出國報告（出國類別：國際研討會）

採用有限差分方式的非線性系統之離散非線性輸出回饋控制

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報告日期：自 97 年 6 月 11 日至 97 年 6 月 13 日
出國時間：自 97 年 6 月 10 日至 97 年 6 月 15 日

報告內容應包括下列各項：

一. 參加會議經過

6月10日下午搭乘中華航空公司前往位於美國西岸西雅圖市。此國際會議會場選在當地 Westin Seattle 飯店內舉行(附件一)。依據大會安排，本人在當地時間6月12日下午的 Computational method 場次進行口頭發表本次論文，演講內容參閱附件二。該場次出席人數約 30 人左右並於下午 5:00 時間結束。會議進行間曾與部分學術界人士交換研究心得，及會議結束後與部分出席人士討論論文發表內容。

關於 2008 年美國控制會議行程包括相當多場次在這三天內進行，研究涵蓋能源，化工，電機，機械，航太等相關控制領域。此次大會安排多場學術性專題演講，讓與會人士共同分享大師級人士研究心得與了解控制在各領域研究成果，因此本人在這期間選擇與個人專業領域及教授課程有關主題到場聆聽吸取經驗。另外，與本人研究興趣或議題上有密切關聯的論文發表會場也是本人獲取研究經驗機會。值得一提是有關非線性控制研究是此次程熱門研究主題之一。另外，除相當多國際大公司贊助外，相當多工業界代表參與學術論壇。所以，此次研討會不僅是一次難得國際學術交流機會，更可以充分了解與掌握業界動向。除了學術性專題演講，大會也藉此機會讓參於人士了解當地風景與歷史文物。另外，藉由頒獎宴會上獎勵各項得獎者，讓與會人士對相關研究發展能激起共鳴。最後，大會依表訂行程在6月13日下午舉行閉幕歡送晚宴，結束後接著互道珍重再見。

二、與會心得

2008 美國控制會議是屬於年度性國際學術研討會,分別在不同州或是著名城鎮舉辦。由於參與人士是來自世界各國的具控制背景先進及專業學者與會，針對相關學術領域進行深入探討與心得分享。這次主辦單位在會議內容上十分用心，特別安排主講場次是大家十分關心未來前瞻性研究議題，及盡可能安排國際知名學者與會發表演說提供寶貴經驗與見解。可是據個人觀察有關化工程序控制等議題的演說則付之闕如，原因不外乎是從事程序控制相關研究人士與大部分參與活動人士比較，相形之下為少數。不過，整體而言與會人士以達 1500 人之多與高達 20 個發表會場同時舉行，這些舉辦經驗十分值得國內相關學術單位借鏡。由於此次是國際學者相互觀摩與交換心得的重要機會，除了學術性質演講外，各式相關展覽也一應俱全，讓我們感受到主辦單位的努力與籌辦方式用心。不過，此次研討會註冊費高昂這對不甚富裕國家的人士參與是一阻力，觀察會場上亞洲人士似乎少了些，但歐美人士出席十分踴躍。總之這趟美國之旅獲益匪淺，期待這些經驗能對個人未來研究工作及人生歷練有所助益。

三、建議

觀察國內研究成果質與量在此次研討會上表現平平，不過出席大陸人士與往年比較似乎成長許多值得我們惕勵與學習地方。

四、攜回資料名稱及內容

1. 會議資料袋及與會論文發表摘要乙份
2. 錄製與會發表論文全文光碟乙份
3. 相關會議會訊

附件一

附件二

Discrete-Time Nonlinear Output Feedback Control for a Class of Nonlinear Systems Using Finite Difference Approaches

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To be presented at *2008 American Control Conference*

Major issues

- Finite difference-based output feedback control
- The effect of sampling period and approximation errors is accounted for the stabilization of closed - loop systems
- An unstable chemical reactor system with sampling time-delay and inlet perturbations is demonstrated

Continuous-time control system

- A class of single-input single-output (SISO) nonlinear system

$$\begin{aligned} \dot{x} &= F(x,u) \\ y &= h(x) \end{aligned} \qquad (1)$$

Using the input-dependent state coordinate transformation

$$\xi = \Theta(x,u,\dot{u},\ldots,u^{(\alpha-1)}) = (y, \dot{y}, ,\ldots, y^{(n-1)})^T \qquad (2)$$

and the full rank condition

$$\text{rank}\left\{ Q(x,u,\dot{u},\ldots,u^{(\alpha-1)}) \equiv \frac{\partial}{\partial x}\begin{bmatrix} h(x) \\ \dot{h}(x) \\ \cdots \\ h^{(r)}(x,u) \\ \cdots \\ h^{(n-1)}(x,u,\dot{u},\ldots,u^{(\alpha-1)}) \end{bmatrix} \right\} = n \qquad (3)$$

Continuous-time control system

- An extended Luenberger-like observer

$$\dot{\hat{x}} = F(x,u) + Q^{-1}(x,u,\dot{u},\ldots,u^{(\alpha-1)})K\left(y - h(x)\right) \qquad (4)$$

and the continuous-time observer-based controller is composed of

$$\begin{aligned} &\dot{\hat{x}} = \tilde{F}(x,t) + \tilde{Q}(x,t)K[y - h(x)] \\ &\chi(\hat{x},u,\dot{u},\ldots,u^{(\alpha)}) + G\tilde{e} = 0 \end{aligned} \qquad (5)$$

where the implicit, nonlinear ODE in Eq. (5) should be solvable.

Continuous-time control system

- The auxiliary closed-loop system is shown by

$$\begin{aligned}\dot{e} &= \bar{A}_n e + B_n\left[\tilde{\chi}_1(x,\hat{x},t) - \tilde{\chi}_2(x,t) + G(e-\tilde{e})\right]\\ \dot{\hat{e}} &= \hat{A}_n e + B_n\left[\tilde{\chi}_1(x,x,t) - \tilde{\chi}_2(x,t)\right]\end{aligned} \qquad (6)$$

Corollary 1: Suppose that (i) the observer design can hold; (ii) the control solution exists; (iii) inequalities for bounds of nonlinearities are sati sfied by

$$\begin{aligned}&\left\|2P_c B_n\left[\tilde{\chi}_1(x,\hat{x},t) - \tilde{\chi}_2(x,t) + G(e-\tilde{e})\right]\right\| \le \ell_1\|e\| + \ell_2\|e\|\\ &\left\|2P_k B_n\left[\tilde{\chi}_1(x,\hat{x},t) - \tilde{\chi}_2(x,t)\right]\right\| \le \ell_3\|e\|\end{aligned} \qquad (7)$$

Then the asymptotic output regulation can be achieved.

$$\lim_{t\to\infty}\|e(t)\| = 0 \qquad (8)$$

Finite difference approach

- Using the forward finite differences and differential operators

$$h^m D^m = \left(\Delta - \frac{\Delta^2}{2} + \frac{\Delta^3}{3} - \frac{\Delta^4}{4} + \ldots\right)^m \qquad (6)$$

and

$$\begin{aligned}D &= \frac{\Delta}{h} + O_m(h)\\ D^2 &= \frac{\Delta^2}{h^2} + O_m(h)\\ &\vdots\\ D^m &= \frac{\Delta^m}{h^m} + O_m(h)\end{aligned} \qquad (7)$$

assuming

$$\chi(\hat{x},u,\dot{u},\ldots,u^{(\alpha)}) + G\tilde{\tilde{e}} = 0 \xrightarrow{\approx} D^{\alpha} u = \Im(x,u,Du,\ldots,D^{\alpha-1}u)$$

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Finite difference approach

Furthermore, the difference-based control equation is shown by

$$\Delta^{\alpha}u = \Im_{\alpha}(x,u,\Delta u,\ldots,\Delta^{\alpha-1}u,h) \quad (8)$$

while the very fast sampling rate is employed, the observer-based controller via the finite difference approach is approximated as

$$\begin{aligned} \hat{x}(k+1) &= F_d(x(k),y(k)) \\ u(k+\alpha) &= \Psi(\hat{x}(k),u(k),\ldots,u(k+\alpha-1)) \end{aligned} \quad (9)$$

If the sampling time-delay T_s is considered, i.e. $T_s = nh$, then the new sampling times become $k' = k/n$, the one-time-delay-ahead predictive control is shown by

$$\begin{aligned} \hat{x}(k+1) &= F_d(x(k),y(k')) \\ u(k'+1) &= \Psi(\hat{x}(k'),u(k'),\ldots,u(k')) \end{aligned} \quad (10)$$

Finite difference approach

Moreover, the discrete-time closed-loop system is described as

$$\begin{aligned} e(k'+1) &= \bar{A}_n e(k') + B_n\left[\Gamma_e(x(k'),\hat{x}(k))\right] \\ \hat{e}(k+1) &= \hat{A}_n e(k) + B_n\left[\Gamma_{\hat{e}}(x(k'),x(k))\right] \end{aligned} \quad (11)$$

Corollary 2: Suppose that (i) the discrete-time observer-based control exists; (ii) inequalities for bounds of nonlinearities are satisfied by

$$\begin{aligned} \left\|2\bar{A}_n^T Q_c B_n\left[\Gamma_e(x(k'),\hat{x}(k))\right]\right\| &\le \gamma_1\|e(k')\| + \gamma_2\|e(k)\| \\ \left\|2\hat{A}_n^T Q_k B_n\left[\Gamma_{\hat{e}}(x(k'),\hat{x}(k))\right]\right\| &\le \gamma_3\|e(k)\| \end{aligned} \quad (12)$$

Then, the discrete-time closed-loop system is asymptotically stable, i.e.

$$\lim_{k'\to\infty} e(k') = 0 \quad (13)$$

Finite difference approach

Moreover, the discrete-time reference-based output feedback control framework is written as

$$u(k'+1)=\hat{\Psi}(\hat{x}(k'),y_m(k'),\ldots,y_m(k'+1),u(k'),\ldots,u(k')) \qquad (14)$$

where y_m is the specific reference model output.

Corollary 3: Suppose that (i) the discrete-time reference-based control exists; (ii) inequalities for bounds of nonlinearities are satisfied by

$$\begin{aligned}&\left\|2\bar{A}_n^T Q_c B_n\left[\bar{\Gamma}_e(x(k'),\hat{x}(k),y_m(k'))\right]\right\|\le\gamma_1\left\|\bar{e}(k')\right\|+\gamma_2\left\|e(k)\right\|+B_e(T_s)\\&\left\|2\hat{A}_n^T Q_k B_n\left[\bar{\Gamma}_{\hat{e}}(x(k'),\hat{x}(k))\right]\right\|\le\gamma_3\left\|e(k)\right\|+B_e(T_s)\end{aligned} \qquad (15)$$

Then the output regulation and estimation error are restricted t o the sampling time-delay, respectively.

$$\left\|\bar{e}(k')\right\|\le\gamma_e(T_s) \qquad \left\|\hat{e}(k)\right\|\le\gamma_{\hat{e}}(T_s) \qquad (16)$$

Demonstration

◆ A unstable chemical reactor system is described by

$$\dot{x}=F(x,u)=\begin{pmatrix}F_1(x)\\F_2(x,u)\end{pmatrix}=\begin{pmatrix}R_A(x_1,x_2)+(C_{Ai}-x_1)/\tau\\R_H(x_1,x_2)/\rho c_p+(T_i-x_2)/\tau+\dfrac{u}{\rho c_p V}\end{pmatrix}$$

$$y=h(x)=x_2$$

◆The discrete-time observer-based control is shown as

$$\hat{x}(k+1)=x(k)+h\left[F(x(k),u(k))+Q^{-1}K\left(y(k)-h(x(k))\right)\right]$$

$$u(k'+1)=u(k')+T_s\left[\left(\frac{\partial F_2(\hat{x}(k),u(k'))}{\partial u(k')}\right)^{-1}\left(-g_1(h(\hat{x}(k))-y_R)-g_2F_2(x(k),u(k'))-\frac{\partial F_2(\hat{x}(k),u(k'))}{\partial\hat{x}_2(k)}F_2(\hat{x}(k),u(k'))-\frac{\partial F_2(\hat{x}(k),u(k'))}{\partial\hat{x}_1(k)}F_1(\hat{x}(k))\right)\right]$$

Demonstration

- The nonlinear term Γ_e as $k' \to \infty$ is bounded by

$$|\Gamma_e| \le \left| \left(\frac{\partial F_2(x,u)}{\partial u} \right) O_m(T_s) \right|$$

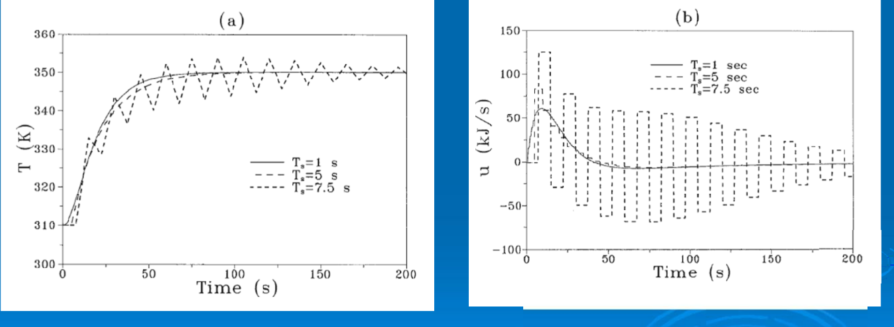
- The nonlinear term $\Gamma_{\hat{e}}$ as $k' \to \infty$ is bounded by

$$|\Gamma_{\hat{e}}| \le \left| \left[\frac{\partial F_2(\hat{x},u)}{\partial \hat{x}_2} q_1 \hat{e}_1 \right] \right| + \left| \left[\frac{\partial F_2(x,u)}{\partial x_1} q_2 e_1 \right] \right|$$
$$+ \left| \left[\left(\frac{\partial F_2(\hat{x},u)}{\partial u} \right) - \left(\frac{\partial F_2(x,u)}{\partial u} \right) \right] O_m(T_s) \right|$$

The above inequalities show that the sampling time -delay would strictly affect the growing bounds of above nonlinearities.

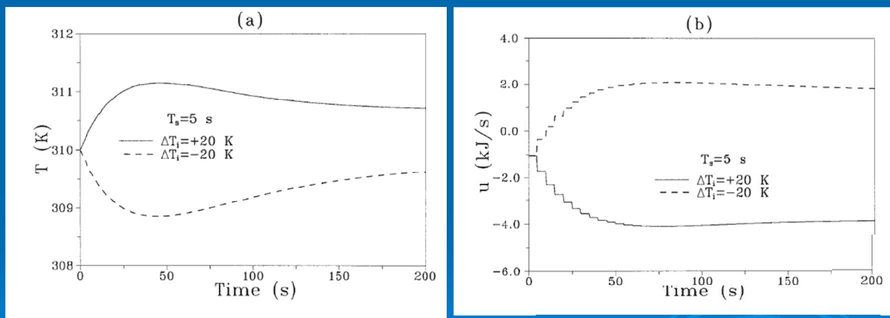
Demonstration

- Under consistent initialization and different sampling period, t he discrete-time observer-based control is executed for constant setpoint change.



Demonstration

- Under consistent initialization, constant sampling period, and inlet temperature perturbation, the discrete-time observer-based control is executed for disturbance rejection.



Demonstration

- Under the same consistent initialization, constant sampling period, and inlet temperature perturbation, the discrete-time observer-based control associated with the integral action is executed for disturbance rejection.