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High-Order Sliding Mode Control of Greenhouse Temperature

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Abstract

This paper deals with the design and implementation of the high order sliding mode controller to control temperature greenhouse. The control objective aims to ensure a favorable microclimate for the culture development and to minimize the production cost. We propose performing regulation for the greenhouse internal temperature based on the second order sliding mode technique known as Super Twisting Algorithm (STA).This technique is able to ensure robustness with respect to bounded external disturbances. A successful feasibility study of the proposed controller is appliedto maintien a desired temperature level under an experimental greenhouse. Theobtained results show promising performances despite changes of the external meteorological conditions

Keywords: *greenhouse, real time temperature control, sliding mode, super twisting algorithm.*

1. Introduction

The control of the climatic environment in greenhouses has received considerable attention in these last years. The main reasons for this increasing interest are related to the following agronomic and financial objectives [1]: (i) to extend the growing season and the potential yield; (ii) to manage the climate in order to reach higher standards of quality; (iii) to develop low-cost production systems, compatible with the scarcity of resources andthe low investment capacity of growers. However, the internal greenhouse climate is strongly influenced by meteorological conditions. Hence, agricultural greenhouses were computerized in order to ensure an automatic microclimate control despite the external climate changes.In fact, the automation of greenhouse is based on a personal computer that allows, via an acquisition card, not only to acquire measurements provided by sensors but also to command several actuators installed in greenhouse.

Greenhouses are considered as complex processes. They are nonlinear, multi-input multi-output (MIMO) systems, they present time-varying behaviors and they are subject to pertinent disturbances depending generally on meteorological conditions [2]. On the other hand, many previous studies have shown that the internal temperature is the most influential parameters on the greenhouse [3]. Thus, inside greenhouse temperature regulation is a priority task for greenhouse growers [4-9]. Since a greenhouse is a nonlinear and complex plant whose parameters vary with the weather conditions, it turns out that a simple and high performance system control is still needed. One of the successful strategies for such plants is sliding mode control.

The sliding mode controller is an attractive robust control algorithm thanks to its inherent insensitivity and robustness to plant uncertainties and external disturbances [10-12]. The conventional sliding mode control (CSMC) scheme is known to be an effective robust nonlinear control approach for systems with uncertainties and/or disturbances.It has many advantages such as fast response, small sensitivity to system uncertainties and/or environmental disturbances, and being easily designed [13]. Nevertheless, CSMC has a main drawback so-called chattering caused by the high-frequency control switching [14]. This undesirable phenomenon could severely degrade the performance of the control system and

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may even lead to instability. To solve this problem, many methodologies have been proposed such as higher order sliding modes (HOSM). This technique can obviously reduce the chattering effect while preserving the advantages of the standard approach [15, 16]. The main disadvantage of the HOSM control design consists of information increasing demand. The only exception is the second order super twisting algorithm (STA) which needs the same amount of information as the original sliding mode. Based on these reasons, this paper is devoted to the design and implementation of STA controller to regulate the temperature under an experimentalgreenhouse.

2. Description of the Experimental System and Modeling

Figure 1 shows the experimental greenhouse setup which is the located in the Laboratory of Electronic, Automatic and Biotechnology, Faculty of SciencesMeknes Morocco. It's equipped with sensors allowing measurements of the internal and external climates such as temperature and relative humidity. In order to control the internal climatea set of actuators (heater, fan ...) were installed inside the greenhouse.The temperature under greenhouse is measured using an LM35DZ temperature sensor. The humidity sensor HIH-4000-001 (Honeywell sensors) is used to measure the relative humidity. The control card allows the actuator supply with variable voltage. For acquisition and controlling purposes, these devices are connected to a microcomputer through the measurement card, control card and data acquisition card PCI 6024E[17-20].

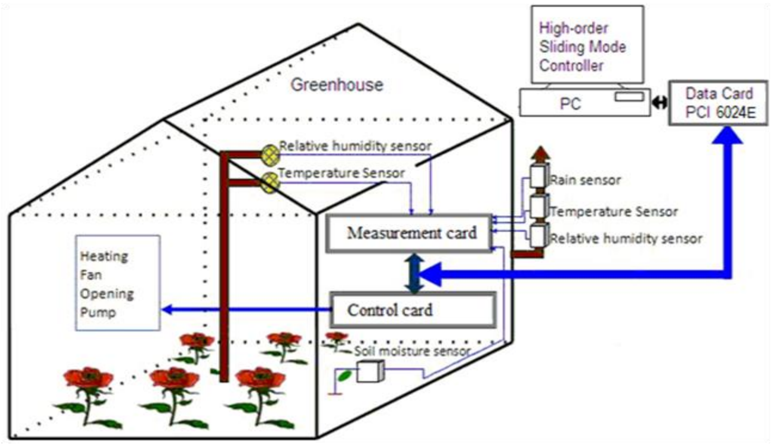

Figure 1. Synoptic Diagram of the Experimental Greenhouse

For real-time implementation, an essential requirement is to elaborate the most real possible representation of the process. For this purpose, the method of BROÏDA is adopted which uses the following structure [21]:

$$G(s) = \frac{Ke^{-\tau s}}{Ts+1} \cong \frac{K}{(1+Ts)(1+\tau s)} = \frac{c}{s^2+as+b} \tag{1}$$

Where K, τ and T are the steady-state gain, time delay and time constant, respectively.

In order to obtain the parameters of the transfer function in equation 1, a step input was applied to the heater under greenhouse. The inside temperature of the open-loop response of the system was measured with a computer via a data acquisition card (DAQ) as shown in Figure 1. The graphical method of BROÏDA led to the following transfer function:

$$G(s) = \frac{3.71e^{-77s}}{467.5s+1} \cong \frac{1.03\times10^{-4}}{s^2+0.015s+2.78\times10^{-5}} = \frac{Y(s)}{U(s)} \tag{2}$$

The transfer function of the system is a second-order over damped transfer function with two poles located on the left half part of the complex plane. Rearranging the system model to represent it in time domain using inverse Laplace transform, one has:

$$\ddot{y}(t) = -2.78\times10^{-5}y(t) - 0.015\dot{y}(t) + 1.03\times10^{-4}u(t) \tag{3}$$

The evolution of the temperature under greenhouse can be described by the model as follows:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -2.78\times10^{-5}x_1 - 0.015x_2 + 1.03\times10^{-4}u \\ x_1 = y \end{cases} \tag{4}$$

Where x=[x1 x2]^T, u and y are state vector, signal control and system output respectively.

3. High-Order Sliding Mode Control

The High order sliding modes generalize the basic sliding mode idea acting on the higher order time derivatives of the system deviation from the constraint instead of influencing the first deviation derivative like it happens in standard sliding modes [22]. In addition to keeping the main advantages of the original approach, at the same time they totally remove the chattering effect and provide for even higher accuracy in realization. The main idea was to change the dynamics in small vicinity of the discontinuity surface inorder to avoid real discontinuity and at the same time to preserve the main properties of the whole system.
Consider a dynamic system described by:

$$\dot{x} = f(t,x,u), u = U(t,x) \in M, S = S(t,x) \in M \tag{5}$$

Where: $x \in M^n$, f is a class C^1 function, u is the input function and the constraint S is a class C^2 functionso-called sliding surface.

The sliding order characterizes the dynamics smoothness degree in the vicinity of the sliding mode. If the task is to provide for keeping a constraint given by equality of a smooth function S to zero, the sliding order is a number of continuous total derivatives of S (including the zero one) in the vicinity of the sliding mode. Hence, the rth-order sliding mode is determined by the equalities [23]:

$$S = \dot{S} = ... = S^{r-1} \tag{6}$$

In the particular case of the second-order sliding mode control (SOSMC), the aim is to synthesize a control u such that the constraint S = 0 is verified and $S = \dot{S} = 0$ is maintained. To design SOSMC, a number of algorithms have been reported in the literature in which twisting,super twisting, suboptimal, and drift are common [24].The main problem in implementation of second-order sliding modes is that they require the time derivatives of sliding variable which seems to be difficult due to noise. The only known exclusion is super twisting sliding controller. It does not need any information about $\dot{S}$ which facilitates its implementation in real time. For this reason; we adopt that type of second-order sliding mode algorithms to regulate temperature under greenhouse. To calculate the controller gains we have to compute the first and second time derivatives of the sliding variable. They can be expressed as:

$$\dot{S} = \frac{\partial S(x,t)}{\partial t} + \frac{\partial S(x,t)}{\partial x} f(x,t,u) \tag{7}$$

$$\ddot{S} = \frac{\partial \dot{S}(x,t,u)}{\partial t} + \frac{\partial \dot{S}(x,t)}{\partial x} f(x,t,u) + \frac{\partial \dot{S}(x,t,u)}{\partial u}\dot{u}(t)$$

$$\ddot{S} = \varphi(x,t,u) + \gamma(x,t,u)\dot{u}(t) \tag{8}$$

Where $\varphi(x,t,u)$ and $\gamma(x,t,u)$ are smooth functions that have to be bounded as follows:

$$0 < \Gamma_m \le \gamma(x,t,u) \le \Gamma_M \tag{9}$$

$$|\varphi(x,t,u)| \le \Phi \tag{10}$$

3.1. Super-Twisting Algorithm

Super-twisting algorithm is intended to the systems having relative degree one for the purpose of reduction in chattering [25, 26]. It has the advantage over other algorithms in that it does not require measurement of $\dot{S}$ during on-line operation. The control law used in this algorithm is constituted by two terms. The first term $u_1(t)$ is the integral of a discontinuous control action whereas the second term $u_2(t)$ is a continuous function of S.

$$u(t) = u_1(t) + u_2(t) \tag{11}$$

$$\dot{u}_1(t) = \begin{cases} -u & \text{if } |u| > 1 \\ -\alpha \operatorname{sign}(S) & \text{if } |u| \le 1 \end{cases} \tag{12}$$

$$\dot{u}_2(t) = \begin{cases} -\lambda |S_0|^{\rho} \operatorname{sign}(S) & \text{if } |S| > S_0 \\ -\lambda |S|^{\rho} \operatorname{sign}(S) & \text{if } |S| \le S_0 \end{cases} \tag{13}$$

Where S_0, ρ, α, λ are positive constants verifying the following inequalities:

$$\alpha > \frac{\Phi}{\Gamma_m}, \quad \lambda^2 \ge \frac{4\Phi}{\Gamma^2_m} \frac{\Gamma_M(\alpha+\Phi)}{\Gamma_m(\alpha-\Phi)}, \quad 0 < \rho \le 0.5 \tag{14}$$

When controlled system is linearly dependent on u, the control law can be simplified as:

$$\dot{u}_1(t) = -\alpha \operatorname{sign}(S) \tag{15}$$

$$u_2(t) = -\lambda |S|^{\rho} \operatorname{sign}(S) \tag{16}$$

3.2. Controller Design

The aim of the control based on the super twisting algorithm consists in following the temperature of reference trajectory. Figure 2 shows the block diagram of the proposed controller. Once The gains α and λ are estimated using the model which is calculated and validated, we elaborate the control order by equations (14) and (15) then it's sent via data acquisition card to acteither on heater or fan depending on the sliding surface sign.

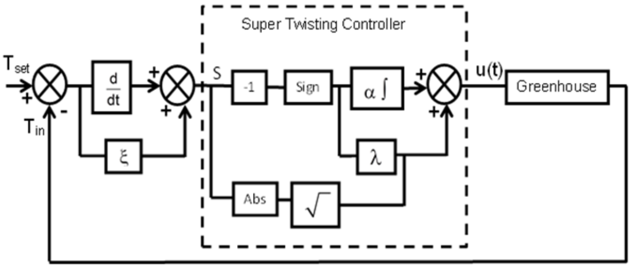

Figure 2. Block Diagram of the Proposed Controller

A temperature regulator attempts to minimize the temperature error, i.e.

$$e(t) = T_{set} - T_{in} \qquad (17)$$

Where T_{set} is the setpoint temperature and T_{in} is the inside temperature. The sliding surface is adopted mostly as a linear combination between the error and a certain number of its derivatives.It can be written as:

$$S = \dot{e}(t) + \xi e(t) \qquad (18)$$

With ξ is an arbitrary positive definite constant.
To calculate the parameters α and λ of the STA control law, we must calculate the second derivative of S with respect to time then choose the constants Φ, Γ_M and Γ_m.

$$\dot{S} = \ddot{e}(t) + \xi\dot{e}(t)$$

$$\dot{S} = \ddot{x}_d - \dot{x}_2 + \xi(\dot{x}_d - \dot{x}_1)$$

By using the equation (3) we get:

$$\dot{S} = \ddot{x}_d + \xi\dot{x}_d + (0.015 - \xi)x_2 + 2.78 \times 10^{-5} x_1 - 1.03 \times 10^{-4} u$$

$$\dot{S} = g(t) + hu \qquad (19)$$

With $g(t) = \ddot{x}_d + \xi\dot{x}_d + (0.015 - \xi)x_2 - 2.78 \times 10^{-5} x_1$ and $h = -1.03 \times 10^{-4}$
We can see that the control input appears in the first order time derivative of the sliding surface which means that therelative degree of thesystemis one.

$$\dot{S} = g(t) + hu \qquad (20)$$

By identification with equations (8) and (9) we have:

$$|\dot{g}(t)| \le \Phi; \quad 0 < \Gamma_m \le 1.03 \times 10^{-4} \le \Gamma_M \qquad (21)$$

The values were chosen as: $\Phi = 10^{-10}; \quad \Gamma_m = 8 \times 10^{-5}; \quad \Gamma_M = 5 \times 10^{-4}$.
The gains of the STA controller are determinated through equation (13):α=0.0028; λ=1; ρ=0.5; ξ=1.

4. Results and Discussion

The regulator was built and implemented under SIMULINK environment. In order to assess the effectiveness of the proposed controller, the actuators were excited by various steps. In Figure 3 wepresent the response, the outside temperature as well asevolution of the heater command and the fan command. As it can be seen, the inside temperature converges to its reference trajectory (setpoint) in despite of its variation. In fact, the temperature under greenhouse rose to 26^0C and maintained at this value during one hour. After that, it has dropped two degrees and stabilized at 24^0C. Furthermore, we can observe that heater functions when the tracking error is positive whereas the fan is put into action to eliminate the negative tracking error. The result illustrated confirms the fact that the system with the second-order sliding mode controller has good tracking performance and finite time convergence without overshoot. Moreover, it can be noticed that the frequency of the control signals is relatively small which means that the chattering effect is reduced.

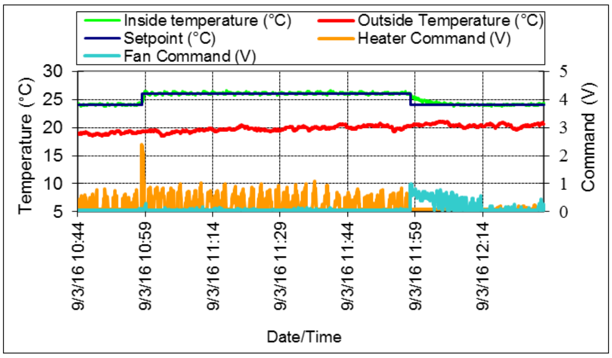

Figure 3. Evolution of Temperatures and Heater/Fancommand

To highlight the performances of the STA control aproach, we have applied to the greenhouse process several steps as desired states during 22 hours. The result is shown in Figure 4, it is obvious that the tracking is very goodindependently of changes in external temperature which varies between 11^0C and 21^0C.That proves the robustness of the used controller with regard to external disturbances and model uncertainties.

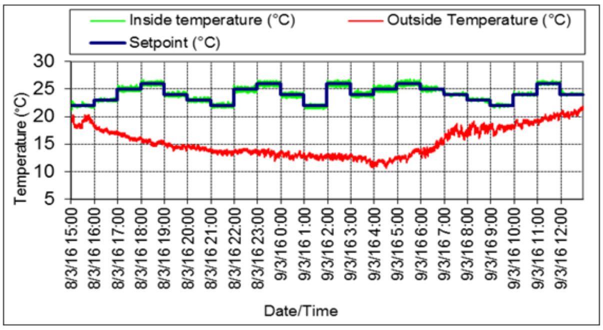

Figure 4. Measured Temperatures and Heater/Fancommandduring 22 hours

5. Conclusion

In this paper, a higher order sliding mode control system (super twisting) has been implemented for temperature control under an experimental greenhouse.To design the controller, we have developed a simplified model, then we have elaborated the control law based on HOSM strategy. In the current study we opted for super twisting algorithm to implement the HOSM controller. In fact, STA control is easy toimplement in practical applications and moreover, this technique is robust against disturbances and model uncertainties. Besides, the capability to reduce chattering effect as well as simplicity of controller design is noticeable. These advantages allowed us to obtain satisfactory results in terms of tracking performance, stabilization and disturbance rejection. As mentioned previously, the internal temperature is the most important variable for the crops grouth in greenhouse. However, it’s correlated with other variables like relative humidity to define the internal climate state of greenhouse. This later is strongly sensitive to the external meteorological conditions. Hence, multivariable control seems to be more efficient.

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