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An observer-based control of linear systems with uncertain parameters via LMI approach

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In this paper, the Linear Matrix Inequality (LMI) method is used to solve the problem of making observer-based control solutions for a class of uncertain linear systems. The study yields both control and observer gains derived from feasible LMI solutions. To illustrate the effectiveness of our approach, we present a practical example, showcasing the practicality and applicability of the proposed solutions.

Key words: observer-based control, Linear Matrix Inequalities, uncertain linear system, Lyapunov function stability

1. Introduction

As is acknowledged, observer-based control is a sophisticated and powerful approach in the field of control theory, designed to enhance the performance and robustness of control systems. It addresses the challenge of accurately estimating the internal states of a dynamic system, even when those states cannot be directly measured. This becomes particularly crucial in scenarios where precise control is required, such as aerospace, robotics, and industrial automation.

So the observer-based control estimates the unobservable states of a system using the available measured outputs. These estimated states are then used to design a control law that can effectively regulate the system's behavior and achieve desired objectives, such as stability or disturbance rejection. The observer was developed first for a deterministic continuous-time linear time-invariant system and

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has been extended by several researchers to time-varying, discrete, and stochastic systems [1, 10–13, 15, 16].

In practice, the mathematical model always involves some uncertain elements. These uncertainties can arise from various sources, such as manufacturing tolerances, environmental changes, nonlinearities, or modeling inaccuracies. Understanding and managing these uncertainties is crucial, as they can significantly impact the stability and performance of the system. Many works have been devoted to the design of the observer or observer-based control of uncertain systems [4, 6, 7, 9, 12].

Lyapunov stability theory provides a powerful framework to create an observer that estimates the unobservable states of a system in such a way that the overall system, including the observer, remains stable, whether the system is linear, time-varying, or nonlinear [3, 5]. The LMI method is a powerful tool in control theory and applications.

In this article, we will adopt these two effective approaches (i.e., Lyapunov stability theory and the LMI approach) to design observer-based control for a class of state-perturbed systems. By formulating LMIs, we can readily derive both control and observer gains. To exemplify the practicality and effectiveness of our findings, we provide a numerical example.

In this work, we will treat the system considered in [14] using the LMI method. The note is organized as follows: In Section 2, we provide the problem formulation and main results concerning observer-based control via the LMI approach for systems with state perturbations. A numerical example is given in Section 3 to illustrate the proposed results. Finally, we draw a conclusion in Section 4.

The following symbols are used in this study:

- $(\star)$ is used for the blocks induced by symmetry;
- S^T represents the transposed matrix of S;
- $\mathbb{R}^{n\times m}$ is the set of all real n by m matrices;
- I is an identity matrix with an approximate dimension, and I_r denotes an identity matrix with dimension r;
- $\mathcal{M}_n(\mathbb{R})$ stands for the space of all $n \times n$ real matrices;
- the value 0 denotes a zero matrix with an approximate dimension, and $0_{n\times m}$ denotes a zero matrix with the dimension n by m;
- for a square matrix S, $S \geqslant 0$ ($S \leqslant 0$) means that this matrix is positive definite (negative definite);
- $X \geqslant Y$ means that the matrix $X - Y$ is symmetric positive semidefinite.

Before giving the formulation of our problem, recall the result that we will use in the proof of our main results:

Lemma 1 (Schur Lemma)**.** *Let H_1, H_2 and H_3 be three matrices of appropriate dimensions such that $H_1 = H_1^T$ and $H_3 = H_3^T$. Then,*

$$\begin{bmatrix} H_1 & H_2 \\ H_2^T & H_3 \end{bmatrix} < 0$$

if and only if $H_3 < 0$ and $H_1 - H_2 H_3^{-1} H_2^T < 0$.

2. Problem formulation and main results

Initially, let's consider a continuous uncertain linear system expressed by:

$$(\mathbb{S}) \quad \begin{cases} \dot{x}(t) = (A + \Delta A)x(t) + Bu(t), \\ x(0) = x_0\,, \end{cases} \tag{1}$$

where $x(t) \in \mathbb{R}^n$ is the state vector, $u(t) \in \mathbb{R}^m$ is the control input vector. $A \in \mathcal{M}_n(\mathbb{R})$, $B \in \mathcal{M}_{n,m}(\mathbb{R})$, are constant matrices and $\Delta A \in \mathcal{M}_n(\mathbb{R})$ is the perturbed matrix. The uncertain parameter ΔA will represent the impossibility for exact mathematical model of a dynamic system due to the system complexity.

The output equation is given by:

$$y(t) = Cx(t), \tag{2}$$

where $C \in \mathcal{M}_{p,n}(\mathbb{R})$.

Initially, let's make the following assumptions:

⋆ the pairs (A, B) and (A, C) are respectively stabilizable and detectable;

⋆ there exist matrices M, N, F, of appropriate dimensions so that

$$\Delta A = MFN,$$

where the unknown matrix F satisfies the condition

$$F^T F \leqslant Id.$$

An appropriate dynamic observer-based control of the system (1)–(2) is provided as follows:

$$(\mathcal{S}) \quad \begin{cases} \dot{\hat{x}}(t) = \hat{A}\hat{x}(t) + \hat{B}u(t) + L(y(t) - \hat{y}(t)), \\ \hat{y}(t) = C\hat{x}(t), \\ u(t) = -K\hat{x}(t), \end{cases} \tag{3}$$

where $\hat{x}(t) \in \mathbb{R}^n$ is the estimation of $x(t)$, $\hat{y}(t) \in \mathbb{R}^p$ is the observer output. $K \in \mathcal{M}_{m,n}(\mathbb{R})$ is the control gain, $L \in \mathcal{M}_{n,p}(\mathbb{R})$ is the observer gain.

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From (1), (2) and (3) we can write:

$$\dot{x}(t) = (A - BK + \Delta A)x(t) + BKe(t),$$

where $e(t) = x(t) - \hat{x}(t)$ is the estimated error. Its derivative is:

$$\dot{e}(t) = \left[A - \hat{A} + \Delta A - BK + \hat{B}K\right] x(t) + \left[\hat{A} + BK - \hat{B}K - LC\right] e(t).$$

Specify $z(t) = \begin{bmatrix} x(t) \\ e(t) \end{bmatrix}$, so

$$\dot{z}(t) = \begin{bmatrix} A - BK + \Delta A & BK \\ A - \hat{A} + \Delta A - BK + \hat{B}K & \hat{A} + BK - \hat{B}K - LC \end{bmatrix} z(t). \tag{4}$$

In this paper, we will employ the LMI approach to design the appropriate observer-based control of system (1).

Let's examine the Lyapunov function

$$\dot{V}(z(t)) = z(t)^T \begin{bmatrix} P & 0 \\ 0 & R \end{bmatrix} z(t) = x^T Px + e^T Re.$$

Now, following the derivative of V, we obtain:

$$\begin{aligned} \dot{V}(t) \leqslant\ & x(t)^T \left[(A - BK)^T P + P(A - BK)\right] x(t) \\ & + e(t)^T \left[(\hat{A} + K(B - \hat{B}) - LC)^T R + R(\hat{A} + K(B - \hat{B}) - LC)\right] e(t) \\ & + x(t)^T \left[PBK + A^T R - \hat{A}^T R + (\hat{B} - B)^T k^T R\right] e(t) \\ & + e(t)^T \left[K^T B^T P + RA - R\hat{A} + RK(\hat{B} - B)\right] x(t) \\ & + x(t)^T \left[(\delta_1 + \delta_2) N^T N + \frac{1}{\delta_1} PMM^T P\right] x(t) + e(t)^T \left[\frac{1}{\delta_2} RMM^T R\right] e(t) \\ = & \begin{bmatrix} x(t) \\ e(t) \end{bmatrix}^T \begin{bmatrix} \sum_{11} & \sum_{12} \\ (\star) & \sum_{22} \end{bmatrix} \begin{bmatrix} x(t) \\ e(t) \end{bmatrix} \\ = & \begin{bmatrix} x(t) \\ e(t) \end{bmatrix}^T \sum \begin{bmatrix} x(t) \\ e(t) \end{bmatrix}, \end{aligned} \tag{5}$$

where P and R are symmetric positive–definite matrices, δ_1, δ_2, are positive constants, and

$$\sum\nolimits_{11} = (A - BK)^T P + P(A - BK) + (\delta_1 + \delta_2) N^T N + \frac{1}{\delta_1} PMM^T P,$$

$$\sum\nolimits_{12} = PBK + A^T R - \hat{A}^T R + \hat{B}^T K^T R - B^T K^T R,$$

$$\sum\nolimits_{22} = (\hat{A} + K(B - \hat{B}) - LC)^T R + R(\hat{A} + K(B - \hat{B}) - LC) + \frac{1}{\delta_2} RMM^T R,$$

$\dot{V}(t) < 0, \forall \begin{bmatrix} x(t) \\ e(t) \end{bmatrix} \neq 0$ if the following matrix inequality holds:

$$\begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ (\star) & \Sigma_{22} \end{bmatrix} < 0. \tag{6}$$

Firstly we present an LMI result for the exponential stability of system (4) with $B = \hat{B}$.

We can get the control gain K and observer gain L for system (4) from the following results [10].

Theorem 1. *System (1) is asymptotically stabilizable by (3) if there exist some positive constants δ_1, δ_2, β, and positive definite matrices $R \in \mathbb{R}^{n\times n}$, $K \in \mathbb{R}^{m\times n}$, $\hat{L} \in \mathbb{R}^{n\times p}$ such that*

$$\begin{bmatrix} G_{11} & G_{12} & M & 0 \\ (\star) & G_{22} & 0 & RM \\ (\star) & (\star) & -\delta_1 I & 0 \\ (\star) & (\star) & (\star) & -\delta_2 I \end{bmatrix} < 0, \tag{7}$$

where

$$G_{11} = A^T + A - K^T B^T - BK + (\delta_1 + \delta_2)\, N^T N + \beta \cdot I,$$
$$G_{12} = BK + A^T R - \hat{A}^T R,$$
$$G_{22} = \hat{A}^T R + R\hat{A} - \hat{L}C - C^T \hat{L}^T + \beta \cdot I.$$

The stabilizing observer-based control gains are given by K and $L = R^{-1}\hat{L}$.

Proof. We put

$$H_1 = \begin{bmatrix} A^T \mathcal{P} + \mathcal{P} A - \hat{K}^T B^T - B\hat{K} & G_{12} \\ G_{12}^T & \hat{A}^T R + R\hat{A} - \hat{L}C - C^T \hat{L}^T \end{bmatrix},$$

$$H_2 = \begin{bmatrix} M & 0 \\ 0 & RM \end{bmatrix}$$

and

$$H_3 = \begin{bmatrix} -\delta_1 I & 0 \\ 0 & -\delta_2 I \end{bmatrix}$$

so by using Schur lemma the LMI condition (7) implies:

$$\sum_1 = H_1 - H_2 H_3^{-1} H_2^{-1} < -\beta \cdot I. \tag{8}$$

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The matrix $\sum_1$ is equal to the matrix $\sum$ with $P = I$ and $L = R^{-1}\hat{L}$. By (6), (7), and (8), we have

$$\min\left[1, \lambda_{\min}(R)\right] \cdot \|z(t)\|^2 \leqslant V(z(t)) \leqslant \max\left[1, \lambda_{\max}(R)\right] \cdot \|z(t)\|^2$$

and

$$\dot{V}(z(t)) \leqslant -\beta \cdot \|z(t)\|^2.$$

We conclude that (1) is exponentially stabilizable by (3) with the convergence rate $[\beta/(2 \cdot \max\left[1, \lambda_{\max}(R)\right])]$, [4]. In Theorem 1 we made particular choice of P, $P = I$. □

Now we add a new condition in order to make the theorem less conservative, so we introduce a new invertible matrix $\hat{P}$ satisfying the condition $PB = B\hat{P}$.

Theorem 2. *System (1) is asymptotically stabilizable by (3) if there exist some positive constants δ_1, δ_2, β, two positive definite matrices $P, R \in \mathbb{R}^{n\times n}$, and $\hat{K} \in \mathbb{R}^{m\times n}$, $\hat{L} \in \mathbb{R}^{n\times p}$, $\hat{P} \in \mathbb{R}^{n\times p}$ such that*

$$\begin{bmatrix} W_{11} & W_{12} & PM & 0 \\ (\star) & W_{22} & 0 & RM \\ (\star) & (\star) & -\delta_1 I & 0 \\ (\star) & (\star) & (\star) & -\delta_2 I \end{bmatrix} < 0, \tag{9}$$

$$PB = B\hat{P}, \tag{10}$$

where

$$W_{11} = A^T P + PA - \hat{K}^T B^T - B\hat{K} + (\delta_1 + \delta_2)\, N^T N + \beta \cdot I,$$
$$W_{12} = B\hat{K} + A^T R - \hat{A}^T R,$$
$$W_{22} = \hat{A}^T R + R\hat{A} - \hat{L}C - C^T \hat{L}^T + \beta \cdot I.$$

The stabilizing observer-based control gains are given by $K = \hat{P}^{-1}\hat{K}$ and $L = R^{-1}\hat{L}$.

Proof. We can complete this proof in view of the proof of Theorem 1 with $PB = B\hat{P}$, $K = \hat{P}^{-1}\hat{K}$ and $L = R^{-1}\hat{L}$. □

Now we treat the case where $B \neq \hat{B}$. When the control gain K has been designed from Theorem 2, we may use this control gain to design the suitable robust observer-based control from the following results.

Theorem 3. *System (1) is asymptotically stabilizable by (3) if there exist some positive constants δ_1, δ_2, β two positive definite matrices $P, R \in \mathbb{R}^{n\times n}$, and*

$\hat{L} \in \mathbb{R}^{n \times p}$, $\hat{P} \in \mathbb{R}^{n \times p}$ *such that*

$$\begin{bmatrix} W_{11} & W_{12} & PM & 0 \\ (\star) & W_{22} & 0 & RM \\ (\star) & (\star) & -\delta_1 I & 0 \\ (\star) & (\star) & (\star) & -\delta_2 I \end{bmatrix} < 0, \tag{11}$$

where

$$W_{11} = A^T P + PA - \hat{K}^T B^T - B\hat{K} + (\delta_1 + \delta_2) N^T N + \beta \cdot I,$$
$$W_{12} = B\hat{K} + A^T R - \hat{A}^T R - B^T K^T R + \hat{B}^T K^T R,$$
$$W_{22} = \hat{A}^T R + R\hat{A} + B^T K^T R - \hat{B}^T K^T R + RKB - RK\hat{B} - \hat{L}C - C^T \hat{L}^T + \beta \cdot I.$$

The stabilizing observer-based control gains are given by K, $L = R^{-1}\hat{L}$.

Proof. This is similar to the proof of Theorem 1 with $L = R^{-1}\hat{L}$ in view of (5).

3. Numerical example

In this section we will treat two cases, the case where $B = \hat{B}$ and when the $B \neq \hat{B}$

Let's explore an example illustrating a basic gene expression process, as described by the following model [14]:

$$\begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} = \begin{bmatrix} -\gamma_1 & 0 \\ k_2 & -\gamma_2 \end{bmatrix} \begin{bmatrix} \dot{x}_1(t) \\ \dot{x}_2(t) \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} u(t), \tag{12}$$

where $x_1 \geqslant 0$ represents the mean number of mRNA in the cell, $x_2 \geqslant 0$ signifies the mean number of protein of interest in the cell and $u(t) \geqslant 0$ is the transcription rate of DNA into mRNA, $\gamma_1 > 0$ is the degradation rate of mRNA, $k_2 > 0$ represents the translation rate of mRNA into protein and $\gamma_2 > 0$ denotes the degradation rate of the protein. The parameters are supposed to be uncertain and described as follows $\gamma_1 = \gamma_1^0 + \varepsilon_1 \gamma_1^1$, $k_2 = k_2^0 + \varepsilon_2 k_2^1$ and $\gamma_2 = \gamma_2^0 + \varepsilon_3 \gamma_2^1$, where $\varepsilon_i \in [-1, 1]$, $i = \{1, 2, 3\}$.

For numerical application, let's assume $\gamma_1^0 = 1$, $k_p^0 = 2$, and $\gamma_2^0 = 1$. Additionally, we posit that the parameters are known up to a percentage $N \in [0, 1)$ of their nominal values, hence $\gamma_1^1 = N\gamma_1^0$, $\gamma_2^1 = N\gamma_2^0$ and $k_2^1 = Nk_2^0$ with $N = \dfrac{1}{2}$, $\varepsilon_1 = -0.5$, $\varepsilon_2 = 0.8$ and $\varepsilon_3 = 0.4$.

Consider $C = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, $\hat{A} = \begin{bmatrix} -0.3 & 1 \\ 1 & -0.3 \end{bmatrix}$.

First we treat the case where $\hat{B} = B$.

The uncertainties can be rewritten under the form $\Delta A = MFN$, with $M = \begin{bmatrix} -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{8}{5} \end{bmatrix}$, $F = \begin{bmatrix} -\frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{bmatrix}$ and $N = \begin{bmatrix} 0 & -\frac{1}{4} \\ 1 & \frac{1}{4} \end{bmatrix}$ by using Matlab LMI toolbox, our LMI is solvable by choosing $\delta_1 = 10.2$, and $\delta_2 = 34.18$, we obtain the following solutions:

$$P = \begin{bmatrix} 10.7203 & 0.4618 \\ 0.4618 & 0.5749 \end{bmatrix}, \qquad R = \begin{bmatrix} 20.9042 & -3.4131 \\ -3.4131 & 10.5531 \end{bmatrix},$$

$$\hat{L} = \begin{bmatrix} 24.1360 & 48.9370 \\ -11.4322 & 51.3965 \end{bmatrix}, \qquad \hat{k} = \begin{bmatrix} 24.4471 & -15.8086 \\ 17.5636 & 34.6514 \end{bmatrix}$$

The gains L and K are respectively given by:

$$L = \begin{bmatrix} 1.0322 & 3.3111 \\ -0.7495 & 5.9411 \end{bmatrix}, \qquad K = \begin{bmatrix} 0.9991 & -4.2167 \\ 29.7484 & 63.6612 \end{bmatrix}.$$

with $x(0) = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$ and $\hat{x}(0) = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ the simulation results are given in Figure 1.

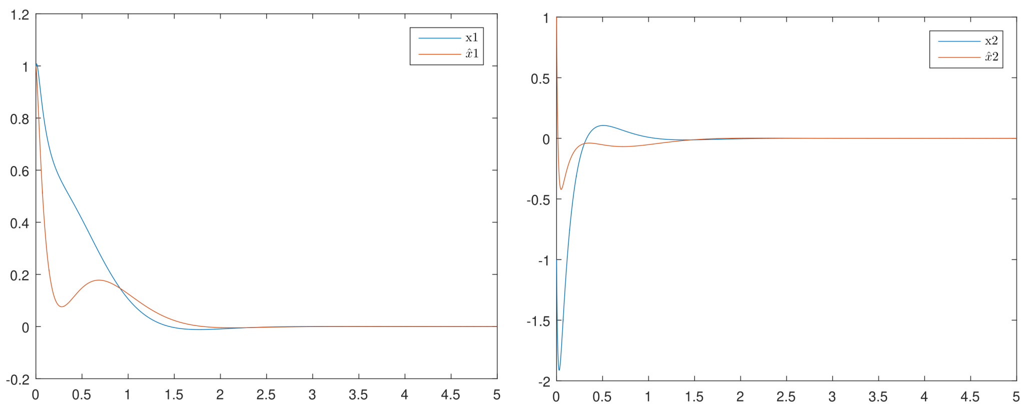

Figure 1: The controlled states x, its estimate $\hat{x}$

Figure 1 depicts the trajectories of the system states and their corresponding estimates. As illustrated, the estimated states effectively track the actual states.

Now we treat the case $B \neq \hat{B}$ where

$$\hat{B} = \begin{bmatrix} 0.9 & 0.01 \\ 0.03 & 1 \end{bmatrix}.$$

The control gain K has been designed from Theorem 2, we find:

$$K = \begin{bmatrix} 0.9991 & -4.2167 \\ 29.7484 & 63.6612 \end{bmatrix}.$$

After solving the LMI we find the following gains:

$$P = \begin{bmatrix} 4.0188 & -1.8335 \\ -1.8335 & 3.4514 \end{bmatrix}, \quad R = \begin{bmatrix} 9.3120 & -0.9744 \\ -0.9744 & 2.2975 \end{bmatrix}, \quad \hat{L} = \begin{bmatrix} 4.4204 & 9.5938 \\ 2.6004 & 6.5247 \end{bmatrix}.$$

The gain L is given by:

$$L = \begin{bmatrix} 0.6207 & 1.3891 \\ 1.3951 & 3.4291 \end{bmatrix}$$

and the system's convergence rate is 0.3061. With $x(0) = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$ and $\hat{x}(0) = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$ the simulation results are given in Figure 2.

Figure 2 show the results of state estimation. Notably, the state estimates produced by the proposed observer converge towards the actual state x.

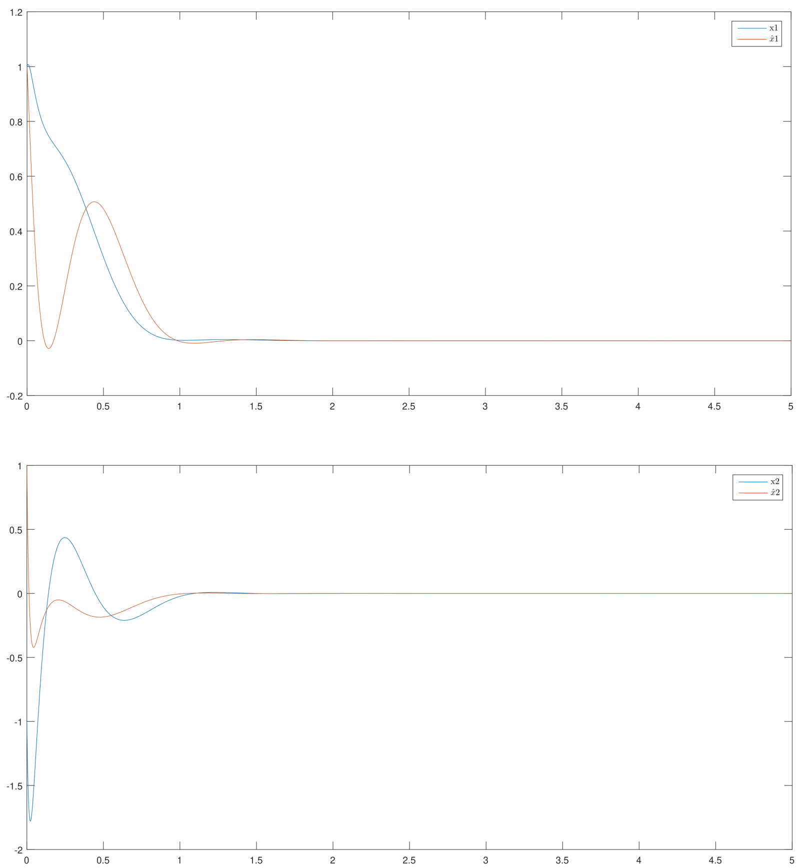

Figure 2: The controlled states x, its estimate $\hat{x}$

4. Conclusion

In this study, we have explored the applicability of the Linear Matrix Inequality (LMI) approach in the design of observer-based control for uncertain linear systems, as formulated in equations (1)–(3). We have considered two distinct cases, namely when $B = \hat{B}$ and when $B \neq \hat{B}$. Our findings are supported by a numerical example, providing practical insights into the utilization of our proposed methodology.

References

[1] M. Aoki: *Optimization of Stochastic Systems: Topics in Discrete-Time Systems.* Elsevier, 2016.

[2] S. Ben Rhila, M. Lhous and M. Rachik: On the asymptotic output sensitivity problem for a discrete linear systems with uncertain initial state. *Mathematical Modeling and Computing*, **8**(1), (2021), 22–34. DOI: 10.23939/mmc2021.01.022

[3] K.K. Busawon and M. Saif: A state observer for nonlinear systems. *IEEE Transactions on Automatic Control*, **44**(11), (1999), 2098–2103. DOI: 10.1109/9.802924

[4] M. Chen and W.H. Chen: Disturbance-observer-based robust control for time delay uncertain systems. *International Journal of Control, Automation and Systems*, **8** (2010), 445–453. DOI: 10.1007/s12555-010-0233-5

[5] D.-W. Gu and F.W. Poon: A robust state observer scheme. *IEEE Transactions on Automatic Control*, **46**(12), (2001), 1958–1963. DOI: 10.1109/9.975500

[6] S. Hui and S. Żak: Observer design for systems with unknown inputs. *International Journal of Applied Mathematics and Computer Science*, **15**(4), (2005), 431–446.

[7] H. Kheloufi, A. Zemouche, F. Bedouhene and M. Boutayeb: A new observer-based stabilization method for linear systems with uncertain parameters. *In 2013 European Control Conference (ECC)*. IEEE, (2013), 1120–1125.

[8] A. Larrache, M. Lhous, S. Ben Rhila, M. Rachik and A. Tridane: An output sensitivity problem for a class of linear distributed systems with uncertain initial state. *Archives of Control Sciences*, **30**(1), (2020), 77–93. DOI: 10.24425/acs.2020.132589

[9] C.-H. Lien: An efficient method to design robust observer-based control of uncertain linear systems. *Applied Mathematics and Computation*, **158**(1), (2004), 29–44. DOI: 10.1016/j.amc.2003.08.062

[10] C.-H. Lien: Robust observer-based control of systems with state perturbations via LMI approach. *IEEE Transactions on Automatic Control*, **49**(8), (2004), 1365–1370. DOI: 10.1109/TAC.2004.832660

[11] D. Luenberger: An introduction to observers. *IEEE Transactions on Automatic Control*, **16**(6), (1971), 596–602. DOI: 10.1109/TAC.1971.1099826

[12] D.G. Luenberger: Observing the state of a linear system. *IEEE Transactions on Military Electronics*, **8**(2), (1964), 74–80. DOI: 10.1109/TME.1964.4323124

[13] M. Rachik, H. Laarabi, O. El Kahlaoui and S. Saadi: Observer for perturbed linear continuous systems. *Applied Mathematical Sciences*, **4**(14), (2010), 681–689.

[14] M. Rachik and M. Lhous: An observer-based control of linear systems with uncertain parameters. *Archives of Control Sciences*, **26**(4), (2016), 565–576. DOI: 10.1515/acsc-2016-0031

[15] M.V. Thuan, V.N. Phat and H. Trinh: Observer-based controller design of time-delay systems with an interval time-varying delay. *International Journal of Applied Mathematics and Computer Science*, **22**(4), (2012), 921–927. DOI: 10.2478/v10006-012-0068-8

[16] O. Zakary, M. Rachik, M. Lhous and S. Bidah: Observer-based tracking control design for a class of nonlinear discrete-time systems. *Recent Advances in Modeling, Analysis and Systems Control: Theoretical Aspects and Applications*, (2020), 163–175. DOI: 10.1007/978-3-030-26149-8_13