ISSN : 0974 - 7435 Volume 10 Issue 20

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(20), 2014 [12371-12378]

Disturbance rejection for discrete-time systems with time-delays

Shao-Ting Ge[1,*], Zhimin Liu[2], Lijuan Kang[1], Yuqing Feng[3], Heng Wen[1]
[1]College of Software Tecnical, Qingdao University, Qingdao 266071
[2]College of Software and Service Outsourcing, Qingdao Technical College, Qingdao 266555
[3]No.15 Middle School, Qingdao 266023
E-mail : shaotingge@gmail.com

ABSTRACT

The disturbance rejection problem for discrete-time linear systems with both state delay and control delay is considered. Using a model transformation, the time-delay system is transformed into a nondelayed system. The disturbance rejection control law is obtained by solving its optimal regulation problem. A dynamic compensator is designed, which is combined by an internal model principle corresponding to the disturbances and an optimal control law which consists of state and control memory terms and a disturbance compensator. Numerical simulations are used to illustrate the effectiveness of the optimal regulator.

KEYWORDS

Discrete-time linear systems; Disturbance rejection; Optimal regulation; Internal model principle.

INTRODUCTION

The problem of disturbance rejection plays an important role. And there are several techniques of disturbance rejection. In the case of undeterministic disturbances, the robust H_∞ controller design[1] and its optimization problem[2] have been investigated by many researches. In the case of deterministic disturbances, various control techniques have been applied such as internal model control[3,4], adaptive control[5,6], predictive control[7], feedforward and feedback control[8]. Based on these techniques, the strategies of disturbance rejection are greatly improved. But many researches tend to the systems without delay.

The controller design for the control-delay systems has been investigated by researchers[9,10]. It was shown that the memoryless controllers are easy to implement, as well as the controller with delay compensation can has more robustness by some examples.

In this paper, we consider the disturbance rejection problem for discrete-time linear systems with both state delay and control delay. Through a model transformation, the delay system is transformed into a nondelayed system. And the memory terms in the controller are designed to compensate the state delay and the control delay perfectly. Furthermore, we apply the internal model principle to eliminate the system's steady-state error.

The paper is organized as follows. After an introduction, in Section 2, system description and problem formulation are considered. In Section 3, by using the model transformation and solving the optimal regulation problem, the optimal controller is designed. Also, in Section 4, an observer-based optimal controller is designed. In order to verify its robustness and effectiveness, some numerical examples are simulated in Section 5. Concluding remarks are given in Section 6.

THE PROBLEM OF OPTIMAL REGULATION FOR DISCRETE-TIME LINEAR SYSTEMS

Consider a discrete-time linear system with delayed control and measurement described by:

$$\begin{aligned} &x(k+1) = Ax(k) + B_1 u(k-h_1) + Dv(k), \\ &y(k) = C_1 x(k-h_2), \\ &x(0) = x_0, \quad k = 0, 1, 2, \cdots, \end{aligned} \tag{1}$$

where $x \in \mathbb{R}^n$ is the state vector, $u \in \mathbb{R}^m$ is the control input, $y \in \mathbb{R}^p$ is the output, $v \in \mathbb{R}^t$ is exogenous disturbance vector, $h_1 > 0, h_1 \in \mathbb{Z}$ is control delay and $h_2 > 0, h_2 \in \mathbb{Z}$ is measurement delay, A, B_1, C_1, D are constant matrices of appropriate dimensions. Assume that the triple (A, B_1, C_1) is controllable-observable completely. The disturbance input v is generated by the linear exosystem

$$w(k+1) = Gw(k), \quad v(k) = Fw(k), \tag{2}$$

where $w \in \mathbb{R}^p$ is state vector, whose initial condition is not known, (G, F) is observable. We present the transformation:

$$\begin{aligned} &z(k) = x(k) + \sum_{i=k-h_1}^{k-1} A^{k-i-1} Bu(i), \\ &\bar{y}(k) = y(k) + C\left(\sum_{i=k-h_1}^{k-1} A^{k-i-1} Bu(i) + \sum_{l=k-h_2}^{k-1} A^{k-1-l} Dv(l) \right), \end{aligned} \tag{3}$$

System (1) is transformed into the following system without delays:

$$\begin{aligned} &z(k+1) = Az(k) + Bu(k) + Dv(k), \\ &\bar{y}(k) = Cz(k), \\ &z(0) = x(0), \\ &y(k) = \bar{y}(k) - \bar{C}\left(\sum_{i=k-h_1}^{k-1} A^{k-i-1} Bu(i) + \sum_{l=k-h_2}^{k-1} A^{k-1-l} Dv(l) \right), \end{aligned} \tag{4}$$

where

$$h = h_1 + h_2, B = A^{-h_1} B_1, C = C_1 A^{-h_2} \tag{5}$$

We reformulate the disturbance rejection problem to the optimal regulation problem as that to find the dynamic compensating controller

$$\xi(k+1)=\Upsilon\xi(k)+N\bar{y}(k),$$
$$u^*(k)=K_i\xi(k)+K_s z(k)=K_i\xi(k)+K_s\left(x(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right) \quad \mathbf{(6)}$$

and make the following hold:

(i) When $v=0$, the closed-loop system

$$\begin{bmatrix} z(k+1) \\ \xi(k+1) \end{bmatrix}=\begin{bmatrix} A+BK_s & BK_i \\ N\bar{C} & \Upsilon \end{bmatrix}\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix} \quad \mathbf{(7)}$$

is asymptotically stable.

(ii)The optimal control law minimizes the average quadratic performance index

$$J=\lim_{N\to\infty}\frac{1}{N}\sum_{k=0}^{N}\left(\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix}^T Q\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix}+u^T(k)Ru(k)\right) \quad \mathbf{(8)}$$

where Q is a positive semi-definite matrix, R is a positive definite matrix, (Υ, N) is controllable. With respect to quadratic performance index (8), Q is decomposed into $Q=C^{\mathrm{T}}KC$, where $K=K^{\mathrm{T}}\in\mathbb{R}^{r\times r}$ is positive definite.

Internal model (6) has the same dynamic characteristics with the disturbances exosystem, which guarantees the system robust, and the stabilizer $u_s(k)=K_s z(k)$ in (6) is to stabilize the closed-loop system and to satisfy the dynamic characteristics. This optimal regulator design process is subject to the following assumptions:

Assumption (i) quadratic performance index $m\geq p$; (ii) To all the eigenvalues λ_i $(i=1,\cdots,n)$ of matrix A, it follows

$$\operatorname{rank}\begin{bmatrix} \lambda_i I-A & B \\ \bar{C} & 0 \end{bmatrix}=n+p\ . \quad \mathbf{(9)}$$

DESIGN OF THE OPTIMAL REGULATOR

The argumented system combined with the internal model compensator and the stabilization controller described as following

$$\begin{bmatrix} z(k+1) \\ \xi(k+1) \end{bmatrix}=\begin{bmatrix} A & 0 \\ NC & \Upsilon \end{bmatrix}\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix}+\begin{bmatrix} B \\ 0 \end{bmatrix}u(k)+\begin{bmatrix} D \\ 0 \end{bmatrix}v(k),$$
$$\bar{y}(k)=\begin{bmatrix} C & 0 \end{bmatrix}\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix}. \quad \mathbf{(10)}$$

Define

$$\tilde{A}=\begin{bmatrix} A & 0 \\ NC & \Upsilon \end{bmatrix},\quad \tilde{B}=\begin{bmatrix} B \\ 0 \end{bmatrix},\quad \tilde{C}=\begin{bmatrix} C & 0 \end{bmatrix},\quad \tilde{D}=\begin{bmatrix} D \\ 0 \end{bmatrix},\quad Z(k)=\begin{bmatrix} z(k) \\ \xi(k) \end{bmatrix} \quad \mathbf{(11)}$$

Then (11) is written as

$$Z(k+1)=\tilde{A}Z(k)+\tilde{B}u(k)+\tilde{D}v(k),$$
$$\bar{y}(k)=\tilde{C}Z(k). \quad \mathbf{(12)}$$

Under the Assumption 2, the pair $(\tilde{A},\tilde{B})$ can be proved controllable. For prove the pair $(\tilde{A},\tilde{C})$ is observerable, we propose the following lemma.

Lemma 1. If the pair (A, C) is observerable such that the pair $(\tilde{A},\tilde{C})$ is observerable.

Theorem 1. Suppose assumptions hold, then the disturbance rejection problem for time-delay system (1) and exosystem (2) with the dynamic compensating controller (6) is solvable by the optimal control law

$$u^*(k) = -S^{-1}\tilde{B}^T\left\{P\begin{bmatrix} A\left(x(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right) \\ NC\left(x(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right)+\Upsilon\xi(k)\end{bmatrix}+P\begin{bmatrix} D \\ 0\end{bmatrix}Fw(k)+\bar{P}Gw(k)\right\}, \quad \textbf{(13)}$$

where $S = R+\tilde{B}^{\mathrm{T}}P\tilde{B}$, the positive definite matrix P is the unique solutions of the Riccati matrix equation

$$\tilde{A}^{\mathrm{T}}(I-P\tilde{B}S^{-1}\tilde{B}^{\mathrm{T}})P\tilde{A}+Q=P \quad \textbf{(14)}$$

where $\tilde{A}=\begin{bmatrix} A & 0 \\ NC & \Upsilon\end{bmatrix}$, $\tilde{B}=\begin{bmatrix} B \\ 0\end{bmatrix}$,

the matrix $\bar{P}$ is the unique solutions of the Stein matrix equation

$$\tilde{A}^{\mathrm{T}}(I-P\tilde{B}S^{-1}\tilde{B}^{\mathrm{T}})\bar{P}G-\bar{P}=-\tilde{A}^{\mathrm{T}}(I-P\tilde{B}S^{-1}\tilde{B}^{\mathrm{T}})P\tilde{D}F \quad \textbf{(15)}$$

where $\tilde{D}=\begin{bmatrix} D \\ 0\end{bmatrix}$

Proof. Disturbance rejection problem (1) to the optimal regulation problem with respect to the quadratic cost functional (8) leads to the two-point boundary value problem

$$\begin{bmatrix} Z(k+1) \\ \lambda(k)\end{bmatrix}=\begin{bmatrix} \tilde{A} & -\tilde{B}R^{-1}\tilde{B}^{\mathrm{T}} \\ Q & \tilde{A}^{\mathrm{T}}\end{bmatrix}\begin{bmatrix} Z(k) \\ \lambda(k+1)\end{bmatrix}+\begin{bmatrix} \tilde{D} \\ 0\end{bmatrix}v(k) \quad \textbf{(16)}$$
$$\begin{bmatrix} Z(0) \\ \lambda(\infty)\end{bmatrix}=\begin{bmatrix} x(0) \\ 0\end{bmatrix}.$$

and the optimal control law is

$$u^*(k) = -R^{-1}\tilde{B}^{\mathrm{T}}\lambda(k+1) \quad \textbf{(17)}$$

Let

$$\lambda(k)=Pz(k)+\bar{P}w(k)\,. \quad \textbf{(18)}$$

We obtain the optimal control law as

$$u^*(k) = -S^{-1}\tilde{B}^T\left\{P\begin{bmatrix} A\left(x(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right) \\ NC\left(x(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right)+\Upsilon\xi(k)\end{bmatrix}+P\begin{bmatrix} D \\ 0\end{bmatrix}Fw(k)+PGw(k)\right\} \quad \textbf{(19)}$$

where $S = R+\tilde{B}^{\mathrm{T}}P\tilde{B}$, and we obtain

$$\lambda(k)=[Q+\tilde{A}^T(I-P\tilde{B}S^{-1}\tilde{B}^{\mathrm{T}})P\tilde{A}]z(k)+\tilde{A}^T(I-P\tilde{B}S^{-1}\tilde{B}^{\mathrm{T}})(P\tilde{D}F+\bar{P}G)w(k) \quad \textbf{(20)}$$

Compared with (18) and (20), we obtained Riccati matrix equation (14) and Stein matrix equation (15). This ends the proof of Theorem 1.

DESIGN OF THE OBSERVER-BASED REGULATOR

In the above design, we suppose every variable of state vector $x(k)$ is measurable. However, in general, there are some unmeasurable variables of state, and we design a reduced-order observer as the stabilizer to estimate the unmeasurable state $x(k)$ from the measured output $y(k)$. First, choose $L \in R^{(n-t)\times t}$ which leads $T^{\mathrm{T}} = [C^{\mathrm{T}}\ L^{\mathrm{T}}]$ nonsingular, and notes that $S = T^{-1} = [S_1 \vdots S_2]$. Then

$$\hat{C} = CT^{-1} = [I_t \ \ 0],$$

where I_t is tth identical matrix. Let $\bar{z}(k) = \Gamma z(k)$ and

$$\begin{aligned}\bar{z}(k+1) &= \begin{bmatrix}\bar{z}_1(k+1)\\ \bar{z}_2(k+1)\end{bmatrix} = \bar{A}\bar{z}(k) + \bar{B}u(k) + \bar{D}v(k)\\ &= \begin{bmatrix}\bar{A}_{11} & \bar{A}_{12}\\ \bar{A}_{21} & \bar{A}_{22}\end{bmatrix}\begin{bmatrix}\bar{z}_1(k)\\ \bar{z}_2(k)\end{bmatrix} + \begin{bmatrix}\hat{B}_1\\ \hat{B}_2\end{bmatrix}u(k) + \begin{bmatrix}\bar{D}_1\\ \bar{D}_2\end{bmatrix}v(k),\\ \bar{y}(t) &= \bar{z}_1(k),\end{aligned} \tag{21}$$

in which $\bar{z}_i, \bar{A}_{ij}, \bar{B}_i, \bar{D}_i\ (i, j = 1, 2)$ are real constant matrices of appropriate dimensions. The reduced-observer is constructed by

$$\begin{aligned}\varphi(k+1) &= \left(\bar{A}_{22} - \bar{L}\bar{A}_{12}\right)\varphi(k) + \left[\left(\bar{A}_{22} - \bar{L}\bar{A}_{12}\right)\bar{L} + \right.\\ &\quad \left.\left(\bar{A}_{21} - \bar{L}\bar{A}_{11}\right)\right]\bar{y}(k) + \left(\bar{B}_2 - \bar{L}\bar{B}_1\right)u(k)\\ &\quad + \left(\bar{D}_2 - \bar{L}\bar{D}_1\right)v(k),\\ \hat{z}(k) &= S_2\varphi(k) + \left(S_1 + S_2\bar{L}\right)\bar{y}(k),\end{aligned} \tag{22}$$

with

$$\begin{aligned}\hat{x}(k) &= \hat{z}(k) - \left(x(k) + \sum_{i=k-h_1}^{k-1} A^{k-i-1}Bu(i)\right),\\ y(k) &= \bar{y}(k) - C\left(\sum_{i=k-h_1}^{k-1} A^{k-i-1}Bu(i)\right.\\ &\quad \left. + \sum_{l=k-h_2}^{k-1} A^{k-1-l}Dv(l)\right)\end{aligned} \tag{23}$$

Further derivation yields the reduced-order observer

$$\begin{aligned}\varphi(k+1) &= \left(\bar{A}_{22} - \bar{L}\bar{A}_{12}\right)\varphi(k) + \left[\left(\bar{A}_{22} - \bar{L}\bar{A}_{12}\right)\bar{L}\right.\\ &\quad \left. + \left(\bar{A}_{21} - \bar{L}\bar{A}_{11}\right)\right]\bar{y}(k) + \left[\left(\bar{A}_{22} - \bar{L}\bar{A}_{12}\right)\bar{L} + \left(\bar{A}_{21} - \bar{L}\bar{A}_{11}\right)\right]\\ &\quad \times C\left[\sum_{i=k-h_1}^{k-1} A^{k-i-1}Bu(i) + \sum_{l=k-h_2}^{k-1} A^{k-1-l}Dv(l)\right]\\ &\quad + \left(\hat{B}_2 - \bar{L}\hat{B}_1\right)u(k) + \left(\bar{D}_2 - \bar{L}\bar{D}_1\right)v(k),\\ \hat{x}(k) &= S_2\varphi(k) + \left(S_1 + S_2\bar{L}\right)\bar{y}(k) + \left[\left(S_1 + S_2\bar{L}\right)C - I\right]\\ &\quad \times\left[\sum_{i=k-h_1}^{k-1} A^{k-i-1}Bu(i) + \sum_{l=k-h_2}^{k-1} A^{k-1-l}Dv(l)\right]\end{aligned} \tag{24}$$

where $\hat{x}(k)$ is the estimate of $x(k)$, φ is the observer state, $\bar{L}$ is the observer gain and the pair $(\bar{A}_{22}, \bar{A}_{12})$ is observable for Assumption 1. By choosing the observer gain $\bar{L}$ and using the pole placement, we get the most perfect estimation state $\hat{x}(k)$ with $\lim_{t\to\infty}\hat{x}(k) = x(k)$. Submitting the estimate state $\hat{x}(k)$ to the state $x(k)$ of controller (13), we obtain the dynamic optimal regulation controller which is summarized in the following:

Corollary 1. Suppose assumptions hold, then the dynamic disturbance rejection problem for time-delay system (1) and exosystem (2) is solvable by the dynamic control law

$$\begin{aligned}\varphi(k+1) &= \left(\bar{A}_{22}-\bar{L}\bar{A}_{12}\right)\varphi(k)+\left[\left(\bar{A}_{22}-\bar{L}\bar{A}_{12}\right)\bar{L}+\left(\bar{A}_{21}-\bar{L}\bar{A}_{11}\right)\right]\bar{y}(k)+\left[\left(\bar{A}_{22}-\bar{L}\bar{A}_{12}\right)\bar{L}+\left(\bar{A}_{21}-\bar{L}\bar{A}_{11}\right)\right]\\ &\quad\times C\left(\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)+\sum_{l=k-h_2}^{k-1}A^{k-1-l}Dv(l)\right)+\left(\hat{B}_2-\bar{L}\hat{B}_1\right)u(k)+\left(\bar{D}_2-\bar{L}\bar{D}_1\right)v(k)\\ \hat{x}(k) &= S_2\varphi(k)+\left(S_1+S_2\bar{L}\right)\bar{y}(k)+\left[\left(S_1+S_2\bar{L}\right)C-I\right]\left(\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)+\sum_{l=k-h_2}^{k-1}A^{k-1-l}Dv(l)\right)\\ u^*(k) &= -S^{-1}B^T\left\{P\begin{bmatrix}A\left(\hat{x}(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right)\\ NC\left(\hat{x}(k)+\sum_{i=k-h_1}^{k-1}A^{k-i-1}Bu(i)\right)+\Upsilon\xi(k)\end{bmatrix}+P\begin{bmatrix}D\\0\end{bmatrix}Fw(k)+\bar{P}Gw(k)\right\}\end{aligned} \quad \textbf{(25)}$$

where the positive definite matrix P is the unique solutions of the Riccati matrix equation (14), the matrix $\bar{P}$ is the unique solutions of the Stein matrix equation (15) respectively.

Consider the discrete-time linear system with delayed control and measurement described by

$$\begin{aligned}&A=\begin{bmatrix}1 & 0.05 & 0.0012\\ 0.0012 & 0.9976 & 0.0475\\ 0.0475 & -0.0939 & 0.9025\end{bmatrix},\quad B_1=\begin{bmatrix}4.4329\times10^{-6}\\ 4.4107\times10^{-6}\\ 0.0291\end{bmatrix}, C_1=[1\quad 0\quad 0],\\ &D=\begin{bmatrix}0.05 & 0\\ 0 & 0.0012\\ 0.0012 & 0.0475\end{bmatrix},\quad x(0)=\begin{bmatrix}0 & 0 & 0\end{bmatrix}^{\mathrm{T}}.\end{aligned} \quad \textbf{(27)}$$

and the quadratic performance index is chosen as (9) with

$$\begin{aligned}&Q_1=Q_2=\begin{bmatrix}0.9971 & -0.1967 & 0.0228\\ -0.1967 & 0.0388 & -0.0045\\ 0.0228 & -0.0045 & 0.0005\end{bmatrix},\\ &Q_{12}=-Q_1,\ K=I,\ R=0.0001\end{aligned} \quad \textbf{(28)}$$

The exosystem generates the disturbances described by

$$\begin{aligned}&G=\begin{bmatrix}0.9987 & 0.05 & -0.05\\ -0.0499 & 0.9938 & 0.0001\\ 0.0062 & -0.0497 & 1\end{bmatrix},\\ &F=\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\end{bmatrix},\qquad w(0)=[1\quad 0\quad 0]^{\mathrm{T}},\end{aligned} \quad \textbf{(29)}$$

We construct the internal model as

$$\xi(k+1)=\begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ -1 & -1 & -1\end{bmatrix}\xi(k)+\begin{bmatrix}0\\0\\1\end{bmatrix}\bar{y}(k), \quad \textbf{(30)}$$

We simulate the performance of the designed controller taking the control delays $h_1=0$, $h_1=30$ and $h_1=60$, simulation curves of states $x_1(k)$, $x_2(k)$, $x_3(k)$ and the optimal control $u^*(k)$ as follows:

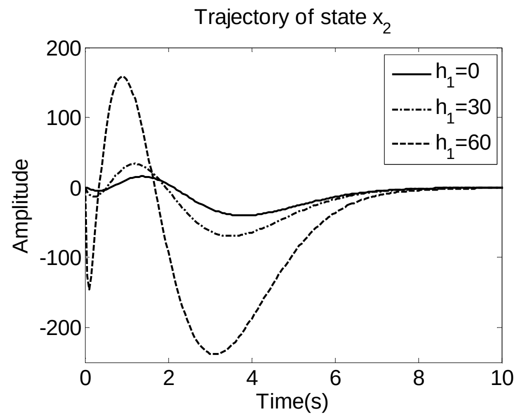

Figure 1 : Simulation curves of state $x_1(k)$

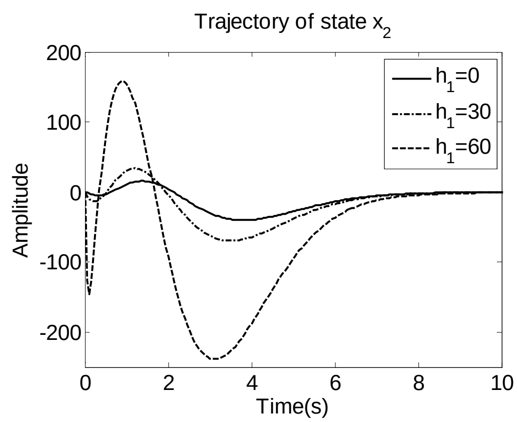

Figure 2 : Simulation curves of state $x_2(k)$

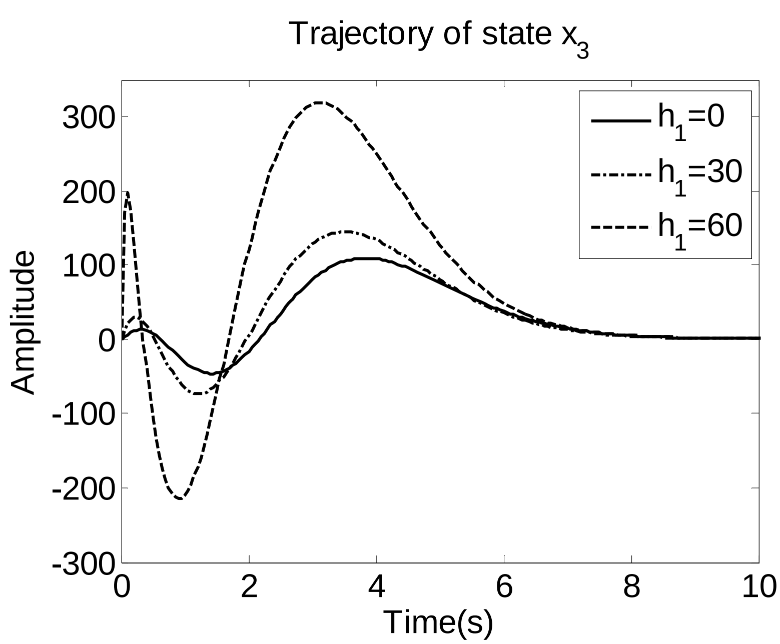

Figure 3 : Simulation curves of state $x_3(k)$

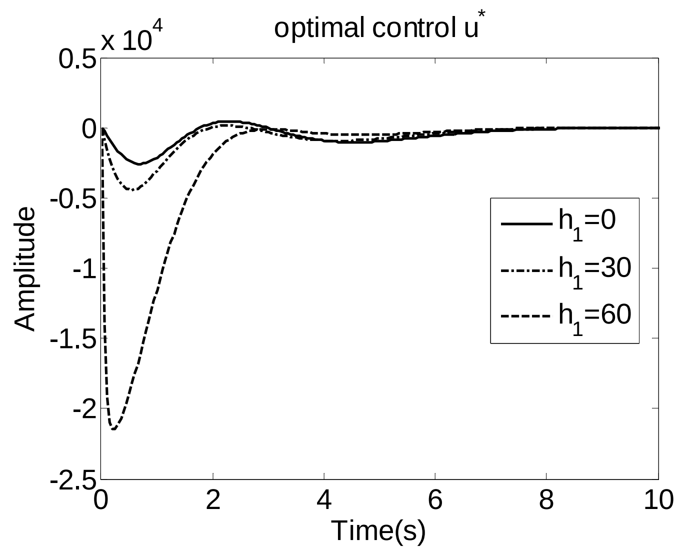

Figure 4 : Simulation curves of optimal control $u^*(k)$

From the above simulation results, we can get that the quality of control is gradually worse when the delay is gradually bigger, the optimal control law designed of via internal model with delayed control and measurement is effective.

CONCLUSIONS

This paper presents an approach of disturbance rejection based on an internal model for discrete-time linear systems. The control law is obtained by model transformation and solving the Riccati equation. The simulation results show clearly that it is effective to compensate the delays and suppress the disturbance. And the observer-based dynamic regulator guarantees the unmeasurable states estimated and the state feedback control physically realizable.

ACKNOWLEDGEMENT

This work is supported by National Natural Science Foundation of China under Grant 41276085, and Innovation Project Foundation of Qingdao University under Grant 201242806051 and 201242806039.

REFERENCES

[1] H.N.Wu; Delay-dependent H_∞ fuzzy observer-based control for discrete-time nonlinear systems with state delay, *Fuzzy Sets and Systems*, **1599(20)**, 2696-2712 **(2008)**.

[2] A.Sinha; Optimal damped vibration absorber for narrow band random excitations: A mixed H_2/H_∞ optimization, Probabilistic Engineering Mechanics, **24(2)**, 251-254 **(2009)**.

[3] H.Deng, Z.Xu, H.X.Li; A novel neural internal model control for multi-input multi-output nonlinear discrete-time processes, Journal of Process Control, **19(8)**, 1392-1400 **(2009)**.

[4] X.Liu, Y.Zhou, L.Cong, F.Ding; High-purity control of internal thermally coupled distillation columns based on nonlinear wave model, Journal of Process Control, **21(6)**, 920-926 **(2011)**.

[5] B.D.O.Anderson, A.Dehghani; Challenges of adaptive control–past, permanent and future, Annual Reviews in Control, **32(2)**, 123-135 **(2008)**.

[6] T.Hayakawa, H.Ishii, K.Tsumura; Adaptive quantized control for nonlinear uncertain systems, Systems & Control Letters, **58(9)**, 625-632 **(2009)**.

[7] M.A.Brdys, M.Grochowski, T.Gminski, K.Konarczak, M.Drewa; Hierarchical predictive control of integrated wastewater treatment systems, Control Engineering Practice, **16(6)**, 751-767 **(2008)**.

[8] K.Graichen, M.Treuer, M.Zeitz; Swing-up of the double pendulum on a cart by feedforward and feedback control with experimental validation, Automatica, **43(1)**, 63-71 **(2007)**.

[9] L.V.Hien, V.N.Phat; Exponential stabilization for a class of hybrid systems with mixed delays in state and control, Nonlinear Analysis: Hybrid Systems, **3(3)**, 259-265 **(2009)**.

[10] S.Qu, Y.Wang; Robust control of uncertain time delay system: a novel sliding mode control design via LMI, Journal of Systems Engineering and Electronics, **17(3)**, 624-628 **(2006)**.