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A New Robust Variable Structure Controller for Uncertain Affine Nonlinear Systems with Mismatched Uncertainties

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Abstract - In this paper, a systematic design of a new robust nonlinear variable structure controller based on state dependent nonlinear form is presented for the control of uncertain affine nonlinear systems with mismatched uncertainties and matched disturbance. After an affine uncertain nonlinear system is represented in the form of state dependent nonlinear system, a systematic design of a new robust nonlinear variable structure controller is presented. To be linear in the closed loop resultant dynamics, the linear sliding surface is applied. A corresponding control input is proposed to satisfy the closed loop exponential stability and the existence condition of the sliding mode on the linear sliding surface, which will be investigated in Theorem 1. Through a design example and simulation study, the usefulness of the proposed controller is verified.

Key Words : Uncertain nonlinear system, Variable structure system, Sliding mode control, Mismatched uncertainties

1. Introduction

Stability analysis and controller design for uncertain nonlinear systems is open problems now[1]. So far numerous design methodologies exist for the controller design of nonlinear systems[2]. These include any of a huge number of linear design techniques[3][4] used in conjuction with gain scheduling[5]; nonlinear design methodologies such as Lyapunov function approach [1][2][6][7][10][11], feedback linearization method[8][9][10], dynamics inversion[10], backstepping[11], adaptive technique which encompass both linear adaptive[13] and nonlinear adaptive control[14], and sliding mode control[15]-[26] etc[27]-[29].

The sliding mode control(SMC) can provide the effective means to the problem of controlling uncertain nonlinear systems under parameter variations and external disturbances[15][16][17]. One of its essential advantages is the robustness of the controlled system to variations of parameters and external disturbances in the sliding mode on the predetermined sliding surface, $s=0$[18]. In [19], for nonlinear output regulator scheme, sliding mode approach is applied. The underlying concept is that of designing sliding submanifold which contains the zero tracking error submanifold. The convergence to a sliding manifold can be attained relying on a control strategy still based on a simplex of control vectors are identified for multi input uncertain nonlinear systems in [20]. Lu and Spurgeon in 1997 considered the robustness of dynamic sliding mode control of nonlinear systems which are in differential input-out form with additive uncertainties in the model[21]. The discrete-time implementation of a second-order sliding mode control scheme is analyzed for uncertain nonlinear system, in [22]. Flemming surveyed so called soft variable structure controls, compared them to other[23]. For 2nd order uncertain nonlinear system with mismatched uncertainties, a swichting control law between a first order sliding mode control and a second order sliding mode control is proposed to obtain the globally or locally asymptotic stability[24]. The optimal SMC for nonlinear system with time-delay is suggested in [25]. The nonlinear time varying sliding sector is designed for a single input nonlinear time varying input affine system which can be represented in the form of state dependent linear time variant system with matched uncertainties[26].

For uncertain affine nonlinear system with mismatched uncertainties and matched disturbance, the systematic design of the SMC is not reported until now.

In this technical note, a systematic design of a new nonlinear variable structure controller based on state dependent nonlinear form is presented for the control of uncertain affine nonlinear systems with mismatched uncertainties and matched disturbances. After an affine

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2. A Nonlinear Variable Structure Systems

2.1 Description of plants

Consider an affine uncertain nonlinear system

$$\dot{x}=f'(x,t)+g(x,t)u+d'(x,t), \qquad x(0) \tag{1}$$

where $x \in R^n$ is the state, $x(0)$ is its initial state, $u \in R^1$ is the control input, $f'(x,t) \in C^k$ and $g(x,t) \in C^k$, $k \geq 1$, $g(x,t) \neq 0$, for $all\, x \in R^n$ and for $all\, t \geq 0$ are of suitable dimensions, and $d'(x,t)$ implies bounded matched external disturbances.

Assumption[26]

A1: $f'(x,t)$ is continuously differentiable and $f'(0,t)=0$ for all $t \geq 0$.

Then, uncertain nonlinear system (1) can be represented in more affine nonlinear system of state dependent coefficient form[26]-[28]

$$\begin{aligned}\dot{x} &= f(x,t)x+g(x,t)u+d'(x,t), \quad x(0) \\ &= [f_0(x,t)+\triangle f(x,t)]x \\ &\quad +[g_0(x,t)-\triangle g(x,t)]u+d'(x,t) \\ &= f_0(x,t)x+g_0(x,t)u+d(x,t)\end{aligned} \tag{2}$$

$$d(x,t)=\triangle f(x,t)x+\triangle g(x,t)u+d'(x,t) \tag{3}$$

where $f_0(x,t)$ and $g_0(x,t)$ is each nominal value such that $f(x,t)=[f_0(x,t)+\triangle f(x,t)]$ and $g(x,t)=[g_0(x,t)-\triangle g(x,t)]$, respectively, $\triangle f(x,t)$ and $\triangle g(x,t)$ are matched or mismatched uncertainties, and $d(x,t)$ is the lumped uncertainties.

Assumption:

A2: The pair $(f_0(x,t), g_0(x,t))$ is controllable for $all\, x \in R^n$ and for $all\, t \geq 0$

A3: The lumped uncertainties $d(x,t)$ is bounded

A4: $\ddot{x}$ is bounded if $\dot{u}$ is bounded.

2.2 Sliding Surface

To control uncertain nonlinear system (1) or (2) with a linear closed loop dynamics, the sliding surface used in this design is as follows:

$$s=C^T x(=0) \tag{4}$$

In (4), C is a nonzero element as the design parameter such that the following assumption is satisfied.

Assumption

A5: $C^T g(x,t)$ and $C^T g_0(x,t)$ have the full rank, i,e are invertible

A6: $C^T \triangle g(x,t)\left[C^T g_0(x,t)\right]^{-1}=\triangle I$ and $|\triangle I| < \delta \leq 1,\ 0<\delta<1$.

The equivalent control input is obtained using $\dot{s}=0$ [15][16] as

$$\begin{aligned}u_{eq} &= -\left[C^T g(x,t)\right]^{-1} C^T f_0(x,t)x \\ &\quad -\left[C^T g(x,t)\right]^{-1} C^T \triangle f(x,t)x-\left[C^T g(x,t)\right]^{-1} d'(x,t)\end{aligned} \tag{5}$$

This control input can not be implemented because of the uncertainties, but used to obtaining the ideal sliding dynamics. The ideal sliding mode dynamics of the sliding surface (4) can be derived by the equivalent control approach[16] as

$$\begin{aligned}\dot{x}_s &= \left[f_0(x_s,t)-g_0(x_s,t)(C^T g_0(x_s,t))^{-1} C^T f_0(x_s,t)\right]x_s, \\ x_s(t_s) &= x(t_s)\end{aligned} \tag{6}$$

$$\dot{x}_s=\left[f_0(x_s,t)-g_0(x_s,t)K(x_s)\right]x_s, \tag{7}$$

$$K(x_s)=\left[C^T g_0(x_s,t)\right]^{-1} C^T f_0(x_s,t) \tag{8}$$

where t_s the reaching time. The solution of (6) identically defines the sliding surface after reaching. Hence to design the sliding surface as stable, this ideal sliding dynamics is designed to be stable. To choose the stable gain based on the Lyapunov stability theory, the ideal sliding dynamics (7) is represented by the nominal plant of (2) as

$$\begin{aligned}\dot{x} &= f_0(x,t)x+g_0(x,t)u, \qquad u=-K(x)x \\ &= f_c(x,t)x, \quad f_c(x,t)=f_0(x,t)-g_0(x.t)K(x)\end{aligned} \tag{9}$$

To select the stable gain, take a Lyapunov function candidate as

$$V(x)=\frac{1}{2}x^T Px, \qquad P>0 \tag{10}$$

The derivative of (10) becomes

$$\begin{aligned}\dot{V}(x) &= x^T\left[f_0(x,t)^T P+Pf_0(x,t)\right]x \\ &\quad +u^T g_0^T(x,t)Px+x^T Pg_0(x,t)u\end{aligned} \tag{11}$$

If take the control input as

$$u=-g_0^T(x,t)Px \tag{12}$$

and $Q(x,t)>0$ for $all\, x \in R^n$ and for $all\, t \geq 0$ is

$$f_0(x,t)^T P+Pf_0(x,t)=-Q(x,t) \tag{13}$$

then

$$\begin{aligned}\dot{V}(x) &= -x^T Q(x,t)x-2x^T Pg_0(x,t)g_0^T(x,t)Px \\ &= -x^T\left[Q(x,t)+2Pg_0(x,t)g_0^T(x,t)P\right]x \\ &= -x^T\left[f_c^T(x,t)P+Pf_c(x,t)\right]x \\ &= -x^T Q_c(x,t)x, \quad Q_c(x,t)=f_c^T(x,t)P+Pf_c(x,t) \\ &\leq -\lambda_{\min}\{Q_c(x,t)\}x^2 \\ &\leq 0\end{aligned} \tag{14}$$

Therefore the stable gain is chosen as

$$K(x)=g_0^T(x,t)P \text{ or } =\left[C^T g_0(x_s,t)\right]^{-1} C^T f_0(x_s,t) \tag{15}$$

2.3 Stabilizing Control Input

A corresponding control input is proposed as follows:

$$u=-K(x)x-\triangle Kx-K_1 s-K_2 sign(s) \tag{16}$$

where $K(x)$ is a nonlinear feedback gain, $\triangle K$ is a state dependent switching gain, K_1 is a feedback gain of the sliding surface, and K_2 is a switching gain, respectively as

$$K(x) = \left[C^T g_0(x,t)\right]^{-1} C^T f_0(x,t) \text{ or } = g_0^T(x,t)P \tag{17}$$

$$\triangle K = \left[C^T g_0(x,t)\right]^{-1} \triangle K' \tag{18}$$

$$\triangle k'_j = \begin{cases} \geq \dfrac{\max\left\{C^T \triangle f(x,t) - \triangle I C^T f_0(x,t)\right\}_j}{\min\{I-\triangle I\}} & sign(sx_j) > 0 \\ \leq \dfrac{\min\left\{C^T \triangle f(x,t) - \triangle I C^T f_0(x,t)\right\}_j}{\min\{I-\triangle I\}} & sign(sx_j) < 0 \end{cases}$$

$$j = 1, \ldots, n \tag{19}$$

$$K_1 = \left[C^T g_0(x,t)\right]^{-1} K_1', \qquad K_1' > 0 \tag{20}$$

$$K_2 = \left[C^T g_0(x,t)\right]^{-1} K_2' \tag{21}$$

$$K'_2 = \frac{\max\left\{C^T d'(x,t)\right\}}{\min\{I-\triangle I\}} \tag{22}$$

The real sliding dynamics by the proposed control with the linear sliding surface is obtained as follows:

$$\begin{aligned} \dot{s} &= C^T \dot{x} \\ &= C^T\left[f_0(x,t)x + \triangle f(x,t)x + g(x,t)u + d'(x,t)\right] \\ &= C^T[f_0(x,t)x + \triangle f(x,t)x \\ &\quad + g(x,t)\{-K(x)x - \triangle Kx - K_1 s - K_2 sign(s)\} + d'(x,t)] \\ &= C^T f_0(x,t)x - C^T g_0(x,t)K(x)x + C^T \triangle f(x,t)x \\ &\quad - C^T \triangle g(x,t)K(x)x - C^T g(x,t)\triangle Kx - C^T g(x,t)K_1 s \\ &\quad + C^T d'(x,t) - C^T g(x,t)K_2 sign(s) \\ &= C^T \triangle f(x,t)x - C^T \triangle g(x,t)K(x)x \\ &\quad - [I-\triangle I]\, C^T g_0(x,t)\triangle Kx - [I-\triangle I]\, C^T g_0(x,t)K_1 s \\ &\quad + C^T d'(x,t) - [I-\triangle I]\, C^T g_0(x,t)K_2 sign(s) \end{aligned} \tag{23}$$

The closed loop stability by the proposed control input with the sliding surface together with the existence condition of the sliding mode will be investigated in next Theorem 1.

Theorem 1: If the sliding surface is designed in the stable, i.e. stable design of $K(x)$, the proposed input with Assumption A1-A6 satisfies the existence condition of the sliding mode on the sliding surface and exponential stability.

Proof; Take a Lyapunov function candidate as

$$V(x) = \frac{1}{2}s^T s \tag{24}$$

Differentiating (24) with respect to time leads to and substituting (23) into (25)

$$\begin{aligned} \dot{V}(x) &= s^T \dot{s} \\ &= s^T C^T \triangle f(x,t)x - s^T C^T \triangle g(x,t)K(x)x \\ &\quad - s^T[I-\triangle I]\, C^T g_0(x,t)\triangle Kx \\ &\quad - s^T[I-\triangle I]\, C^T g_0(x,t)K_1 s + s^T C^T d'(x,t) \\ &\quad - s^T[I-\triangle I]\, C^T g_0(x,t)K_2 sign(s) \\ &\leq -\epsilon K_1'\|s\|^2, \qquad \epsilon = \|(I-\triangle I)\| \\ &= -\epsilon K_1' s^T s \\ &= -2\epsilon K_1' V(x) \end{aligned} \tag{25}$$

From (25), the following equation is obtained as

$$\dot{V}(x) + 2\epsilon K_1' V(x) \leq 0 \tag{26}$$

$$V(t) \leq V(0)e^{-2\epsilon K_1' t} \tag{27}$$

And the second order derivative of $V(x)$ becomes

$$\ddot{V}(x) = \dot{s}\dot{s} + s\ddot{s} = (\dot{s})^2 + sC^T\ddot{x} < \infty \tag{28}$$

and by Assumption A4 $\ddot{V}(x)$ is bounded which completes the proof of Theorem 1.

To show the effectiveness of the algorithm, an example will be presented.

3. Design Example and Simulation Studies

Consider a second order affine uncertain nonlinear system with mismatched uncertainties and matched disturbance

$$\begin{aligned} \dot{x}_1 &= -x_1 + x_1\sin^2(x_1)) + x_2 + 0.02\sin(2x_1)u \\ \dot{x}_2 &= x_2 + x_2\sin^2(x_2) + (2 + 0.5\sin(2t))u + d(x,t) \end{aligned} \tag{29}$$

$$d(x,t) = 0.7\sin(x_1) - 0.8\sin(x_2) + 0.2(x_1^2 + x_2^2) + 2\sin(5t) \tag{30}$$

Since (29) satisfy the Assumption A1, (29) can be represented in state dependent coefficient form as

$$\begin{bmatrix}\dot{x}_1 \\ \dot{x}_2\end{bmatrix} = \begin{bmatrix} -1+\sin^2(x_1) & 1 \\ 0 & 1+\sin^2(x_2)\end{bmatrix}x + \begin{bmatrix}0.02\sin(x_1) \\ 2+0.5\sin(2t)\end{bmatrix}u + \begin{bmatrix}0 \\ d(x,t)\end{bmatrix} \tag{31}$$

where the nominal parameter $f_0(x,t)$ and $g_0(x,t)$ and mismatched uncertainties $\triangle f(x,t)$ and $\triangle g(x,t)$ are

$$f_0(x,t) = \begin{bmatrix}-1 & 1 \\ 0 & 1\end{bmatrix}, \; g_0(x,t) = \begin{bmatrix}0 \\ 2\end{bmatrix},$$

$$\triangle f(x,t) = \begin{bmatrix}\sin^2(x_1) & 0 \\ 0 & \sin^2(x_2)\end{bmatrix}, \quad \triangle g(x,t) = \begin{bmatrix}0.02\sin(x_1) \\ 0.5\sin(2t)\end{bmatrix} \tag{32}$$

To design the sliding surface, $f_c(x,t)$ is selected as

$$f_c(x,t) = f_0(x,t) - g_0(x.t)K(x) = \begin{bmatrix}-1 & 1 \\ 20 & -21\end{bmatrix} \tag{33}$$

in order to have the two poles at -21.9545 and -0.0455. The P in (10) is chosen as

$$P = \begin{bmatrix}10 & -5 \\ -5 & 5.5\end{bmatrix} > 0 \tag{34}$$

so as to be

$$f_c(x,t)^T P + Pf_c(x,t) = \begin{bmatrix}-220 & 230 \\ 230 & -241\end{bmatrix} < 0 \tag{35}$$

Hence, the continuous feedback gain is chosen as

$$K(x) = g_0^T(x,t)P = [-10 \quad 11] \tag{36}$$

Therefore, the coefficient of the sliding surface is determined as

$$C = [20 \quad 1]^T \tag{37}$$

The selected gains in the control input are as follows:

$$\triangle k_1 = \begin{cases} 26.5 & \text{if } sx_1 > 0 \\ -26.5 & \text{if } sx_1 < 0\end{cases}, \quad \triangle k_2 = \begin{cases} 10 & \text{if } sx_2 > 0 \\ -10 & \text{if } sx_2 < 0\end{cases} \tag{38}$$

$$K_1 = 5 \tag{39}$$

$$K_2 = 1.75 + 0.1(x_1^2 + x_2^2) \tag{40}$$

The simulation is carried out under 1[msec] sampling time and with $x(0) = [5 \; -5]^T$ initial state. Fig. 1 shows (i) x_1 and (ii) x_2 time trajectories. The phase trajectory(i) and ideal sliding trajectory(ii) are depicted in Fig. 2.

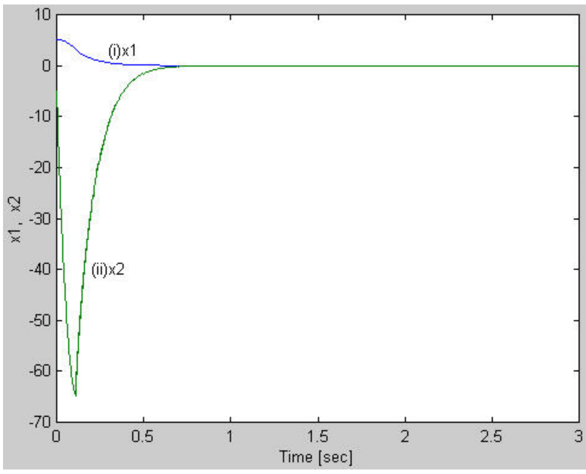

Fig. 1 (i) x_1 and (ii) x_2 time trajectories

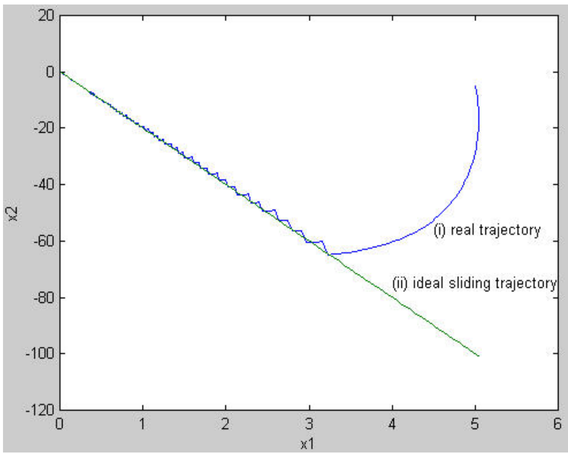

Fig. 2 (i) real phase trajectory and (ii) ideal sliding trajectory

The sliding surface $s(t)$ is shown in Fig. 3. The control input is depicted in Fig. 4. From the simulation studies, the effectiveness of the proposed SMC is proven.

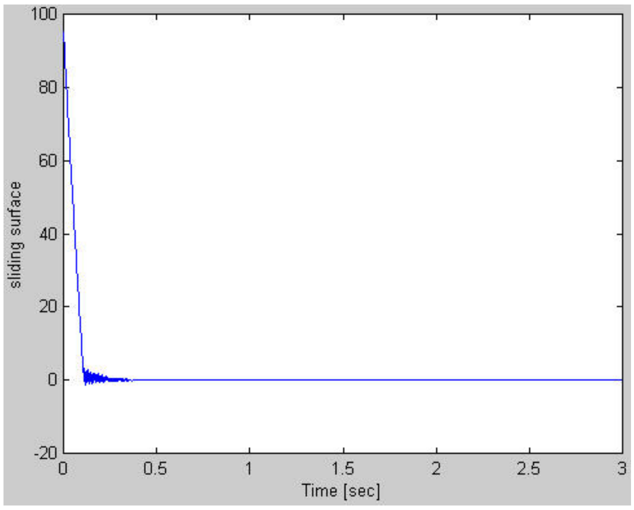

Fig. 3 Sliding surface

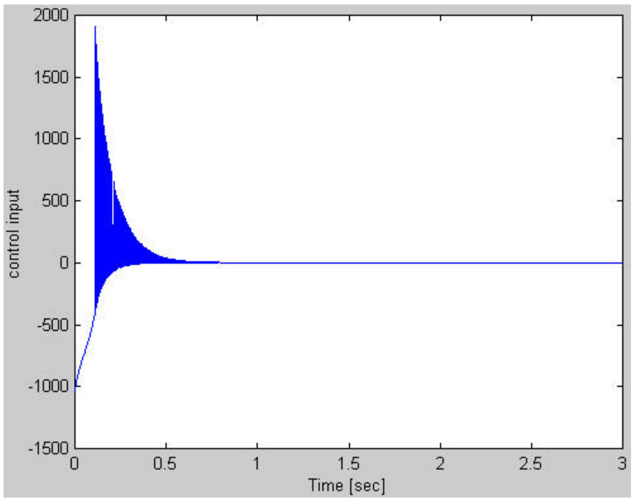

Fig. 4 Control input

4. Conclusions

In this note, a systematic design of a new robust nonlinear variable structure controller based on state dependent nonlinear form is presented for the control of uncertain affine nonlinear systems with mismatched uncertainties and matched disturbance. After an affine uncertain nonlinear system is represented in the form of state dependent nonlinear system, a systematic design of a new robust nonlinear variable structure controller with the linear sliding surface is suggested. A corresponding control input is proposed. The closed loop stability by the proposed control input with linear sliding surface together with the existence condition of the sliding mode on the selected sliding surface will be investigated in Theorem 1 for all mismatched uncertainties and matched disturbance. Through a design example and simulation studies, the usefulness of the proposed controller is verified.

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References

[1] M. Vidyasagar, "New Directions of Research in Nonlinear System Theory," Proc. of the IEEE vol.74 no.8 pp.1060-1091, 1986.

[2] P Kokotovic and M. Arcak, "Constructive Nonlinear Control: a Historical Perspective," Automatica, vol.37, pp.637-662, 2001.
[3] B. D. O. Anderson and J. B. More, Optimal Control, Prentice-Hall, 1990.
[4] I. Horowitz, "Survey of Quantitative Feedback Theory(QFT), Int. J. Control, vol.53, no.2 pp.255-291, 1991.
[5] W. J. Rugh and J. Shamma, "Research on Gain Scheduling," Automatica, vol.36, pp.1401-1425, 2000.
[6] X. Cai, R. Lin and S. Su, "Robust stabilization for a class of Nonlinear Systems, IEEE CDC pp.4840-4844, 2008.
[7] S. Gutman, "Uncertain dynamical Systems:A Lyapunov Min-Max Approach," IEEE Trans. Autom. Contr, AC-24, no. 1, pp.437-443, 1979.
[8] L. R. Hunt, R. Su, and G. Meyer, "Global Transformations of Nonlinear Systems," IEEE Trans. Autom. Contr, AC-28, no. 1, pp.24-31, 1987.
[9] A Isidori, Nonliear Control System, 2e Springer-Verlag, 1989.
[10] J. J. E. Slottine and W Li, Applied Nonlinear Control, Prentice-Hall, 1991.
[11] H. K. Khalil, Nonlinear Systems, 2e Prentice-Hall, 1996.
[12] L. Lijun and X Chengkand, "Robust Backstepping Design of a Nonlinear Output Feedbcak System," IEEE CDC 2008, pp.5095-5099.
[13] K. S. Narendra, "Parameter Adaptive Control-the End...or the Beginning?" Proc. 33rd IEEE CDC, 1994.
[14] Q. Zheng and F. Wu, "Lyapunov Redesign of Adpative Controllers for Polynomial Nonlinear systems," Proc. IEEE ACC 2009, pp.5144-5149.
[15] V.I. Utkin,, Sliding Modes and Their Application in Variable Structure Systems. Moscow, 1978.
[16] Decarlo, R.A., Zak, S.H., and Mattews, G.P., "Variable Structure Control of Nonlinear Multivariable Systems: A Tutorial," Proc. IEEE, 1988, 76, pp.212-232.
[17] Young, K.D., Utkin, V.I., Ozguner, U, "A Control Engineer's Guide to Sliding Mode Control," 1996 IEEE Workshop on Variable Structure Systems, pp.1-14
[18] Drazenovic, B.:The invariance conditions in variable structure systems, Automatica, 1969, (5), pp.287-295.
[19] B. C. Toledo and R. C. Linares, "On Robust Regulation via sliding Mode for Nonlinear Systems," System & Control Letters, vol.24, pp.361-371, 1995.
[20] G. Bartolini and A Ferrara, "On Multi-Input Sliding Mode Control of Uncertain Nonlinear Systems," Proc. IEEE 34th CDC, p.2121-2124, 1995.
[21] X. Y. Lu and S. K. Spurgeon, "Robust Sliding Mode Control of Uncertain Nonlinear System," System & control Letters, vol.32, pp.75-90, 1997.
[22] G. Bartolini A. Pisano, E. Usai, " Digital Second-Order sliding Mode Control for Uncertain Nonlinear Systems," Automatica, vol.37 pp.1371-1377, 2001.
[23] J. Adamy and A. Flemming, "Soft Variable Structure Control:a survey," Automatica, vol.40, pp.1821-1844, 2004.
[24] Y. Wang, C. Jiang, D. Zhou, F. Gao, "Variable Structure Control for a Class of Nonlinear Systems with Mismatched Uncertainties," Applied Mathematics and Computation, pp.1-14, 2007.
[25] G. Y. Tang, R. Dong, and H. W. Gao, "Optimal sliding Mode Control for Nonlinear System with Time Delay," Nonlinear Analysis: Hybrid Systems, vol.2, pp891-899, 2008.
[26] Y. D. Pan, K. D. Kumar, G. J. Liu, and K. Furuta, "Design of Variable Strucutre Control system with Nonlinear Time Varying sliding Sector," IEEE Trans. Autom. Contr, AC-54, no. 8, pp.1981-1986, 2009.
[27] X. Hu and C. Martin, " Linear Reachability Versus Global Stabilization," IEEE Trans. Autom. Contr, AC-44, no. 6, pp.1303-1305, 1999.
[28] Y. M. Sun, " Linear Controllability Versus Global Controllability," IEEE Trans. Autom. Contr, AC-54, no. 7, pp.1693-1697, 2009.
[29] W. H. Chen, D. J. Ballance, and P. J. Gawthrop, "Optimal Control of Nonlinear System:A Predictive Control Approach," Automatic, vol. 39, pp633-641, 2003
[30] J. H. Lee and M. J. Youn, "An Integral-Augmented Optimal Variable Structure control for Uncertain dynamical SISO System, KIEE(The Korean Institute of Electrical Engineers), vol.43, no.8, pp.1333-1351, 1994.
[31] J. H. Lee, "Highly robust position control of BLDDSM using an improved integral variable structure system," Automatica, vol.42,, pp.929-935, 2006

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