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Title: Adaptive Temperature Control For Plastic Extrusion Process

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Problem Description: The Extruder

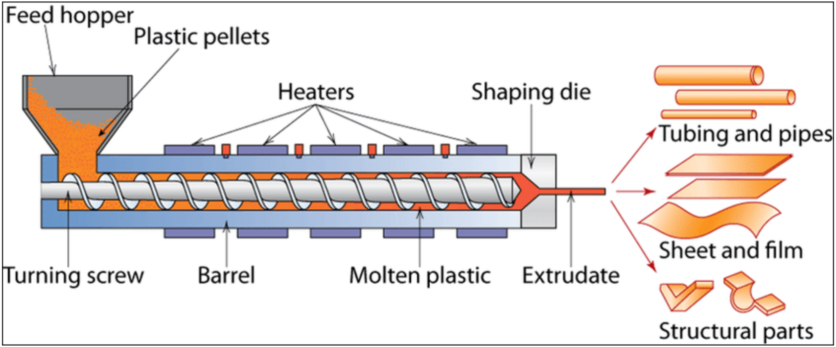

Figure 1:Typical plastic extruder schematic.

Heating zones

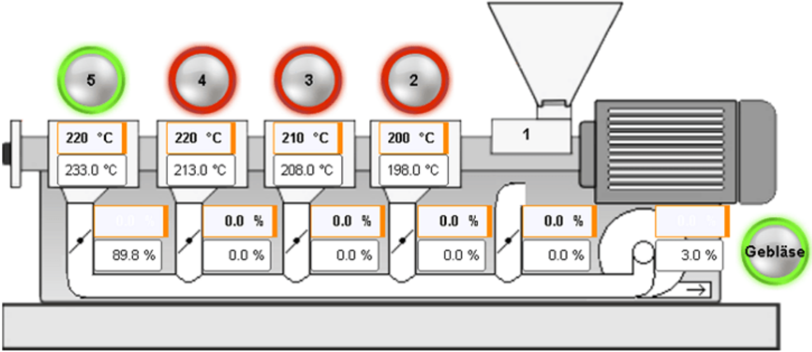

Figure 2:Heating zones of the plastic extruder.

Control PID

Figure 3:Temperature controller.

Control PID:

$$u = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{d}{dt} e(t) \qquad (1)$$

System Dynamics

The first law of Thermodynamics

$$\rho c_p V_e \frac{dT}{dt} = \omega - hA(T - T_\infty) \tag{2}$$

where T is the temperature, T_∞ is the enviroment's temperature. ρ and c_p is the density and specific heat of the material, respectively. V_e is the filament output velocity, A stands for area, and h is the heat transfer coefficient. Finally, ω is the energy input rate and it is considered as the control term.

Taking the following variable:

$$v = \frac{hA}{\rho V_e c_p} T_\infty + \frac{\omega}{\rho V_e c_p} \tag{3}$$

System Dynamics

The Eq. (2) can be rewritten as follows:

$$\frac{dT}{dt} = -\frac{hA}{\rho V_e c_p} T + v \tag{4}$$

$$\frac{dv}{dt} = \frac{u(\cdot)}{\rho V_e c_p} + \xi_0(t) \tag{5}$$

where $u(\cdot)$ is the control signal. Finally, if we rewrite the above system in terms of the nominal parameters, yields to:

$$\frac{dT}{dt} = -\hat{\alpha}_1 T + v + d_1(t) \tag{6}$$

$$\frac{dv}{dt} = \hat{\alpha}_2 u(\cdot) + d_2(t) \tag{7}$$

where $\hat{\alpha}_i$ represents the nominal parameters and $d_i(t)$ are time-varying external disturbances.

Control Design

How to select the control signal to heat the barrel to the desired temperature?

We use robust controllers as Sliding Mode Control.

Main Properties:

1. Robust towards parametric uncertainties and external disturbances.
2. Reaching in finite time.
3. Easy implementation.
4. Undesired effect: Chattering.

Control Design

1 Define the sliding surface as follows:

$$\sigma = \dot{e}(t) + \lambda e(t) \tag{8}$$

where $e(t) = T(t) - T^d(t)$ is the error signal, $\dot{e}(t)$ it derivative, and $\lambda \in R^+$.

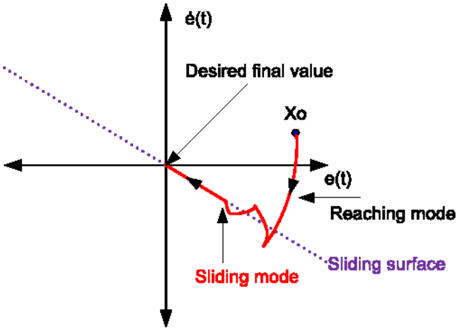

Figure 4: Sliding surface dynamics.

Controller Design

2 Assumption about the external disturbance:

$$\|d_i(t)\| \le \delta_i \quad \forall i = 1, 2. \tag{9}$$

3 We can achieve the condition $\sigma = 0$ by the following control law:

$$u = \frac{1}{\hat{\alpha}_2}\left[\ddot{T}^d + \hat{\alpha}_1 T_1 - \lambda \dot{e} - \hat{K}\, sgn(\sigma)\right] \tag{10}$$

where the gain is defined by:

$$\dot{\hat{K}} = \begin{cases} \beta|\sigma|^{\frac{1}{2}} sign(|\sigma| - \mu) & \text{if } \hat{K} \ge K_{min} \\ \kappa & \text{if } \hat{K} < K_{min} \end{cases} \tag{11}$$

where $\beta, \mu, \kappa, K_{min} \in R^+$

Controller Design

Finally, we propose the main theorem:

Theorem

Let the dynamic system (5)-(6), and the suppose that the disturbance satisfies the assumption (9).Then for any initial condition $\sigma(0)$ the sliding surface $\sigma = 0$ will be reached in finite time via the adaptive controller given by (10) with the adaptive gain (11).

Simulation Results

We propose to test the robustness of the proposed controller under four scenarios, namely:

1. Nominal scenario.

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1. Nominal scenario.
2. Controller's robustness towards parametric uncertainties.
3. Controller's robustness towards external disturbances.
4. Trajectory tracking test.

1. Nominal Case

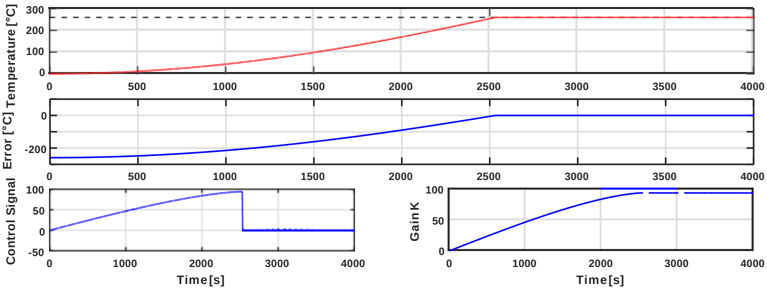

Figure 5:Nominal Case. Upper,The temperature signal (Red) follows the reference (black dashed line) $T^d = 260^\circ C$. Middle, the plot of the tracking errors. Lower, the control signal (left) and the controller gain evolution (right).

2. Parametric uncertainties

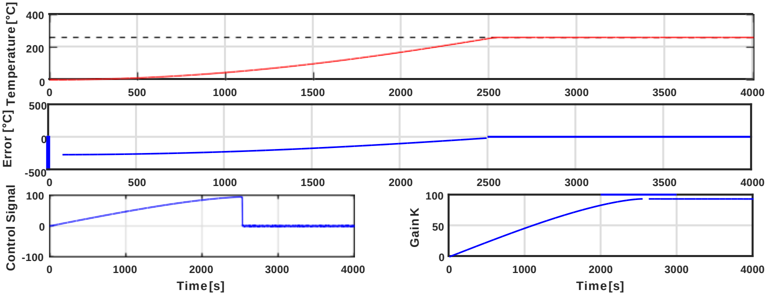

Figure 6:Controller robustness towards parametric uncertainties. Upper,The temperature signal (Red) follows the reference (black dashed line). Middle, the plot of the tracking errors. Lower, the control signal (left) and the controller gain evolution (right).

3. External disturbances

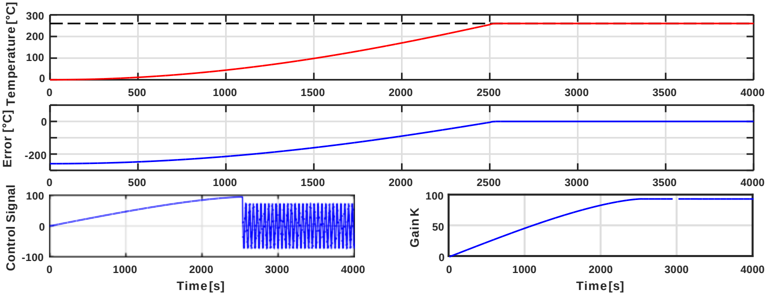

Figure 7:Controller robustness towards constant disturbance. Upper,The temperature signal (Red) follows the reference (black dashed line). Middle, the plot of the tracking errors. Lower, the control signal (left) and the controller gain evolution (right). The disturbance considered is $d_1(t) = 5sin(2ft)$.

4. Trajectory tracking

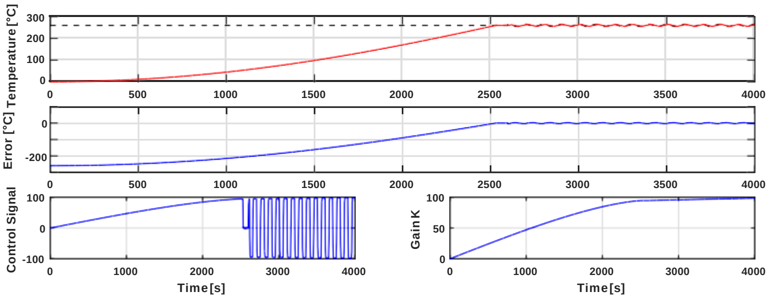

Figure 8: Trajectory tracking test. Upper, The temperature signal (Red) follows the reference (black dashed line). Middle, the plot of the tracking errors. Lower, the control signal (left) and the controller gain evolution (right). The reference is defined as $T^d(t) = 260 + 5\cos(2\pi f t)$.

Conclusions

In this paper, an adaptive first order sliding mode control has been proposed. The adaptive controller is designed to address the set-point regulation paradigm. The proposed controller has been tested by computer simulations in MATLAB for several scenarios to prove its robustness towards disturbances. The simulation experiments results demonstrate the effectiveness, and robustness of the proposed scheme to uncertainties on the parameters of the system and to external disturbances, as well.

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