in Figure 7 the minor influence of vpON (arrow) and no influence of dON, showing its robustness when compared to the PID. The control signal is typical of switched systems (Figure 8), but smoothness is made possible through appropriate filters without performance losses. Additionally, the voltage range is within limits normally used in instrumentation, +/- 10 V.

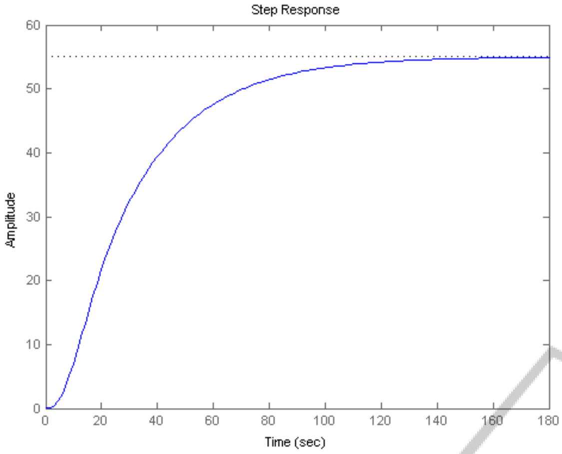

Figure 2: Open loop response of the thermal plant.

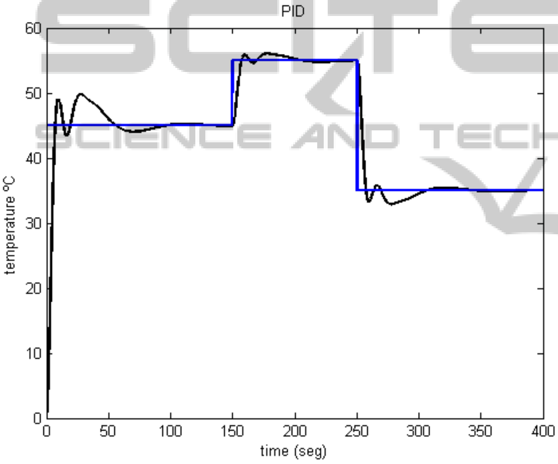

Figure 3: PID – ideal conditions.

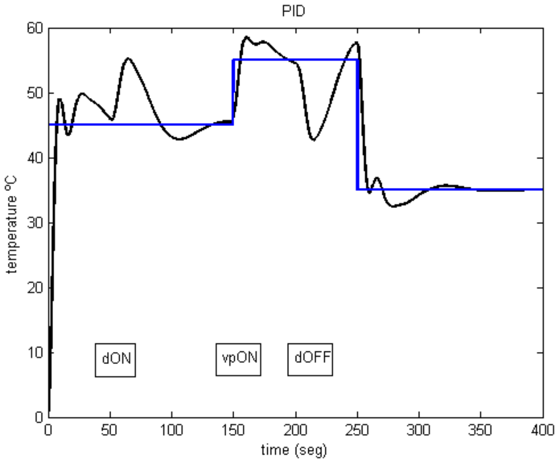

Figure 4: PID – with disturbances.

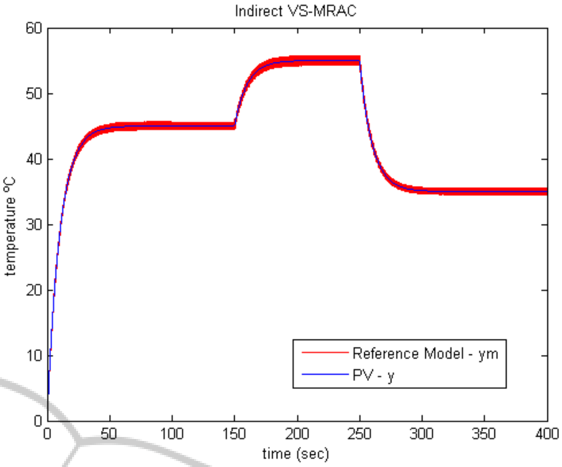

Figure 5: IVS-MRAC acting on the thermal plant with disturbances but without delay.

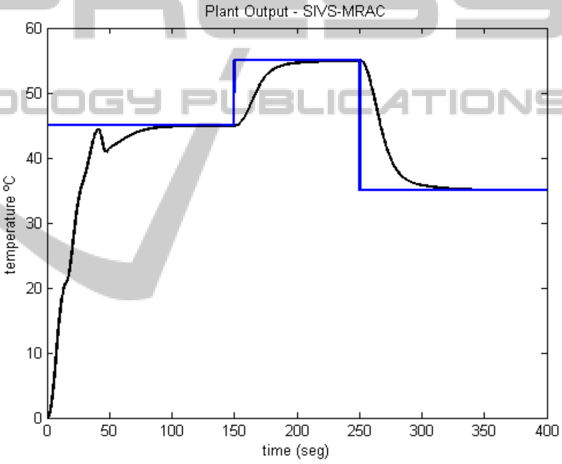

Figure 6: SIVS-MRAC – ideal conditions.

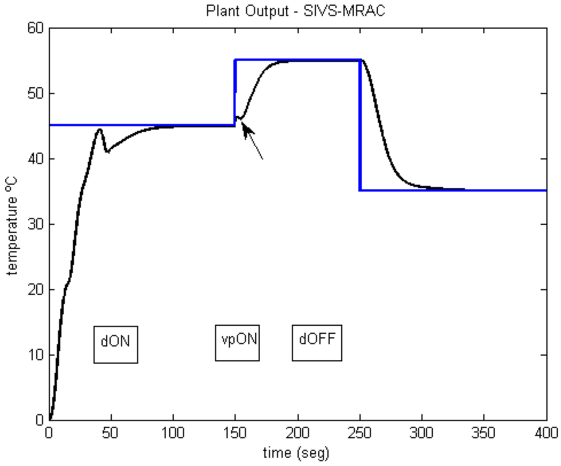

Figure 7: SIVS-MRAC - with disturbances.

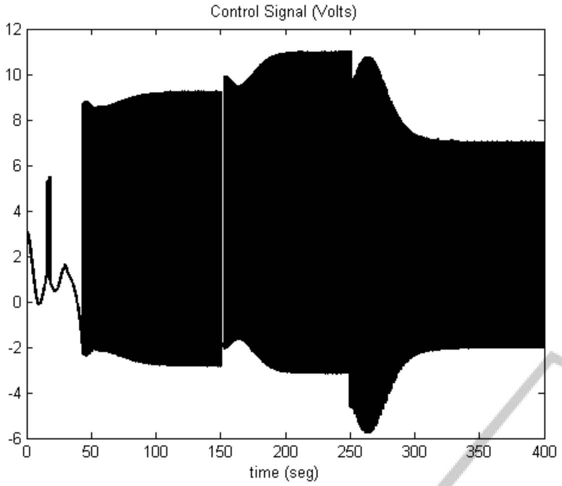

Figure 8: Characteristic of the SIVS-MRAC control signal.

5 CONCLUSIONS

This work presented the successfully computational simulation of a nonlinear robust controller, named SIVS-MRAC, applied to the mathematical model of a drying grain system. The simulation results suggest that the proposed strategy aggregates robustness to external disturbances typical in agroindustrial facilities and, thus, it gives more quality to the dried grains. As suggestions and perspectives of future works, modifications in the algorithm should be made to reduce the control signal magnitude and increase its smoothness, the practical experiment and the physical-chemical analysis of the grains when dried by different temperature control strategies. Further, the SIVS-MRAC will be embedded in microcontrollers, Digital Signal Processors (DSP) or Field Array Programmable Devices (FPGA).

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