Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 2, rok 2006, ročník LII, řada strojní
článek č. 1561

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APPLICATION OF ROBUST CONTROLS

VYUŽITÍ ROBUSTNÍCH ALGORITMŮ ŘÍZENÍ

Abstract

The paper describes design of robust control algorithms based on state variables aggregation method. The control algorithms were applied to temperature and flow-air control of laboratory model, which is a physical model of air-conditioning. All designed algorithms were verified by digital simulation and also directly on laboratory model.

Abstrakt

Příspěvek popisuje návrh robustního řízení pomocí metody agregace stavových proměnných. Algoritmy byly použity pro návrh řízení teploty a průtoku vzduchu na laboratorním modelu, který představuje fyzický model klimatizace. Všechny navržené algoritmy byly ověřeny simulací a poté aplikovány na laboratorním modelu.

1 INTRODUCTION

The paper deals with nonlinear control systems synthesis with help the state variables aggregation method. This method allows design of non-robust, robust algorithm with high gain and also robust algorithms in sliding mode. The non-robust control requests knowledge of nonlinear controlled subsystems mathematical model and deviations. It causes that this control algorithm have not to ensure the required control quality in real applications, where properties of nonlinear controlled subsystems have changed and disturbances have occurred. In addition the closed control system could be unstable. This very important problem can be solved by continuous calculation of closed-loop control and robust control algorithms can be obtained. The procedure description can be found in [WAGNEROVÁ 2002], [ZÍTEK, P & VÍTEČEK. 1999].

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2 LABORATORY MODEL OF AIR-CONDITIONING

The robust controls were applied to the hot-air aggregate, which is a laboratory model designed on Department of Control Systems and Instrumentation [SMUTNÝ, L. 2005]. On Figure 1; we can see the block schema of experimental laboratory model as a physical model of air-conditioning. It consists of a lamp (hot source) and a fan (flow air source) located in a tunnel and fed by a controlled supply voltage. In tunnel there are also many sensors for measuring the temperature and flow air (thermometer T1 and sensor KTY82 are situated on bulb, thermometer T2 is placed 5 mm from bulb). When we consider the model as SISO systems, we have two control tasks: 1. a temperature control of aggregate, as a disturbance it is possible to introduce the flow air, 2. a flow air control. The other possibility is that the model is considered as MIMO system, where we can control both variables, temperature and flow air.

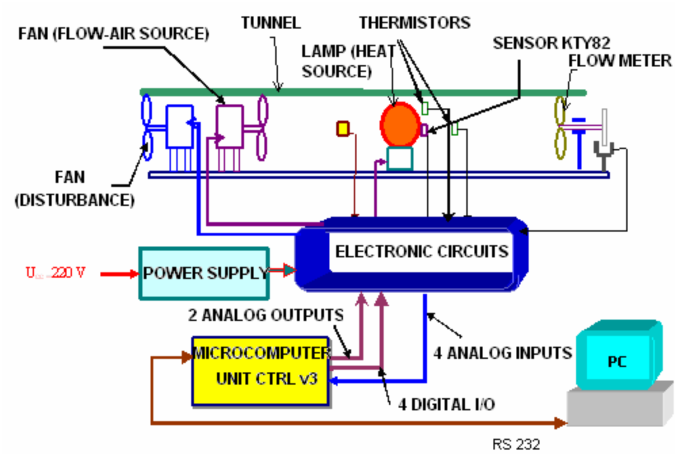

Fig. 1 Schema of laboratory model

3 THE ROBUST CONTROL

3.1 Temperature control

The mathematical model was obtained by experimental identification from measured step responses. We found out that the system can be written by first-order differential equation with time delay. That is why the aggregation matrix and matrix of time constant for each control variable are presented as

$$\mathbf{D} = d^T = 1, \qquad \mathbf{T} = T_w, \tag{1}$$

where: T_w - constants chosen with the respect for required course of closed control system.

Robust control with high gain is described by equation

$$u^x = \Theta_1\left(e_1 - e_{10} + \frac{1}{T_w}\int_0^t e_1 dt\right) \tag{2}$$

where: e_1 –difference between required and real temperature, e_{10}- initial value of error, u_1 – control variable Θ_1 - gain.

Sliding control with saturation function is written

$$u^{sat} = U^M \mathrm{sat}\left(\Theta_1\left((e_1 - e_{10}) + \frac{1}{T_w}\int_0^t e_1 dt\right)\right) \tag{3}$$

where: U^M – limit value of control (from 0 V to 10 V), sat - saturation function.

Sliding control with hyperbolic tangent function is written

$$u^{\tanh} = U^M \tanh\left(\Theta_1\left((e_1 - e_{10}) + \frac{1}{T_w}\int_0^t e_1 dt\right)\right) \tag{4}$$

where: tanh – hyperbolic tangent.

3.2 Flow-air control

The mathematical model was obtained by experimental identification from measured step responses. We found out that the system can be written by second-order differential equation. That is why the aggregation matrix and matrix of time constant for each control variable are presented as

$$D = \begin{bmatrix} \frac{1}{T_{w1}} & 1 \end{bmatrix} \qquad \mathbf{T} = T_{w1}, \tag{5}$$

where: T_{w1} - constants chosen with the respect for required course of closed control system response (marginal a-periodical course).

Robust control with high gain is described by equation

$$u^x = \Theta\left[\frac{2}{T_{w1}}(e_1 - e_{10}) + \dot{e}_1 + \frac{1}{T_{w1}^2}\int_0^t e_1 dt\right] \tag{6}$$

where: e_1 –difference between required and real flow-air, e_{10}- initial value of error, u_1 – control variable Θ_1 - gain.

Sliding control with saturation function is written

$$u^{sat} = U^M \cdot \mathrm{sat}\left(\Theta\left(\frac{2}{T_{w1}}\cdot(e_1 - e_{10}) + \dot{e}_1 + \frac{1}{T_{w1}^2}\int_0^t e_1\, dt\right)\right) \tag{7}$$

where: U^M – limit value of control (from 0 V to 10 V), sat - saturation function.

Sliding control with hyperbolic tangent function is written

$$u^{\tanh} = U^M \cdot \tanh\left(\Theta\left(\frac{2}{T_{w1}}\cdot(e_1 - e_{10}) + \dot{e}_1 + \frac{1}{T_{w1}^2}\int_0^t e_1\, dt\right)\right) \tag{8}$$

where: tanh – hyperbolic tangent.

4 VERIFICATION ON LABORATORY MODEL

Designed control algorithms were verified by computer simulation and than directly on laboratory model. The control algorithms constants (control with high gain, sliding controls) were chosen so that we can control temperature measured by all sensors; flow-air is measured with one sensor.

The laboratory model is connected to PC with help of unit CTRL v3, which communicates through serial port. The designed controls were realized with discrete representation, where sampling period was chosen $T = 0{,}5$ s.

4.1 Temperature control

Sliding mode control with saturation function can be described in discrete time by equation

$$u^{sat} = U^M \mathrm{sat}\left(\Theta_1\left(e(i) - e(i-1) + \frac{T}{T_w}\cdot\frac{e(i) - e(i-1)}{2}\right)\right) \tag{9}$$

where: T - sampling period.

Figure 2 and Figure 3 show results temperature control when the sliding model control was used and parameters values were $T_w = 19$ s, $U^M = 8$ V, $\Theta_1 = 0{,}12$.

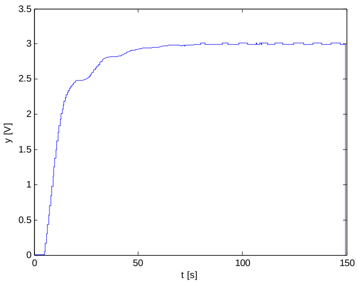

Fig. 2 Course of temperature

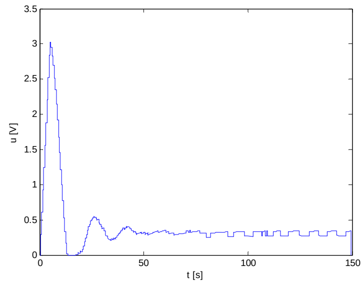

Fig. 3 Course of manipulated variable

Sliding mode control with hyperbolic tangent function can be rewrite in discrete time by equation

$$u^{\tanh} = U^M \tanh\left(\Theta_1\left(e(i) - e(i-1) + \frac{T}{T_w}\cdot\frac{e(i)-e(i-1)}{2}\right)\right) \tag{10}$$

On Figure 4 and Figure 5 there is shown temperature control when the sliding model control was used and parameters values were $T_w = 6$ s, $U^M = 8$ V, $\Theta_1 = 0{,}12$.

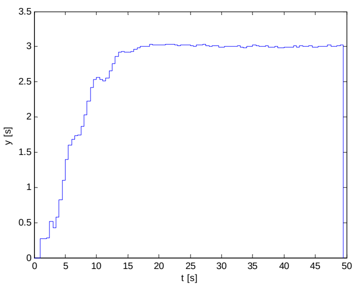

Fig. 4 Course of temperature

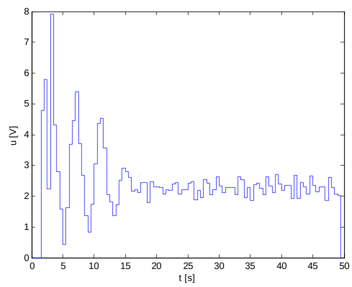

Fig. 5 Course of manipulated variable

4.2 Flow-air control

Sliding mode control with saturation function can be rewrite in discrete time by equation

$$u^{sat} = U^{M} \cdot \mathrm{sat}\left(\Theta\left(\left(\frac{2}{T_{w1}}\cdot\left(e(i)-e(i-1)\right)\right)+\frac{T}{T_{w1}^{\ 2}}\cdot\left(\frac{e(i)+e(i-1)}{2}\right)+\frac{1}{T}\left(e(i)-\frac{2}{T}e(i-1)+e(i-2)\right)\right)\right) \quad (11)$$

Figure 6 and Figure 7 show results of flow-air control when the sliding model control was used and parameters values were T_{w1} = 10 s, Θ =1,6, U^M = 8 V.

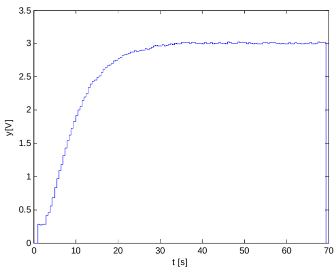

Fig. 6 Course of flow-air

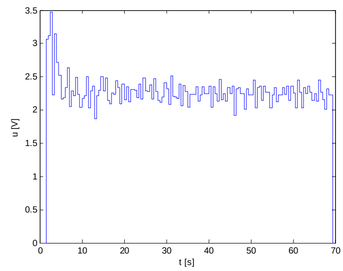

Fig. 7 Course of control

Sliding mode control with hyperbolic tangent function can be rewrite in discrete time by equation

$$u^{\tanh} = U^{M} \cdot \tanh\left(\Theta\left(\frac{2}{T_{w1}}\cdot\left(e(i)-e(i-1)\right)\right)+\frac{T}{T_{w1}^{\ 2}}\cdot\left(\frac{e(i)+e(i-1)}{2}\right)+\frac{1}{T}\left(e(i)-\frac{2}{T}e(i-1)+e(i-2)\right)\right). \quad (12)$$

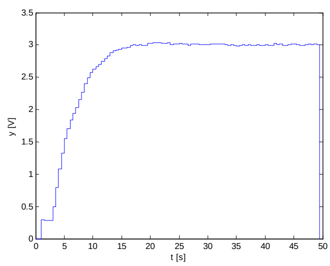

Fig. 8 Course of flow-air

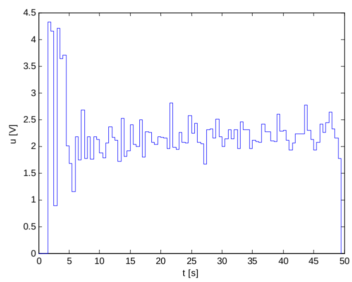

Fig. 9 Course of control

On Figure 8 and Figure 9 there is shown temperature control when the sliding model control was used and parameters values were T_{w1} = 10 s, Θ = 0,9, U^M = 8 V.

5 CONCLUSIONS

The contribution describes achieved results of robust controls applied on temperature and flow-air control. All designed algorithms were verified by computer simulation and directly on real system. Generally, all robust control algorithms ensured reaching the required temperature.

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