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Robust l_2-l_∞ Filter Design for Uncertain Discrete-Time State-Delayed Systems[1)]

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Abstract　This paper is concerned with the problem of full-order robust l_2-l_∞ filtering for uncertain discrete-time systems with a single delay in the state. The uncertain parameters are supposed to belong to a given convex bounded polyhedral domain, entering into all the matrices of the system state-space model. Sufficient conditions are established in terms of linear matrix inequalities for the existence of filters guaranteeing a prescribed energy-to-peak disturbance attenuation level for all possible uncertainties and time delays. And the admissible filter can be found by solving a convex optimization problem with global convergence assured. A numerical example demonstrates the validity of the proposed filter design procedure.

Key words　Robust filtering, linear matrix inequality, energy-to-peak performance

1 Introduction

Time delay exists commonly in dynamic systems due to measurement, transmission and transport lags, computational delays, or unmodeled inertias of system components, which has been generally regarded as a main source of instability and poor performance. Therefore, in recent years considerable attention has been devoted to the analyses and syntheses for time-delayed systems. In contrast with the great number of results obtained for controller designs, the filtering problem receives relatively less attention and still leaves much to be investigated, especially for systems with both parametric uncertainties and time delays. For discrete-time state-delayed systems, both Kalman filters[1,2] and H_∞ filters[3,4] have been designed. In this paper, another important performance (l_2-l_∞) is introduced, upon which the corresponding energy-to-peak filtering problem is considered.

The l_2-l_∞ performance first appeared in [5], following which considered the controller design upon such a performance index[6]. Then[7,8] introduced it into the filtering problem, with both full-order and reduced-order filters designed for precisely known systems. Very recently, [9,10] further extended these filtering results to systems with parameter uncertainties. However, to the best of the authors' knowledge, the l_2-l_∞ filtering problem has not been addressed for time-delayed systems, whether with or without parameter uncertainties.

The main objective of l_2-l_∞ filtering problem is to design filters guaranteeing a prescribed l_2-l_∞ disturbance attenuation level for the filtering error system with respect to all energy bounded disturbance signals. We consider a class of discrete-time systems with a single delay in the state and parameter uncertainties residing in a polytope. Sufficient conditions for the existence of full-order robust l_2-l_∞ filters are established in terms of linear matrix inequalities (LMIs) and the filter design problem is finally cast into a convex optimization problem, which can be easily solved via effective interior point algorithms.

2 Problem formulation

Consider the following uncertain discrete-time state-delayed system:

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$$x(k+1)=A_0x(k)+A_dx(k-d)+B\omega(k),\quad x(k)=\mathbf{0},\ \forall k\leqslant 0 \tag{1}$$
$$y(k)=Cx(k)+D\omega(k),\quad z(k)=Hx(k)$$

where $x(k)\in R^n$ is the state vector, $y(k)\in R^m$ is the measurement output, $z(k)\in R^p$ is the signal to be estimated, $\omega(k)\in R^q$ is the disturbance input, and $d\geqslant 0$ is a known constant delay. Suppose the system matrices are uncertain but belong to a given polytope

$$M\doteq[A_0,A_d,B,C,D,H]\in\Re \tag{2}$$
$$\Re\doteq\left\{[A_0(\lambda),A_d(\lambda),B(\lambda),C(\lambda),D(\lambda),H(\lambda)]=\sum_{i=1}^{s}\lambda_i[A_{0i},A_{di},B_i,C_i,D_i,H_i];\ \sum_{i=1}^{s}\lambda_i=1,\lambda_i\geqslant 0\right\}$$

Construct the following full-order filters

$$x_F(k+1)=A_Fx_F(k)+B_Fy(k),\quad x_F(0)=\mathbf{0} \tag{3}$$
$$z_F(k)=C_Fx_F(k)$$

Then the filtering error system can be described by

$$\xi(k+1)=\bar{A}_0\xi(k)+\bar{A}_dK\xi(k-d)+\bar{B}\omega(k),\quad \xi(k)=\mathbf{0},\ \forall k\leqslant 0 \tag{4}$$
$$e(k)=\bar{C}\xi(k)$$

where $\xi(k)=\{x^{\mathrm T}(k),x_F^{\mathrm T}(k)\}^{\mathrm T}$, $e(k)=z(k)-z_F(k)$

$$\bar{A}_0=\begin{bmatrix}A_0 & 0\\ B_FC & A_F\end{bmatrix},\quad \bar{A}_d=\begin{bmatrix}A_d\\ 0\end{bmatrix},\quad \bar{B}=\begin{bmatrix}B\\ B_FD\end{bmatrix},\quad \bar{C}=[H\ \ -C_F],\ K=[I\ \ 0] \tag{5}$$

and I denotes an identity matrix of appropriate dimensions.

Our purpose is to design filters of form (3) for system (1), which guarantee: a) the filtering error system (4) is asymptotically stable when $\omega\equiv 0$; b) the l_2-l_∞ gain of the filtering error system (4) is below a prescribed positive constant γ, i. e., under zero initial conditions

$$\|e\|_\infty^2\leqslant\gamma^2\|\omega\|_2^2,\quad \forall\omega\in l_2[0,\infty) \tag{6}$$

where $\|\omega\|_2^2=\sum_{k=0}^{\infty}\omega^{\mathrm T}(k)\omega(k)$, and $\|e\|_\infty^2=\sup_k\{e^{\mathrm T}(k)e(k)\}$. Filters satisfying the above two conditions are called l_2-l_∞ filters. In the following, $[\bar{A}_{0i},\bar{A}_{di},\bar{B}_i,\bar{C}_i]$ denotes matrices $[A_{0i},A_{di},B_i,C_i,D_i,H_i]$ evaluated at each vertex of the polytope.

3 l_2-l_∞ filtering analysis

To facilitate the presentation of our results, first consider the system with exact data, i. e., $M\in\Re$ is fixed.

Theorem 1. Consider system (1) with $M\in\Re$ fixed and let $\gamma>0$ be a given constant. Then the filtering error system (4) is asymptotically stable with (6) guaranteed if there exist matrices $P\in R^{2n\times 2n}$ and $Q\in R^{n\times n}$ satisfying

$$\begin{bmatrix}-P & P\bar{A}_0 & P\bar{A}_d & P\bar{B}\\ * & -P+K^{\mathrm T}QK & 0 & 0\\ * & * & -Q & 0\\ * & * & * & -I\end{bmatrix}<0,\quad \begin{bmatrix}P & \bar{C}^{\mathrm T}\\ * & \gamma^2 I\end{bmatrix}>0 \tag{7),(8}$$

where $*$ denotes the entries induced by symmetry.

Proof. First, the asymptotical stability of the filtering error system (4) with $\omega\equiv\mathbf{0}$ is established. Choose the following Lyapunov functional candidate:

$$V(\xi(k))\doteq\xi^{\mathrm T}(k)P\xi(k)+\sum_{s=k-d}^{k-1}\xi^{\mathrm T}(s)K^{\mathrm T}QK\xi(s) \tag{9}$$

where $P\in R^{2n\times 2n}$ and $Q\in R^{n\times n}$ are positive definite matrices to be determined. Then along the trajectory of system (4), we have

$$\Delta V(\xi(k))\doteq V(\xi(k+1))-V(\xi(k))=$$

$$\xi^{\mathrm{T}}(k)[\bar{A}_0^{\mathrm{T}}P\bar{A}_0 - P + K^{\mathrm{T}}QK]\xi(k) + 2\xi^{\mathrm{T}}(k)\bar{A}_0^{\mathrm{T}}P\bar{A}_dK\xi(k-d) +$$
$$\xi^{\mathrm{T}}(k-d)K^{\mathrm{T}}[\bar{A}_d^{\mathrm{T}}P\bar{A}_d - Q]K\xi(k-d) =$$
$$\eta^{\mathrm{T}}(k)\Xi\eta(k)$$

where

$$\eta(k) \doteq \{\xi^{\mathrm{T}}(k) \quad \xi^{\mathrm{T}}(k-d)K^{\mathrm{T}}\}^{\mathrm{T}}, \quad \Xi \doteq \begin{bmatrix} \bar{A}_0^{\mathrm{T}}P\bar{A}_0 - P + K^{\mathrm{T}}QK & \bar{A}_0^{\mathrm{T}}P\bar{A}_d \\ * & \bar{A}_d^{\mathrm{T}}P\bar{A}_d - Q \end{bmatrix}$$

By Schur complement, (7) guarantees $\Xi<0$. Therefore, from the standard Lyapunov stability theory we can conclude that the filtering error system (4) is asymptotically stable. To establish the l_2-l_∞ performance, consider the following index:

$$J \doteq V(\xi(k)) - \sum_{s=0}^{k-1}\omega^{\mathrm{T}}(s)\omega(s) \tag{10}$$

Under zero initial condition $V(\xi(k))|_{k=0}=0$. Then for any nonzero $\omega\in l_2[0,\infty)$ and $k>0$, we have

$$J = V(\xi(k)) - V(\xi(k))|_{k=0} - \sum_{s=0}^{k-1}\omega^{\mathrm{T}}(s)\omega(s) = \sum_{s=0}^{k-1}[\Delta V(\xi(s)) - \omega^{\mathrm{T}}(s)\omega(s)]$$
$$= \sum_{s=0}^{k-1}\bar{\eta}^{\mathrm{T}}(s)\Pi\bar{\eta}(s)$$

where

$$\bar{\eta}(s) \doteq \{\xi^{\mathrm{T}}(s) \quad \xi^{\mathrm{T}}(s-d)K^{\mathrm{T}} \quad \omega^{\mathrm{T}}(s)\}^{\mathrm{T}},$$
$$\Pi \doteq \begin{bmatrix} \bar{A}_0^{\mathrm{T}}P\bar{A}_0 - P + K^{\mathrm{T}}QK & \bar{A}_0^{\mathrm{T}}P\bar{A}_d & \bar{A}_0^{\mathrm{T}}P\bar{B} \\ * & \bar{A}_d^{\mathrm{T}}P\bar{A}_d - Q & \bar{A}_d^{\mathrm{T}}P\bar{B} \\ * & * & \bar{B}^{\mathrm{T}}P\bar{B} - I \end{bmatrix}$$

By Schur complement, (7) guarantees $\Pi<0$, which implies $J\leqslant 0$. Then from (9) and (10) we have

$$\xi^{\mathrm{T}}(k)P\xi(k) \leqslant V(\xi(k)) \leqslant \sum_{s=0}^{k-1}\omega^{\mathrm{T}}(s)\omega(s) \tag{11}$$

On the other hand, by a Schur complement operation (8) is equivalent to

$$\bar{C}^{\mathrm{T}}\bar{C} < \gamma^2 P \tag{12}$$

Now we can conclude from (4), (11) and (12) that for any $k>0$ there exists

$$e^{\mathrm{T}}(k)e(k) = \xi^{\mathrm{T}}(k)\bar{C}^{\mathrm{T}}\bar{C}\xi(k) < \gamma^2\xi^{\mathrm{T}}(k)P\xi(k) \leqslant \gamma^2\sum_{s=0}^{k-1}\omega^{\mathrm{T}}(s)\omega(s) \leqslant \gamma^2\sum_{s=0}^{\infty}\omega^{\mathrm{T}}(s)\omega(s)$$

Taking the supremum over $k>0$ yields (6). And this concludes the proof. □

Extend Theorem 1 to uncertain cases, and we obtain the following corollary.

Corollary 1. Consider system (1) with $M\in\mathfrak{R}$ representing an uncertain system and let $\gamma>0$ be a given constant. Then the filtering error system (4) is robustly stable with (6) guaranteed if there exist matrices $P\in R^{2n\times 2n}$ and $Q\in R^{n\times n}$ satisfying

$$\begin{bmatrix} -P & P\bar{A}_{0i} & P\bar{A}_{di} & P\bar{B}_i \\ * & -P+K^{\mathrm{T}}QK & 0 & 0 \\ * & * & -Q & 0 \\ * & * & * & -I \end{bmatrix} < 0, \quad \begin{bmatrix} P & \bar{C}_i^{\mathrm{T}} \\ * & \gamma^2 I \end{bmatrix} > 0, \quad \forall i = 1,\cdots,s$$

(13),(14)

4 l_2-l_∞ filtering synthesis

Theorem 2. Consider system (1) with $M\in\mathfrak{R}$ fixed and let $\gamma>0$ be a given constant. Then an admissible l_2-l_∞ filter exists if there exist matrices $R\in R^{n\times n}$, $F\in R^{n\times n}$, $Q\in R^{n\times n}$, $\bar{A}_F\in R^{n\times n}$, $\bar{B}_F\in R^{n\times m}$, $\bar{C}_F\in R^{p\times n}$ satisfying

$$\begin{bmatrix} -R & -F & RA_0+\bar{B}_FC & RA_0+\bar{B}_FC+\bar{A}_F & RA_d & RB+\bar{B}_FD \\ * & -F & FA_0 & FA_0 & FA_d & FB \\ * & * & -R+Q & -F+Q & 0 & 0 \\ * & * & * & -F+Q & 0 & 0 \\ * & * & * & * & -Q & 0 \\ * & * & * & * & * & -I \end{bmatrix}<0, \quad \begin{bmatrix} R & F & H^T \\ * & F & H^T-\bar{C}_F^T \\ * & * & \gamma^2 I \end{bmatrix}>0 \tag{15),(16}$$

Furthermore, under the above conditions, an admissible l_2-l_∞ filter can be given by:

$$A_F=(F-R)^{-1}\bar{A}_F, \quad B_F=(F-R)^{-1}\bar{B}_F, \quad C_F=\bar{C}_F \tag{17}$$

Proof. Since (16) implies $\begin{bmatrix} R & F \\ * & F\end{bmatrix}>0$, $I-RF^{-1}$ is nonsingular and $F-FR^{-1}F>0$. Therefore, we can always find square and non-singular matrices M and N satisfying $I-RF^{-1}=MN^T$. Now introduce the following matrices

$$J_P \doteq \begin{bmatrix} R & I \\ M^T & 0 \end{bmatrix} \quad J_S \doteq \begin{bmatrix} I & F^{-1} \\ 0 & N^T \end{bmatrix} \tag{18}$$

$$P \doteq J_P J_S^{-1} = \begin{bmatrix} P_{11} & P_{12} \\ P_{12}^T & P_{22} \end{bmatrix} = \begin{bmatrix} R & M \\ M^T & -M^TF^{-1}N^{-T} \end{bmatrix} \tag{19}$$

With $R>0, F>0, F-FR^{-1}F>0, MN^T=I-RF^{-1}$ and by means of matrix inverse lemma, we can conclude that $P_{11}>0$ and $P_{22}-P_{12}^TP_{11}^{-1}P_{12}=M^TR^{-1}F[F-FR^{-1}F]^{-1}FR^{-1}M>0$. Thus we have $P>0$ by the Schur complement. Performing congruence transformations to (15) by $J_1 \doteq \mathrm{diag}\{I,F^{-1},I,F^{-1},I,I\}$ and to (16) by $J_2 \doteq \mathrm{diag}\{I,F^{-1},I\}$ yields

$$\begin{bmatrix} -R & -I & RA_0+\bar{B}_FC & RA_0F^{-1}+\bar{B}_FCF^{-1}+\bar{A}_FF^{-1} & RA_d & RB+\bar{B}_FD \\ * & -F^{-1} & A_0 & A_0F^{-1} & A_d & B \\ * & * & -R+Q & -I+QF^{-1} & 0 & 0 \\ * & * & * & -F^{-1}+F^{-1}QF^{-1} & 0 & 0 \\ * & * & * & * & -Q & 0 \\ * & * & * & * & * & -I \end{bmatrix}<0 \tag{20}$$

$$\begin{bmatrix} R & I & H^T \\ * & F^{-1} & F^{-1}H^T-F^{-1}\bar{C}_F^T \\ * & * & \gamma^2 I \end{bmatrix}>0 \tag{21}$$

Define the following matrices

$$A_F \doteq M^{-1}\bar{A}_FF^{-1}N^{-T}, \quad B_F \doteq M^{-1}\bar{B}_F, \quad C_F \doteq \bar{C}_FF^{-1}N^{-T} \tag{22}$$

Since M, N, and F are all non-singular, the matrices (A_F, B_F, C_F) are uniquely defined. Then with the standard matrix manipulations, it is not difficult to show that (20) and (21) are equivalent to

$$\begin{bmatrix} -J_P^TJ_S & J_P^T\bar{A}_0J_S & J_P^T\bar{A}_d & J_P^T\bar{B} \\ * & -J_P^TJ_S+J_S^TK^TQKJ_S & 0 & 0 \\ * & * & -Q & 0 \\ * & * & * & -I \end{bmatrix}<0, \quad \begin{bmatrix} J_S^TJ_P & J_S^T\bar{C}^T \\ * & \gamma^2 I \end{bmatrix}>0 \tag{23),(24}$$

Performing congruence transformations to (23) by $J_3 \doteq \mathrm{diag}\{J_S^{-1}, J_S^{-1}, I, I\}$ and to (24) by $J_4 \doteq \mathrm{diag}\{J_S^{-1}, I\}$ and considering (19) yield (7) and (8). Then we can conclude from Theorem 1 that the filter with a state-space realization (A_F, B_F, C_F) defined in (22) guarantees that the filtering error system (4) is asymptotically stable with an l_2-l_∞ noise attenuation level γ.

From the above proof we know that the filter matrices can be calculated from (22). However, there seems to be no systematic way to determine the matrices M and N needed for the filter matrices. To deal with such a problem, first of all, let us denote the filter transfer function from $y(k)$ to $z_F(k)$ by $T_{z_F y} = C_F(zI - A_F)^{-1} B_F$. Substituting the filter matrices with (22) and considering $MN^T = I - RF^{-1}$ yield $T_{z_F y} = \bar{C}_F[zI - (F-R)^{-1}\bar{A}_F]^{-1}(F-R)^{-1}\bar{B}_F$. Therefore, an admissible filter can be constructed by (17). □

Then we have the following corollary.

Corollary 2. Consider system (1) with $M \in \Re$ representing an uncertain system and let $\gamma > 0$ be a given constant. Then an admissible robust $l_2 - l_\infty$ filter exists if there exist matrices $R \in R^{n\times n}$, $F \in R^{n\times n}$, $Q \in R^{n\times n}$, $\bar{A}_F \in R^{n\times n}$, $\bar{B}_F \in R^{n\times m}$, $\bar{C}_F \in R^{p\times n}$ satisfying

$$\begin{bmatrix} -R & -F & RA_{0i} + \bar{B}_F C_i & RA_{0i} + \bar{B}_F C_i + \bar{A}_F & RA_{di} & RB_i + \bar{B}_F D_i \\ * & -F & FA_{0i} & FA_{0i} & FA_{di} & FB_i \\ * & * & -R+Q & -F+Q & 0 & 0 \\ * & * & * & -F+Q & 0 & 0 \\ * & * & * & * & -Q & 0 \\ * & * & * & * & * & -I \end{bmatrix} < 0 \tag{25}$$

$$\begin{bmatrix} R & F & H_i^T \\ * & F & H_i^T - \bar{C}_F^T \\ * & * & \gamma^2 I \end{bmatrix} > 0, \qquad \forall i = 1, \cdots, s \tag{26}$$

Furthermore, under the above conditions, an admissible $l_2 - l_\infty$ filter can be given by (17).

Remark 1. Corollary 2 casts the robust $l_2 - l_\infty$ filtering problem for system (1) into an LMI feasibility test, and any feasible solution to (25) and (26) will yield a suitable robust filter. Note that (25) and (26) are LMIs not only over the matrix variables, bust also over the scalar γ^2. This implies that the scalar γ^2 can be included as one of the optimization variables for LMI (25) and (26) to obtain the minimum noise attenuation level. Then the optimal full-order robust $l_2 - l_\infty$ filter can be readily found by solving the following convex optimization problem:

$$\min_{R, F, Q, \bar{A}_F, \bar{B}_F, \bar{C}_F, \delta} \delta \qquad \text{subject to (25), (26) with } \delta \doteq \gamma^2 \tag{27}$$

The minimum noise attenuation level is given by $\gamma^* = \sqrt{\delta^*}$, where δ^* is the optimal value of δ, and the corresponding filter is given by (17).

5 An illustrative example

Consider the following uncertain discrete-time system:

$$x(k+1) = \begin{bmatrix} 0 & 0.3 \\ -0.2 & \rho \end{bmatrix} x(k) + \begin{bmatrix} 0 & 0 \\ 0.1 & \rho \end{bmatrix} x(k-d) + \begin{bmatrix} 0 \\ 0.4 \end{bmatrix} \omega(k) \tag{28}$$
$$y(k) = [1 \quad 0] x(k) + 0.4\omega(k), \quad z(k) = [1 \quad 2] x(k)$$

where $d \geqslant 0$ is a constant delay, and ρ represents an uncertain parameter satisfying $|\rho| \leqslant 0.2$. Assume $\omega(k)$ is an energy-bounded signal and our objective is to design a robust $l_2 - l_\infty$ filter for estimating $z(k)$. By solving the convex optimization problem (27), we can obtain the minimum noise attenuation level $\gamma^* = 0.4565$ with the associate filter matrices

$$A_F = \begin{bmatrix} 0.0001 & 0.2999 \\ -1.4848 & -0.0010 \end{bmatrix} \quad B_F = \begin{bmatrix} 0.0001 \\ 1.2514 \end{bmatrix} \quad C_F = [0.9596 \quad 1.5297] \tag{29}$$

Figure 1 shows the $l_2 - l_\infty$ disturbance attenuation level bound of the filtering error system by connecting the obtained filter (29) to (28) for the whole uncertain domain, which is evaluated by Theorem 1 in a pointwise manner. The effectiveness of the filter design is apparent.

Figure 2 presents the simulation curves of estimating signal $z(k)$ by filter (29) for the fixed system $\rho = 0$. Here we assume $\omega(k)$ to be

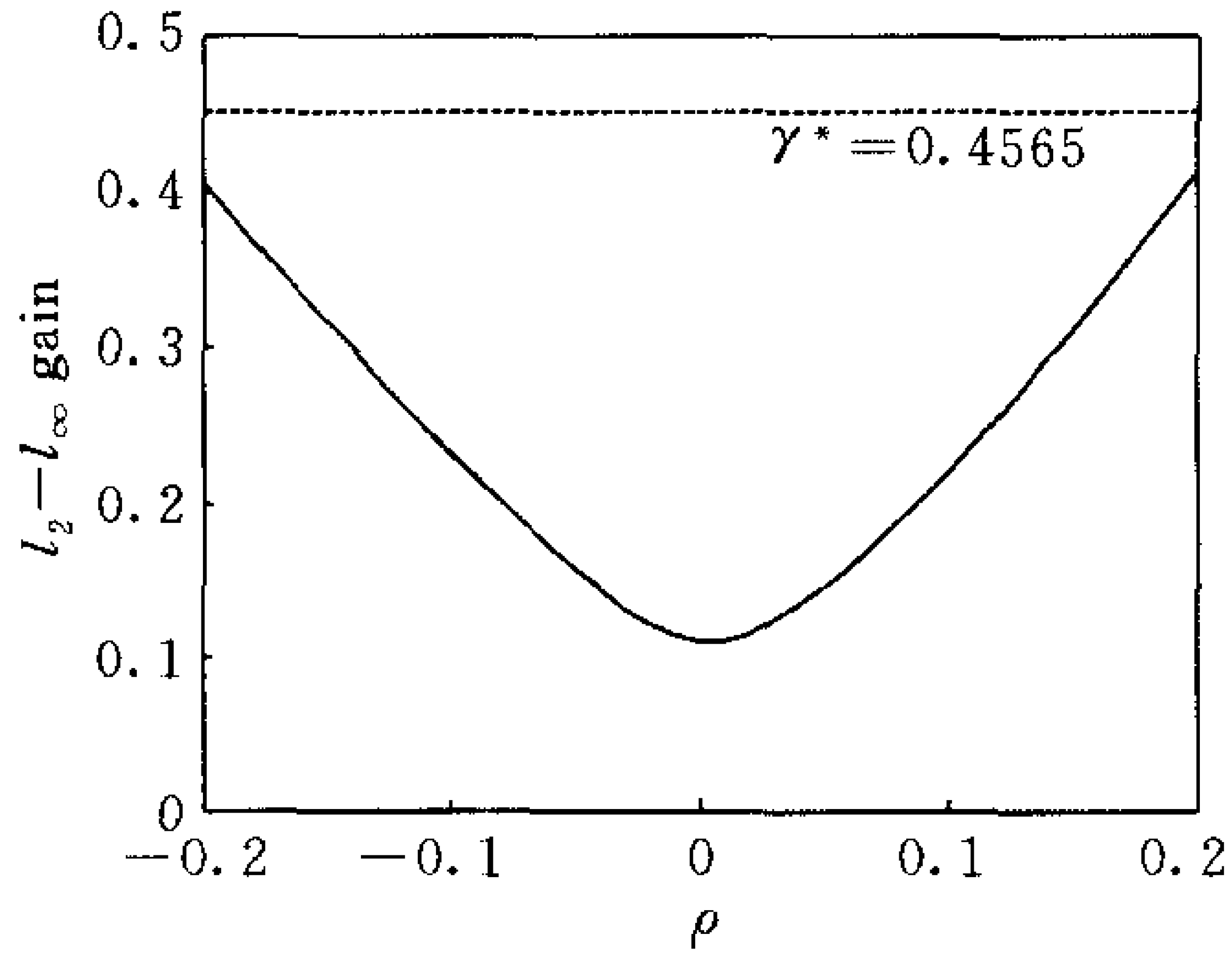

Fig. 1 Disturbance attentuation level of the filtering error system

$$\omega(k)=\begin{cases}2, & 20\leqslant k\leqslant 30\\ -2, & 20\leqslant k\leqslant 30\\ 0, & \text{else}\end{cases} \tag{30}$$

From the figure we can see that $\omega(k)$ drives $z_F(k)$ to deviate from $z(k)$. However, when $\omega(k)$ is zero, the deviation tends to be zero due to the asymptocal stability of the filter error system. Now we will further analyze l_2-l_∞ performance. Fig. 3 gives the changing curves of the disturbance signal and the filtering error signal. From (30) and Fig. 3, we obtain that $\|\boldsymbol{\omega}\|_2=\sqrt{\sum_{k=0}^{\infty}\boldsymbol{\omega}^{\mathrm{T}}(k)\boldsymbol{\omega}(k)}=9.3808$ and $\|\boldsymbol{e}\|_\infty=\sqrt{\sup_k\{\boldsymbol{e}^{\mathrm{T}}(k)\boldsymbol{e}(k)\}}=0.1755$. Then it can be easily established that $\frac{\|\boldsymbol{e}\|_\infty}{\|\boldsymbol{\omega}\|_2}=0.0187<\gamma^*=0.4565$, showing the effectiveness of the filter design procedure.

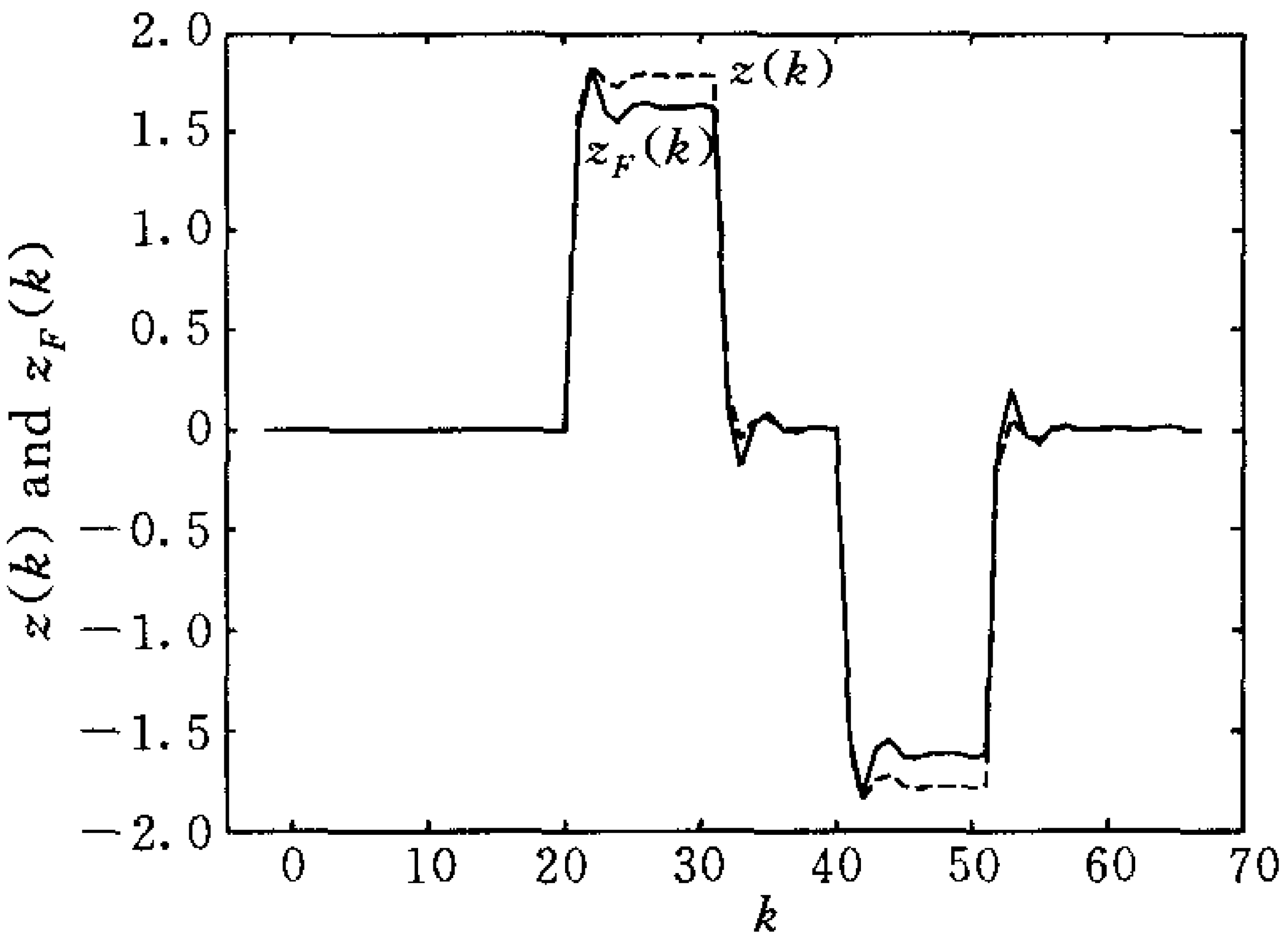

Fig. 2 $z(k)$ and $z_F(k)$ signals

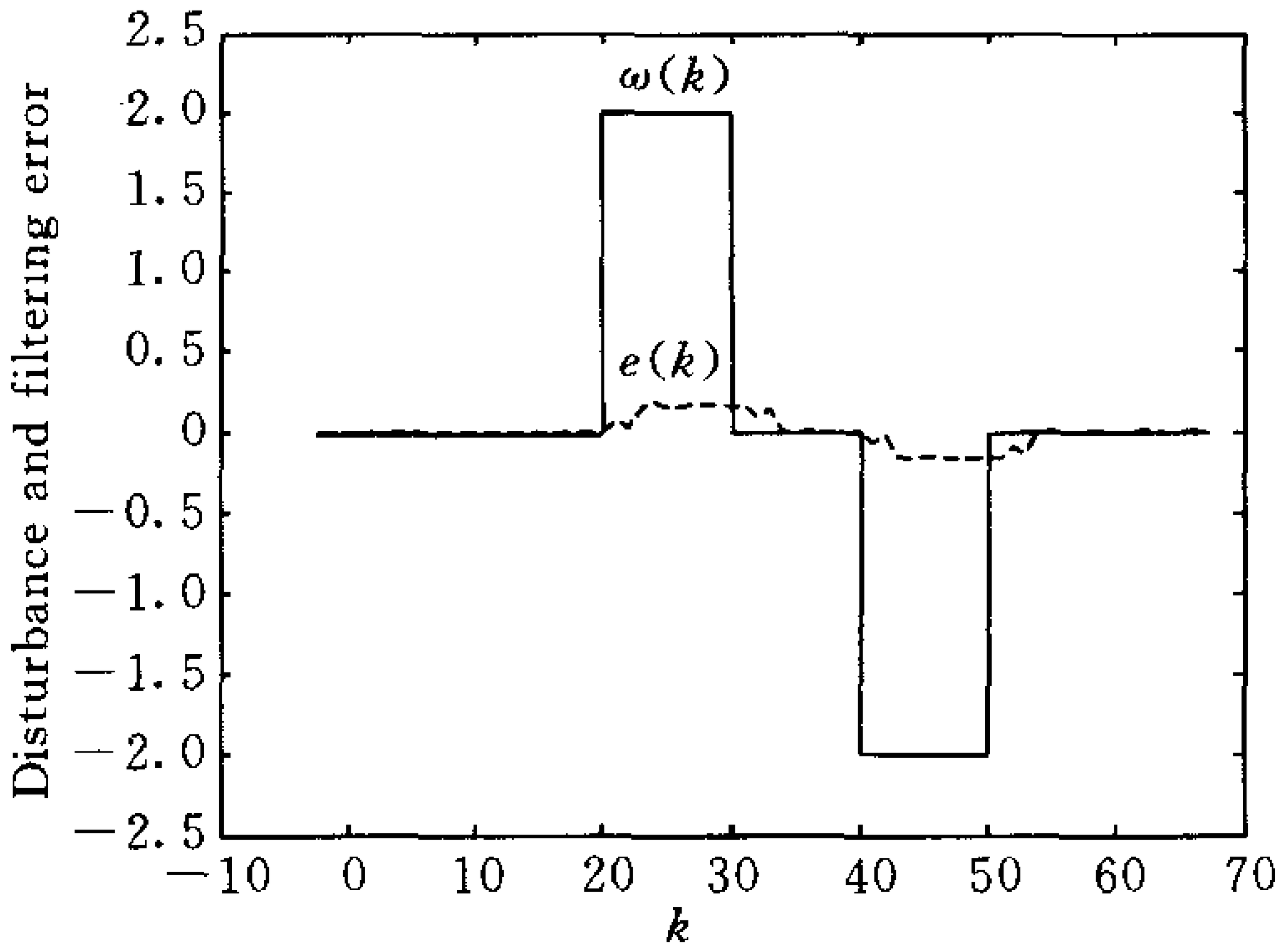

Fig. 3 Disturbance and filtering error

6 Concluding remarks

The l_2-l_∞ performance index is introduced into uncertain discrete-time state-delayed systems and full-order robust l_2-l_∞ filters are designed by means of linear matrix inequalities. It should be noted that the filtering analysis and synthesis addressed in this paper are delay-independent, and will be inevitably conservative in the presence of small delays. Therefore, further investigation efforts can be directed at developing delay-dependent approaches to the filtering problems for time-delayed systems.

References

1 Mahmoud M S, Xie L, Soh Y C. Robust Kalman filtering for discrete state-delay systems. *IEE Proceedings of Control Theory Application*, 2000, **147**(6): 613～618

2 Larsen T D, Andersen N A, Ravn O, Poulsen N K. Incorporation of time delayed measurements in a discrete-time Kalman filter. In: Proceedings of 37th IEEE Conference Decision Control, Tampa, FL, 1998. 3972～3977

3 Wang Z D, Huang B, Unbehauen H. Robust H_∞ observer design of linear state delayed systems with parametric uncertainty: the discrete-time case. *Automatica*, 1999, **35**(6): 1161～1167

4 Palhares R M, De Souza C E, Peres P L D. Robust H_∞ filtering for uncertain discrete-time state delayed systems. *IEEE Transactions on Signal Processing*, 2001, **49**(8): 1696～1703

5 Wilson D A. Convolution and Hankel operator norms for linear systems. *IEEE Transactions on Automatic Control*, 1989, **34**(1): 94～97

6 Rotea M A. The generalized H_2 control problem. *Automatica*, 1993, **29**(2): 373～385

7 Grigoriadis K M, Watson J T. Reduced order H_∞ and L_2-L_∞ filtering via linear matrix inequalities. *IEEE Transactions on Aerospace and Electronic Systems*, 1997, **33**(4): 1326～1338

8 Watson J T, Grigoriadis K M. Optimal unbiased filtering via linear matrix inequalities. *Systems Control Letters*, 1998, **35**(1): 111～118

9 Palhares R M, Peres P L D. Robust filtering with guaranteed energy-to-peak performance—an LMI approach. *Automatica*, 2000, **36**(4): 851～858

10 Gao Hui-Jun, Wang Chang-Hong. New approaches to robust l_2-l_∞ and H_∞ filtering for uncertain discrete-time systems. *Science in China (Series E)*, 2003, **33**(8)

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时滞不确定离散系统的鲁棒 l_2-l_∞ 滤波

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摘　要　将 l_2-l_∞ 性能指标引入时滞不确定离散时间系统，研究基于这一指标的滤波器设计问题. 所研究的对象是同时具有状态时滞和多面体不确定性的离散时间系统. 采用线性矩阵不等式技术推导了此类不确定系统鲁棒 l_2-l_∞ 滤波器存在的充分条件，并将滤波器的设计转化为一个凸优化的求解问题，可以采用较为有效的内点方法进行求解. 所设计的滤波器能够保证相对于所有能量有界的外界扰动信号，滤波误差系统具有一定的 l_2-l_∞ 扰动衰减水平. 数值仿真验证了所提出算法的可行性.

关键词　鲁棒滤波，线性矩阵不等式，l_2-l_∞ 性能

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