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Fault Diagnosis of NLPV fuzzy system

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Abstract: *This paper deals with the Fault Detection and Diagnosis (FDD) design for a Nonlinear Parameter Varying (NLPV) descriptor system, subject to external disturbances, and actuator faults. The purpose is to synthesize a robust observer of NLPV model with unmeasurable premise variables, and its application to fault isolation and estimation. In order to design the FDD scheme, a Proportional-Integral (PI) observer is adopted which estimate both of the faults and the faulty system states. A conventional fault detection scheme is considered by means of residual generation and evaluation. A robust $\mathcal{L}_2$ approach is considered to minimize the effect of uncertainties given by the nonlinearities, the unmeasurable premise variables, and disturbance. As a result, a set of relaxed linear Matrix Inequalities (LMIs) are derived, which provides sufficient conditions to guarantee the convergence of the proposed observer. Finally, an example is given to show the effectiveness of the proposed method.*

Keywords: Fault Diagnosis, actuator fault detection, Proportional-Integral (PI) residual generator observer, approach, NLPV system.

Résumé : *Cet article traite la détection et le diagnostic des défauts pout les systèmes Non linéaire à Paramètre Variables, soumis à la perturbation extérieurs et aux défauts actionneurs. Le but est de synthétiser un observateur robuste pour les modèles NLPV à variable de prémisse non mesurables, et leur application pour l'isolation et l'estimation des défauts. Pour la conception du schéma de diagnostic, un observateur Proportionnel-Integral (PI) est adopté pour estimer simultanément l'état et les défauts affectant l'entrée du système. La détection de défaut est considérée par l'évaluation d'un observateur générateur de résidu. L'approche $\mathcal{L}_2$ est utilisée afin de minimiser l'effet d'incertitudes données par les nonlinéarités, les variables de prémisse non mesurable, et atténuer l'effet des perturbations. Par conséquent ; des conditions suffisantes sous forme des inégalités matricielles linéaires (LMIs), sont calculées pour garantir la convergence de l'observateur proposé. Finalement, un exemple d'un robot mobile à 2 DDL est donné, pour montrer l'efficacité de la méthode proposée.*

Mots-clés : *Diagnosic de défaut, détection de défaut actionneur, observateur Proportionnel-Intégral générateur de résidu, approche approach, système NLPV.*

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1. Introduction :

For centuries, the only way to know about faults and their location was through human intervention, either by observing changes of shape, color, listening to sounds unusual, touching to feel heat or vibrations and so on (Derbel N and al. 2019, Escobart. 2019). Later, measuring devices were introduced, which provided more exact information about important physical variables (BEng, R. M. 2018, Li, D and al. 2020).

In general, faults are deviations from the normal behavior in the system or its instrumentation. There are many reasons for the appearance of faults (Djeddi. 2017, Li, D and al. 2020). To name a few examples: wrong design, wrong assembling, wrong operation, missing maintenance, ageing, corrosion, wear during normal operation, etc.

Fault diagnosis scheme implement the following tasks: fault detection, the indication that something is going wrong in the monitored system. Fault isolation, is the determination of the exact location of the fault (the component which is faulty). Fault estimation, is the determination of the magnitude of the fault (Qianqianand al. 2022, Silvestre and al. 2017).

In addition, there is always a static error between the system state and its estimation. To overcome this drawback, a PI observer was used by (Djeddi. 2017, Marx. 2016, Escobart. 2019, Do, M and al. 2020). The application of PI observer to estimate the system states and faults was then presented in (Marx. 2016). In (Djeddi. 2017) the authors introduced a robust PI observer in order to detect the faults of Takagi-Sugeno system by applying the LMI optimization; however, their work can only be applied to the uncertainties existing in state-matrix A.

In this paper the PI observer-based fault diagnosis is designed for uncertain descriptor systems. The full scheme of fault diagnosis includes the tasks of fault detection, isolation and estimation, so that, we have proposed an observer based of the PI structure to deal with the tasks of fault detection and fault isolation through the residual generation. The advantage of this approach proposed is to obtain independent residuals, i.e. each residual respond just to one fault, in such way we can isolate multiple faults. This observer deals also with simultaneous state and fault estimation by using an adequate observer. With this we complete the scheme of fault diagnosis.

As a result, there is a need for the reconciliation of previous methods to overcome fault estimation problems. Hence, the robust $\mathscr{L}_2$ PI observer design is introduced in this study with the following contribution:

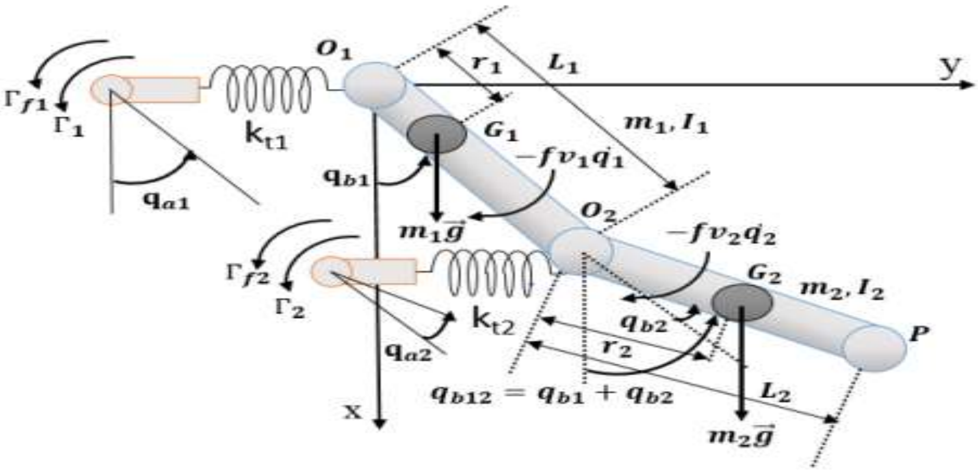
• Fault detection result is robust against the system uncertainties existing in the matrices of states. The application of robust $\mathscr{L}_2$ PI observer to robot arm system is also presented, to cope with system uncertainties and disturbances. The proposed observer design is applied to fault estimation of robot arm (Van Anh Nguyen. 2019, Dombre and al. 2013, Siciliano and Khatib. 2016, Spong and Vidyasagar. 2008) input and output.

This paper is organized as follows: firstly, the proposed system for modeling is presented in Section 2. In Section 3, under actuator fault occurrence, the observer design problem against system uncertainties is solved by using LMI optimization to deal with fault detection, isolation and estimation, which the main results for descriptor systems are treated. Section 4 deals with the conclusion.

2. Proposed system:

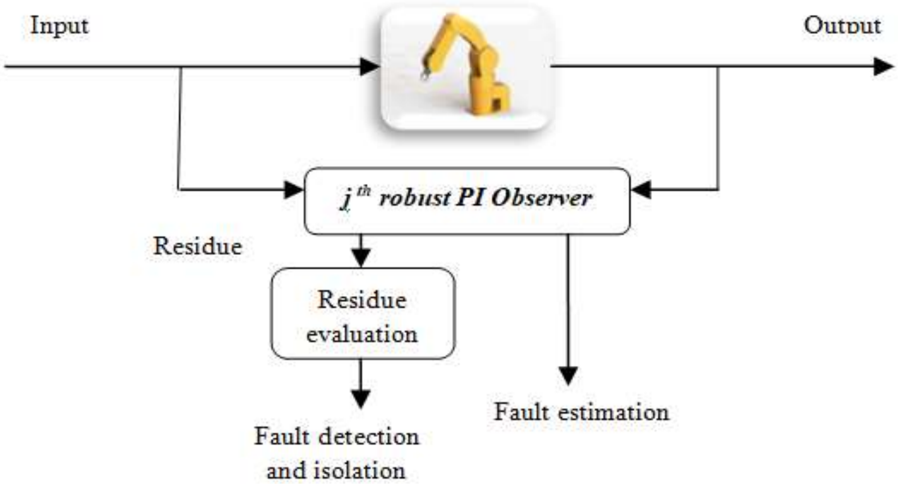
Fig. 1 illustrates a simplified model describing the motion of this 2-DoF serial manipulator of robot arm. The parameters of the robot are given in Table I. The first arm of length L_1 and mass m_1 rotates about the $z-$axis. The second arm of length L_2 and mass m_2 is attached to the first arm by a pivot link at point O_2. Let us denote q_1 the rotational angle of the first arm about the $z-$axis measured clockwise from O_1, q_2 the rotational angle of the second arm about the $z-$axis measured clockwise from the first arm position, and $q_{12} = q_1 + q_2$. The torques at Joint 1 and Joint 2 are respectively denoted by Γ_1 and Γ_2.

Figure (1): System global performance.



The structure of residual generators observer, allows isolation of actuator faults affecting the system. To isolate an existing fault, a set of PI observers is important to consider, each observer is sensitive to a certain fault and capable of mitigating the influence of frictions. This procedure is illustrated in figure (2):

Figure (2): Diagnosis scheme applied.



3. Simulation Results:

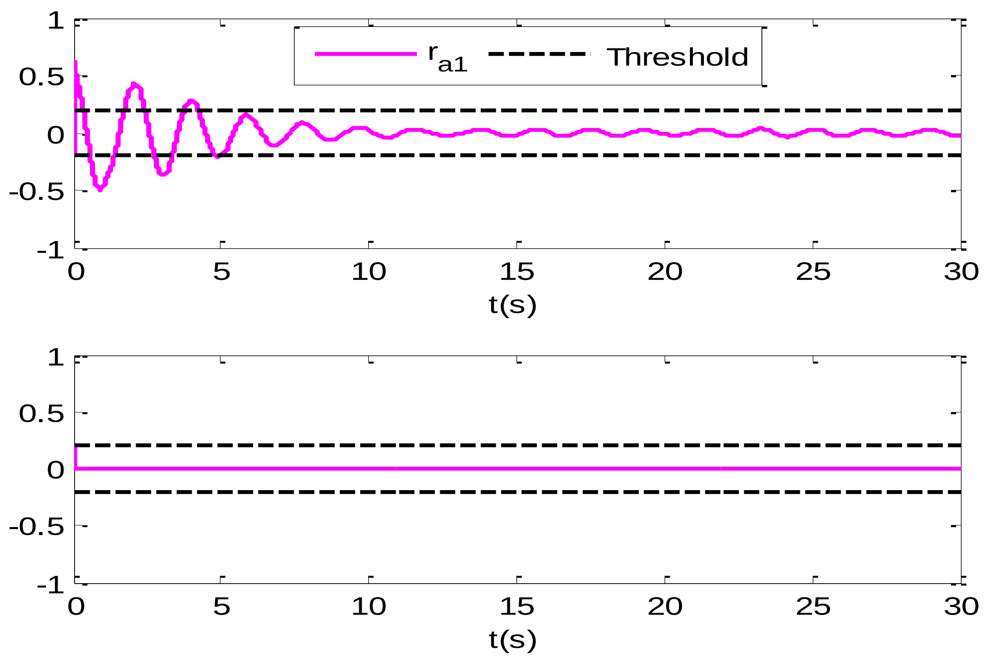
The actuator loses its efficiency i.e. faults affecting the dynamics of the system represent a partial loss of actuator. Then the actuator faults are given by:

$$\begin{cases} f_{a1} = -0.4\Gamma_1 \\ f_{a2} = -0.4\Gamma_2 \end{cases} \tag{1}$$

To validate this actuator fault detection/location approach, we simulated a loss of efficiency on each of the actuators. The following figures show that simple logic it is possible to locate an actuator fault. Figure (3)~(5) shows the simulation results obtained for fault diagnosis in the event of a loss of efficiency. In this figures we have simulated a loss of 40% of the nominal control input. For the actuator faults, we propose to adopt a diagram of the PI observer's bank. Each observer j is driven by the motor torque (control inputs) applied to the two arms denoted by $\Gamma = [\Gamma_1 \quad \Gamma_2]^T$, and their joint positions (output signals) $y = [q_1 \quad q_2]^T$ respectively, which makes it possible to determine the estimates of the detection to generate the residues $r_{a,k}^j$.

The first observer(for $j = 1$), generate the faults $\hat{f}_{a1}$, so it is sensitive to faults f_{a1} and insensitive to fault f_{a2}.

Figure (3): Residue generate with PI_1**.**



Using this decision logic and the represented residuals, we can conclude that the fault $f_{a,1}$ occurs at $t \in (0[s] \quad 30[s])$, which effectively corresponds to the faults injected on the simulated measurement signals.

The second observer (for $j = 2$) generates the faults $\hat{f}_{a2}$, therefore it is sensitive to fault f_{a2}, and insenstive to fault f_{a1}. We can conclude that the default $f_{a,2}$ which effectively corresponds to the faults injected on the simulated measurement signals.

Figure (4): Residue generate with PI_2.

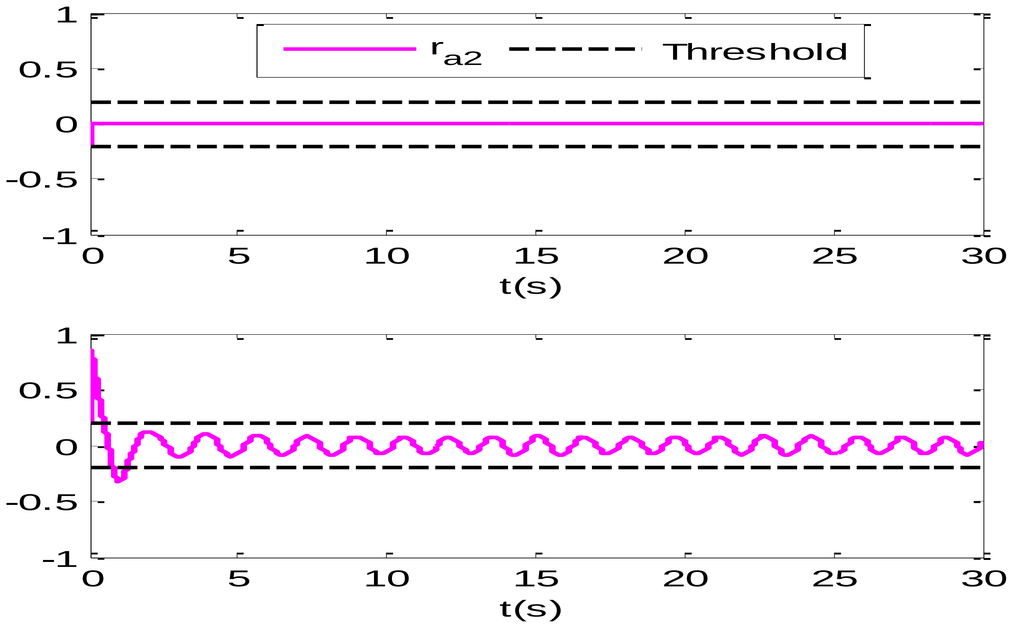
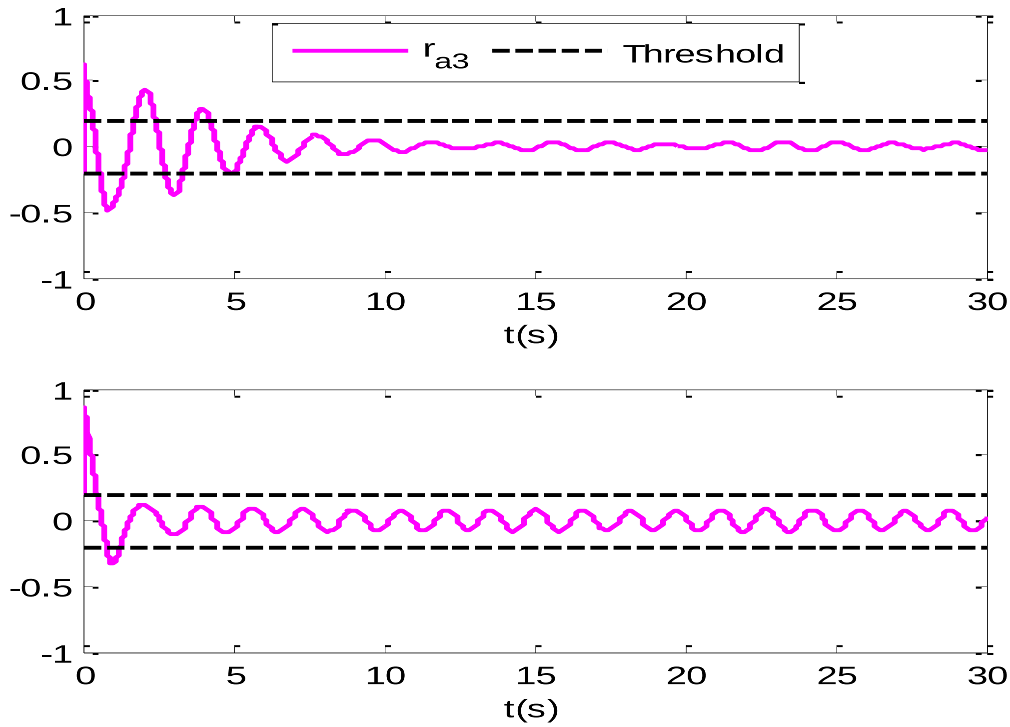


Figure (5): Residue generate with PI_3.



A third observer is driven by the two inputs and the two outputs, estimate all actuator faults $f_{a,k} = [f_{a,1} \quad f_{a,2}]^T$ simultaneously, so it is sensitive to all faults.

For brevity, the system nomenclature used in this work is given in Table 1.

Table (1): System nomenclature of robot arm.

Symbol	Description	Value
L_1, L_2	Lengths of robot arm (m).	*0.5, 0.5*
m_1, m_2	Masses of robot arms (Kg).	*15, 9*
I_1, I_2	Inertia of robot arms (Kg.m^2)	*0.313, 0.313*
r_1, r_2	Distances between joints and mass center (m)	*0.25, 0.25*
f_{v1}, f_{v2}	Coeffiscients of viscous friction (Nms/rd)	*1/7, 1/7*
f_{s1}, f_{s2}	Coeffiscients of dry/sec friction (Nms/rd)	*1/7, 1/7*
g	Gravitational acceleration (m/s^2)	*9.81*

Conclusion: This paper, the fault diagnosis scheme was treated thought a PI observer with unmeasurable premise variables; this observer was responsible for fault detection and isolation from the residual to the fault, which was proposed to isolate multiple faults. And it dealt with simultaneous estimation of state and faults, and is robust to a certain class of uncertainties. The conditions for the existence of the observer-based fault-diagnosis have been given in the form of LMIs. In order to illustrate the faults occurrence, a robot arm example with an actuator fault was presented. A future work will include an active fault tolerant tracking control.

References:

Van Anh Nguyen 2019) Van Anh Nguyen, T. (2019). Commande de robot manipulateurs basée sur le modèle de Takagi-Sugeno: nouvelle approche pour le suivi de trajectoire (Doctoral dissertation, Université Polytechnique Hauts-de-France).

(Ding 2021) Ding, S. X. (2021). Advanced methods for fault diagnosis and fault-tolerant control. Springer Berlin Heidelberg.

(Djeddi 2017) Djeddi, A. (2017). Diagnostic de défaut Capteur à base de multiobservateur à entrées inconnues. Thèse de doctorat l'Université de Annaba 2017.

(Marx 2016) Marx, B. (2016). Estimation, diagnostic et commande tolérante de systèmes décrits par des multimodèles, Université de Lorraine.

(Qianqianand al. 2022) Qianqian, W., Weili, L., Minan, T., & Kaiyue, Z. (2022). Diagnosis Method for Multiple Compensation Capacitor Faults of Jointless Track Circuit. *Electrotehnica, Electronica, Automatica*, (3).

(Silvestre and al. 2017) Silvestre, D., Rosa, P., Hespanha, J. P., & Silvestre, C. (2017). Set-based fault detection and isolation for detectable linear parameter-varying systems. *International Journal of Robust and Nonlinear Control*, *27*(18), 4381-4397.

(BEng, R. M. 2018) BEng, R. M. (2018). A Set-theoretic Approach to Sensor Fault Tolerant Control of Constrained Linear Parameter Varying Systems.

(Li, D and al. 2020) Li, D., Wang, Y., Wang, J., Wang, C., & Duan, Y. (2020). Recent advances in sensor fault diagnosis: A review. *Sensors and Actuators A: Physical*, *309*, 111990.

(Derbel, N and al. 2019) Derbel, N., Ghommam, J., & Zhu, Q. (Eds.). (2019). *New Developments and Advances in Robot Control*. Springer Singapore.

(Escobart 2019) Escobet, T., Bregon, A., Pulido, B., & Puig, V. (2019). Fault diagnosis of dynamic systems. Springer International Publishing.

(Boyd and al. 1994) Boyd, S., El Ghaoui, L., Feron, E., & Balakrishnan, V. (1994). Linear matrix inequalities in system and control theory. Society for industrial and applied mathematics.

(Do, M and al. 2020) Do, M. H., Koenig, D., & Theilliol, D. (2020). Robust H∞ proportional-integral observer-based controller for uncertain LPV system. Journal of the Franklin Institute, 357(4), 2099-2130.

(Dombre and al. 2013) Dombre, E., & Khalil, W. (Eds.). (2013). Robot manipulators: modeling, performance analysis and control. John Wiley & Sons.

(Du, D and al. 2021) Du, D., Xu, S., & Cocquempot, V. (2021). Observer-Based Fault Diagnosis and Fault-Tolerant Control for Switched Systems (Vol. 323, p. 255). Springer Singapore.

(Siciliano and Khatib 2016) Siciliano, B., & Khatib, O. (2016). Robotics and the Handbook. In Springer Handbook of Robotics (pp. 1-6). Springer, Cham.

(Spong and Vidyasagar 2008) Spong, M. W., & Vidyasagar, M. (2008). Robot dynamics and control. John Wiley & Sons.

(Righi and al. 2021) Righi, I., Aouaouda, S., Chadli, M., & Khelil, K. (2021). Robust controllers design for constrained nonlinear parameter varying descriptor systems. International Journal of Robust and Nonlinear Control, 31(17), 8295-8328.