CIÊNCIAS SOCIALMENTE APLICÁVEIS:

INTEGRANDO SABERES E ABRINDO CAMINHOS

JORGE JOSÉ MARTINS RODRIGUES
MARIA AMÉLIA MARQUES
(Organizadores)

VOL VIII

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APRESENTAÇÃO

O oitavo volume desta coleção segue a lógica dos livros anteriores. Procura apresentar ao leitor uma coletânea de artigos sobre problemáticas que são transversais ao campo das ciências sociais aplicadas.

Sendo discutível, na metodologia seguida na organização dos vários volumes procurou-se privilegiar artigos que abordassem novas tendências e/ou problemáticas transversais relevantes, adotassem metodologias mais holísticas e/ou modelos de investigação aplicada, apresentassem estudos de caso nacionais e/ou internacionais e procurassem ser reflexivos. Nesse contexto, o presente volume está organizado em três grandes eixos – Programação, Sustentabilidade, Educação e redes sociais.

Na construção da estrutura de cada eixo procurou-se seguir uma lógica em que cada artigo possa contribuir para uma melhor compreensão do artigo seguinte, gerando-se um fluxo de conhecimento acumulado que se pretende fluido e em espiral crescente.

Assim, o eixo Programação é constituído por um conjunto de oito artigos. A programação pode ser entendida como um conjunto de actividades que visam transformar tarefas repetitivas e monótonas em rotinas cooperativas e colaborativas. Estas rotinas são algoritmos e modelos matemáticos geradores de informação estruturada e eficiente que, apesar da sua racionalidade limitada, é útil para a tomada de decisões, sejam individuais ou de grupo.

O eixo Sustentabilidade junta um conjunto de sete artigos que, em comum, contribuem para a construção da responsabilidade social. As mudanças climáticas estão a perturbar a vida de milhões de pessoas no planeta, com especial ênfase nas regiões rurais mais pobres e com impacto negativo na economia. Assim, exigem-se políticas públicas inclusivas que incentivem o uso de materiais multiusos, amigos do ambiente. Os resíduos sólidos urbanos necessitam de ser melhor geridos e as empresas deverão ser incentivadas a incorporar aquelas políticas nas suas estratégias, para reforço dos seus valores, conforto e bem-estar dos seus constituintes.

O eixo Educação e redes sociais tem seis artigos. As principais teorias de liderança parecem apontar para que esta seja contingencial, podendo ser ensinada e as respectivas competências treinadas e melhoradas. Todo o ensino, presencial ou a distância, tem os seus pontos fortes e pontos fracos. Exigem-se comportamentos éticos, nomeadamente em ambiente de redes sociais, para evitar fraudes quer com os conteúdos quer com a respectiva avaliação, com eventuais traumas psicológicos em quem é visado.

Com a disponibilização deste livro e seus artigos esperamos que os mesmos gerem inquietude intelectual e curiosidade científica, procurando a satisfação de novas necessidades e descobertas, motor de todas as fontes de inovação.

Jorge Rodrigues, ISCAL/IPL, Portugal
Maria Amélia Marques, IPS/ESCE, Portugal

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Ángel Garibo
División de Estudios de Posgrado de la Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
angel_gari12@hotmail

Marco A. Rodríguez
División de Estudios de Posgrado de la Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
marco_roma19@hotmail.com

Juan M. de la Torre
División de Estudios de Posgrado de la Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
ingenieria_delatorre@hotmail.com

Marisela Y. Hernández
División de Estudios de Posgrado de la Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
yeraldinhz14@gmail.com

Juan Anzurez Marín
División de Estudios de Posgrado y de la Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
https://orcid.org/0000-0002-6686-3277

Salvador Ramírez Zavala
Facultad de Ingeniería Eléctrica de la Universidad Michoacana de San Nicolás de Hidalgo
Morelia, Michoacán, México
https://orcid.org/0000-0001-5480-6593

ABSTRACT: In this document, we present the design and results of a Takagi-Sugeno fuzzy compensator and observer as sliding modes for a non-linear system. The control is designed for a non-linear liquid level system consisting of: two-tank, two valves for fluid control in the system, as well as two ultrasonic sensors for reading the liquid level. For the optimization of the compensations of the compensator and the observer linear matrix inequalities (LMI) are used, which in addition to optimizing these gains make the control have a better response in stable state. The implementation of the control is carried out with the help of software and NI-LabVIEW hardware, which provide us with a programming environment for the control algorithm, as well as a data acquisition card to carry out the communication of the control with the system dynamic.

KEYWORDS: Fuzzy logic control. Takagi Sugeno fuzzy model. LMI sliding modes observer.

DISEÑO EXPERIMENTAL DE UN CONTROLADOR-OBSERVADOR DE MODO DESLIZANTE PARA EL SISTEMA HIDRÁULICO DE DOS TANQUES MODELADO TAKAGI-SUGENO

RESUMEN: En este documento, se presenta el diseño y los resultados de un compensador difuso Takagi-Sugeno y un observador como modos deslizantes para un sistema no lineal. El control está diseñado para un sistema de nivel de líquido no lineal que consta de: dos tanques, dos válvulas para control de fluido en el sistema, así como dos sensores ultrasónicos para leer el nivel de líquido. Para la optimización de las compensaciones del compensador y del observador se utilizan desigualdades matriciales lineales (LMI), que además de optimizar estas ganancias hacen que el control tenga una mejor respuesta en estado estable. La implementación del control se realiza con la ayuda del software y hardware de NI_LabVIEW, los cuales brindan un entorno de programación para el algoritmo de control, así como una tarjeta de adquisición de datos para realizar la comunicación del control con el sistema dinámico.
PALABRAS CLAVE: Control con lógica difusa. Modelo difuso Takagi Sugeno. Observador de modos deslizantes LMI.

1 INTRODUCTION

In industrial processes it is required to control or maintain constant variables some variables such as: pressure, flow, level, temperature, pH, speed, etc. for which automatic control is used keeping those variables in the most suitable conditions, that is, at a control point called “set point”. The control system performs these actions comparing the value of the variable or condition with the set point and takes a correction action according to the existing deviation without the intervention of the system operator at all (C.T.Chen, 1999).

Fuzzy logic systems provide a simple and direct way to break down the modeling and control design task into a group of local tasks, which tend to be handled more easily. Fuzzy logic also provides the mechanism to link these local tasks to deliver modeling and complete control design (K. Tanaka, H.O. Wang, 2001).

The fuzzy model consists of decomposing the non-linear system in a simple way, which takes linear local dynamics of the system to handle it more easily. With fuzzy logic we can interpolate all the local models in order to have the best response and complete design of the system (C.T. Chen, 1999).

At present there is a great variety of control techniques which make the design and modeling of a system either linear or non-linear more favorable. These techniques range from classical control, control in the state space, optimal and adaptive control and even robust control.

The Takagi-Sugeno model, which consists of the interpolation of local models, which are given by a set of rules which depend on membership functions which evaluate compliance with the rules.

The tool used in this work for compensator design is linear matrix inequalities (LMI) with which multiple conditions have been solved for analysis and design of control systems, which facilitates the criteria of asymptotic stability, minimization of response times (L. Fortuna, et al. 2012), (S. Boyd, et al., 1994).

Systems with sliding modes have proven to be an efficient technique to control complex high-order nonlinear dynamic plants operating under uncertainty conditions, a common problem for many processes of modern technology. This explains the high level of research and publication activity in the area and unremitting interest of practicing engineers in sliding mode control during the past two decades (B. Castillo-Toledo, J. Anzurez-Marin, 2005).

So in this paper we present the design and results of a Takagi-Sugeno fuzzy controller-observer sliding modes observer for a non-linear liquid level system.

2 METHOD DESCRIPTION

2.1 TAKAGI-SUGENO FUZZY MODEL

The model proposed by Takagi and Sugeno (TS) is described by a fuzzy set rules of the form IF-THEN, which represent linear input-output relationships of a non-linear system. The main characteristic of a Takagi-Sugeno Fuzzy Model (TSFM) is the ability to express the local dynamics of each fuzzy implication (rule) by means of a linear subsystem. The complete fuzzy model of the system is obtained from the fuzzy "combination" of the linear models.

The i-th rule of the TSFM for a continuous System is given by (1).

Rule Model i:

$$\text{IF } z_1\,(\text{t}) \text{ es } M_{i1} \text{ y} \cdots \text{y } z_p\,(t) \text{ es } M_{ip},$$
$$\text{THEN} \begin{cases} \dot{x}(t) = A_i x(t) + B_i u(t), \\ y(t) = C_i x(t), \end{cases} \quad i = 1, 2, \dots, r. \tag{1}$$

where, M_{ij} is the fuzzy set and r is the number of rules; $x(t) \in \boldsymbol{R}^n$ it is the state vector, $A_i \in \boldsymbol{R}^{nxn}$, $B_i \in \boldsymbol{R}^{nxm}$, and $C_i \in \boldsymbol{R}^{qxn}$ are known matrices; $z_1\,(t),\ldots, z_p\,(t)$ they are known premise variables that can be functions of state variables, disturbances or time. We will use $z(t)$ to denote the vector that contains the individual elements $z_1\,(t),\ldots, z_p\,(t)$. It is assumed that the premise variables are not functions of the estimated variables. Each linear equation represented by $A_i\, x(t)+B_i\, u(t)$ it is called a subsystem. The final outputs of the Fuzzy System are expressed as (2) y (3).

$$\dot{x} = \sum_{i=1}^{r} h_i(z)(A_i x + B_i u)\,, \tag{2}$$

$$y = \sum_{i=1}^{r} h_i(z) C_i x\,, \tag{3}$$

where

$$z = [z_1 \quad z_2 \quad \dots \quad z_p], \qquad h_i(z) = \frac{w_i(z)}{\sum_{i=1}^{r} w_i(z)}, \qquad w_i(z) = \prod_{j=1}^{p} M_{ij}(z_j)\,. \tag{4}$$

The fuzzy controller is described as (5)

$$u = -\sum_{i=1}^{r} h_i(z) F_i x\,. \tag{5}$$

The fuzzy observer, for the case in which the variables z(t) do not depend on the estimated variables, it takes the following form (6) y (7).

$$\dot{\hat{x}} = \sum_{i=1}^{r} h_i(z)\{A_i \hat{x} + B_i u + K_i(y - \hat{y})\}\,, \tag{6}$$

$$\hat{y} = \sum_{i=1}^{r} h_i(z) C_i \hat{x}. \tag{7}$$

If the observed states are feedback, the controller is represented as (8).

$$u = -\sum_{i=1}^{r} h_i(z) F_i \hat{x}\,. \tag{8}$$

Combining the controller and fuzzy observer is obtained (9) y (10).

$$\dot{x} = \sum_{i=1}^{r}\sum_{j=1}^{r} h_i(z) h_j(z)\{(A_i - B_i F_j)x + B_i F_j e\}, \tag{9}$$

$$\dot{e} = \sum_{i=1}^{r}\sum_{j=1}^{r} h_i(z) h_j(z)(A_i - K_i C_j)e, \tag{10}$$

where e is the error vector between the state and the estimated state.

The augmented system can be written as (11).

$$\dot{x}_a = \sum_{i=1}^{r} h_i(z)h_i(z)G_{ii}x_a + 2\sum_{i=1}^{r}\sum_{i<j} h_i(z)h_j(z)\frac{G_{ij}+G_{ji}}{2}x\,, \quad (11)$$

where:

$$x_a = \begin{bmatrix} x \\ e \end{bmatrix}, \qquad G_{ij} = \begin{bmatrix} A_i - B_iF_j & B_iF_j \\ 0 & A_i - K_iC_j \end{bmatrix}. \quad (12)$$

2.2 LINEAR MATRIX INEQUALITIES (LMI)

The Linear Matrix Inequalities (LMI) give rise to an important problem of optimization, these constitute a special and wide class of problems of convex optimization that attracts researchers in control. Two reasons that explain this interest are the great variety of specifications and design restrictions that can be expressed through LMI, once the LMI is correctly formulated, a problem can be solved by very efficient algorithms of convex optimization, especially based on internal point methods. Using numerical methods can solve a variety of problems in automatic control whose solution is unknown or do not. The field of application extends to various techniques, such as robust control, optimal control and fuzzy control (K. Tanaka, H.O. Wang, 2001, M. Junca, 2005).

A LMI has the form (13).

$$F(x) = F_0 + \sum_{i=1}^{m} x_iF_i > 0 \quad (13)$$

where: $x^T=(x_1, x_2,\ldots,x_m)$, F_i they are symmetric matrices given, and F(x) >0 it is positive defined.

LMI's are matrices, Lyapunov inequality is used to meet the stability criteria.

The LMI means that F(x) is a positive definite matrix. It can also be given in the form F (x) ≥ 0 it is easy to see that an LMI defines a convex set; that is, the set of X is convex, in addition it does not necessarily have a smooth boundary.

The type of mathematical program that minimizes a linear function with LMI constraints is called a semi-definite program. Inequalities in which variables are matrices with common problems that come from control theory, such is the case of Lyapunov's inequality.

$$A'P+PA<0 \quad (14)$$

where P are n x n symmetric matrices, which is the variable.

A it is a matrix of nxn and P = PT It is the variable. The previous inequality can be expressed as P1, P2, ..., Pm.

2.3 SLIDING MODE OBSERVER APPLIED TO THE SYSTEM WITH DISTURBANCE

For the linear system with disturbance as (15) y (16).

$$\dot{x} = Ax + Bu + Ed, \tag{15}$$

$$y = Cx, \tag{16}$$

where, $d \in \mathbb{R}^p$ is the unknown inputs vector and *E* is the disturbance distribution matrix.

The sliding mode observer we proposed as (17) y (18).

$$\dot{\xi} = A\xi + Bu + K(\hat{y} - y) + \varphi, \tag{17}$$

$$\hat{y} = C\xi, \tag{18}$$

where, φ is the discontinuous vector of sliding mode.

The error is defined as (19).

$$e = x - \xi. \tag{19}$$

The dynamics of the error is (20).

$$\dot{e} = \bar{A}e + Ed - \varphi, \tag{20}$$

where:

$$\bar{A} = A - KC \tag{21}$$

Using the sliding mode fuzzy observer on T-S model.

The dynamics of the error is (23).

$$\dot{e} = \sum_{i=1}^{r}\sum_{j=1}^{r} h_i(z)h_j(z)\left[\left(A_i - K_iC_j\right)e + E_id + \varphi_i\right], \tag{23}$$

It is possible to demonstrate by Lyapunov's stability that the system is stable if

$$\varphi^T = k\,\mathrm{sgn}(e^T P) \tag{22}$$

where, k>0 and P>0 a symmetric matrix such that $A'P+PA<0$ (V. Utkin, et. at. 2009, K. Tanaka, H.O. Wang, 2001, B. Castillo-Toledo, J. Anzurez, 2005).

3 DESCRIPTION OF THE LIQUID LEVEL SYSTEM

The liquid level system consists of two tanks, two electro valves, a pump and a cistern. The system's dynamics are described in general: the pump takes the water from the cistern and carries it to the tank 1, this is connected to the tank 2 and the flow between them is regulated by the electro-valves 1; the electro-valves 2 controls the flow between tank 2 and the cistern.

The electro-valves are controlled by means of a voltage signal. A value of 0 volts causes the valve to close, while a value of 5 volts causes the valve to be open. Intermediate voltage values allow partial openings. Ultrasonic sensors located at the top of each tank are used to measure the liquid level.

The actual system to be controlled is shown in Figure 1. We can see both tanks and their respective sensor located on the top of each, the electro-valves and the cisterns, located in the lower right.

Figure 1. Schematic diagram of the liquid level system.

The dynamics of the system can be described in the space of states through matrices (14).

$$A = \begin{bmatrix} -\frac{R_1}{2C_t\sqrt{h_1}} & -\frac{\sqrt{h_1}}{C_t} & 0 & 0 \\ 0 & -\frac{1}{T_1} & 0 & 0 \\ \frac{R_1}{2C_t\sqrt{h_1}} & \frac{\sqrt{h_1}}{C_t} & -\frac{R_2}{2C_t\sqrt{h_2}} & -\frac{\sqrt{h_2}}{C_t} \\ 0 & 0 & 0 & -\frac{1}{T_2} \end{bmatrix} \tag{24}$$

$$B^T = \begin{bmatrix} 0 & \frac{l_{e1}}{T_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{l_{e2}}{T_1} \end{bmatrix}, \qquad C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

where:

R_1 y R_2 are the opening factors of the electro-valves.

h_1 y h_2 are the desired liquid heights in the tanks.

T_1 y T_2 are the opening time constants of the electro-valves.

L_{e1} y l_{e2} are the constants of proportionality of the electro-valves.

C_t is the transverse area of each tank (both have the same cross-sectional area).

4 THE FUZZY SLIDING MODE COMPENSATOR DESING

The membership functions were chosen as (25) to (28).

$$M_1(x_1) = \left[1 - \frac{1}{1+e^{-35(x_1-\pi/12.5)}}\right]\left[\frac{1}{1+e^{-35(x_1+\pi/12.5)}}\right], \quad (25)$$

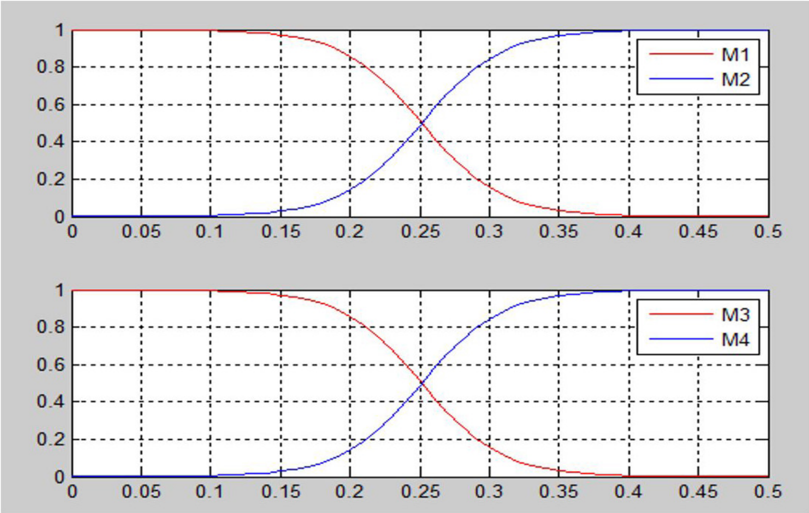
$$M_2(x_1) = 1 - M_1(x_1), \quad (26)$$

$$M_3(x_3) = \left[1 - \frac{1}{1+e^{-35(x_3-\pi/12.5)}}\right]\left[\frac{1}{1+e^{-35(x_3+\pi/12.5)}}\right], \quad (27)$$

$$M_4(x_3) = 1 - M_3(x_3). \quad (28)$$

The membership functions are shown in Figure 2

Figure 2. Membership functions.



Using these fuzzy sets, the nonlinear system may be represented according to the fuzzy model Takagi-Sugeno as:

Rule Model 1:

IF x_1 es M_1 y $x_3(t)$ es M_3,

$$\text{THEN} \begin{cases} \dot{x}(t) = A_1x(t) + B_1u(t), \\ y(t) = C_1x(t). \end{cases} \quad (29)$$

Rule Model 2:

IF x_1 es M_1 y $x_3(t)$ es M_4,

$$\text{THEN} \begin{cases} \dot{x}(t) = A_2x(t) + B_2u(t), \\ y(t) = C_2x(t). \end{cases} \quad (30)$$

Rule Model 3:

IF x_1 es M_2 y $x_3(t)$ es M_3,

$$\text{THEN} \begin{cases} \dot{x}(t) = A_3x(t) + B_3u(t), \\ y(t) = C_3x(t). \end{cases} \quad (31)$$

Rule Model 4:

IF x_1 es M_2 y $x_3(t)$ es M_4, d

$$\text{THEN} \begin{cases} \dot{x}(t) = A_4x(t) + B_4u(t), \\ y(t) = C_4x(t). \end{cases} \quad (32)$$

Where A_i, B_i, y C_i are known dimensions matrices of the subsystems at local region. Table 1, Table 2, Table 3 and Table 4 show the respective values of each subsystem.

Table 1. Operation point of subsystem 1.

$C_t = 0.1482m^2$	
$h_1 = 0.06\ m$	$h_2 = 0.12\ m$
$T_1 = 8.41\ s$	$T_2 = 12.2\ s$
$R_1 = 0.01643$	$R_2 = 0.02213$
$l_{e1} = -0.0022$	$l_{e2} = -0.0022$

Table 2. Operation point of subsystem 2.

$C_t = 0.1482m^2$	
$h_1 = 0.13\ m$	$h_2 = 0.25\ m$
$T_1 = 8.41\ s$	$T_2 = 8.99\ s$
$R_1 = 0.01643$	$R_2 = 0.01643$
$l_{e1} = -0.0021$	$l_{e2} = -0.0021$

Table 3. Operation point of subsystem 3.

$C_t = 0.1482m^2$	
$h_1 = 0.47\ m$	$h_2 = 0.13\ m$
$T_1 = 7.25\ s$	$T_2 = 8.68\ s$
$R_1 = 0.01472$	$R_2 = 0.02213$
$l_{e1} = -0.0021$	$l_{e2} = -0.0023$

Table 4. Operation point of subsystem 4.

$C_t = 0.1482m^2$	
$h_1 = 0.39\ m$	$h_2 = 0.37\ m$
$T_1 = 7.54\ s$	$T_2 = 12.2\ s$
$R_1 = 0.01415$	$R_2 = 0.01586$
$l_{e1} = -0.0021$	$l_{e2} = -0.0021$

Linear Matrix Inequalities (LMIs) that must be resolved to determine the gains Fi and Ki of the fuzzy compensator are:

$$P_1, P_2 > 0,$$

$$P_1 A_i^T - M_{1i}^T B_i^T + A_i P_1 - B_i M_{1i} < 0,$$

$$A_i^T P_2 - C_i^T N_{2i}^T + P_2 A_i - N_{2i} C_i < 0,$$

$$P_1 A_i^T - M_{1j}^T B_i^T + A_i P_1 - B_i M_{1j} + P_1 A_j^T - M_{1i}^T B_j^T + A_j P_1 - B_j M_{1i} < 0, \quad i < j\ s.t.\ h_i \cap h_j \neq \emptyset, \tag{33}$$

$$A_i^T P_2 - C_j^T N_{2i}^T + P_2 A_i - N_{2i} C_j + A_j^T P_2 - C_i^T N_{2j}^T + P_2 A_j - N_{2j} C_i < 0, \quad i < j\ s.t.\ h_i \cap h_j \neq \emptyset.$$

Thus the gains can be calculated as:

$$F_i = M_{1i} P_1^{-1}, \qquad K_i = P_2^{-1} N_{2i}. \tag{34}$$

For the sliding mode vector (φ), the positive definite P matrices were obtained for each subsystem such that it is fulfilled $(P\bar{A} + \bar{A}^T P) < 0$

To reach a constant reference a constant term is introduced in the control, as (35).

$$u = -\sum_{i=1}^{r} h_i(z) * (F_i\hat{x} + v). \tag{35}$$

Which is calculated as:

$$v = H(0)^{-1} * y_d \tag{36}$$

Where: H(0) is the transfer function evaluated in 0 of the system with feedback and yd is the desired output vector.

Thus, the system with fuzzy compensator that reaches a constant reference and observer with sliding modes can be described as (3 7) and (38).

$$\dot{x} = \sum_{i=1}^{r}\sum_{j=1}^{r} h_i(z)h_j(z)[(A_i - B_iF_j)x + B_iF_je + B_iv_i], \tag{37}$$

$$\dot{e} = \sum_{i=1}^{r}\sum_{j=1}^{r} h_i(z)h_j(z)[(A_i - K_iC_j)e + E_id + \varphi_i]. \tag{38}$$

5 RESULT

The first part of the experiment it was determined to use a reference of 20 cm of liquid level for each of the tanks and after some time we changed the reference of both tanks to 10 cm, the control responded of tank 1 and 2 can be seen in Figure 3 and 4. We can see that the observer converges to the 20 cm reference and then responds to the reference chance. The same way we can observe a similar behavior in tank 2 (Figure 4). So, we can observe that the state error converge to zero, Figure 5 y 6.

It is important to show the sliding mode signal that adds strength to the fuzzy observer, in Figure 7 we can observe a high frequency signal once the output reaches the reference.

Figure 3. Response of tank 1 with fuzzy controller and observer.

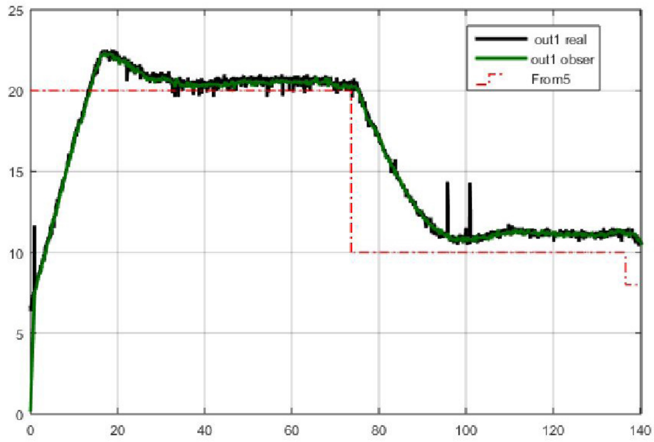


Figure 4. Tank 2 response with fuzzy controller and observer.

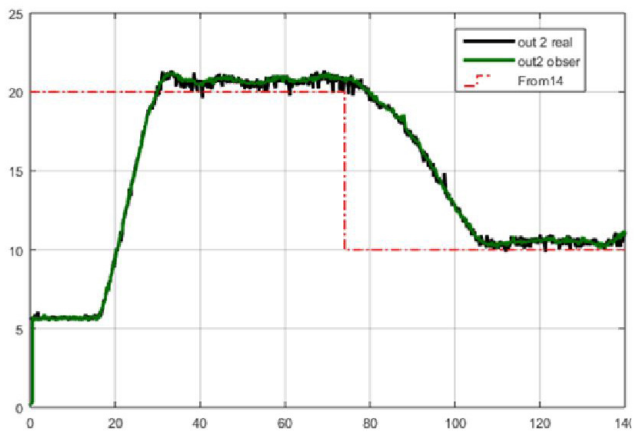


Figure 5. Error of the outputs and observed outputs corresponding to the state x1 and x3 respectively.

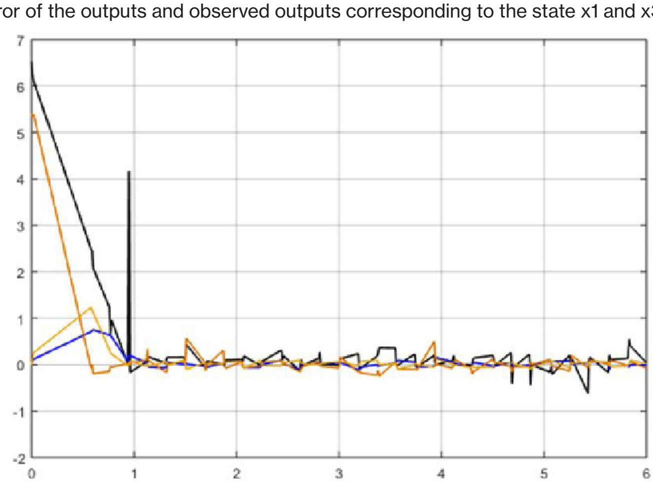


Figure 6. State's error.

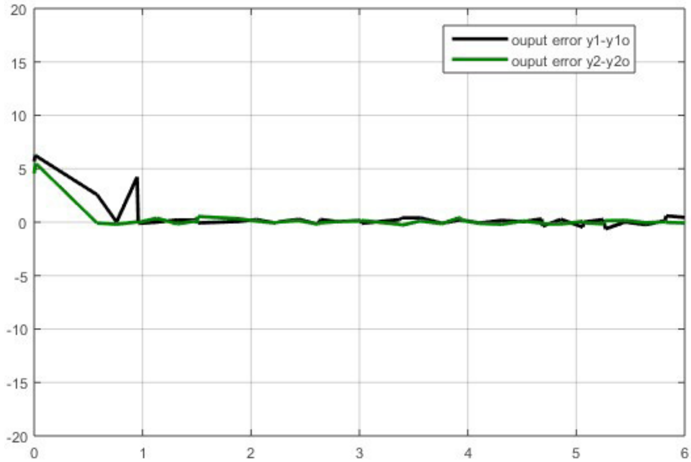
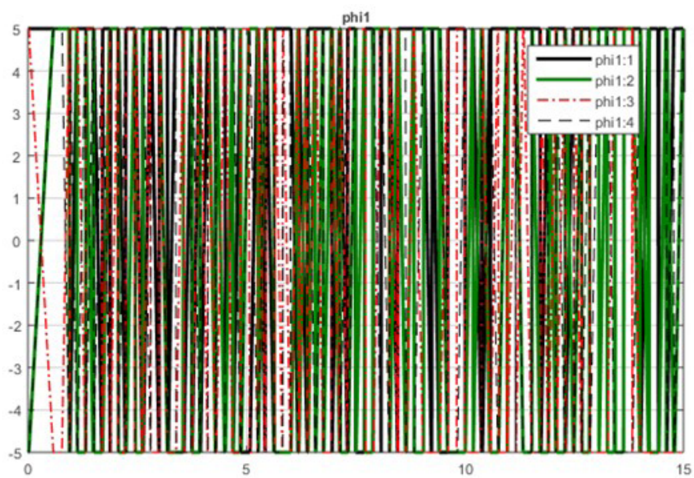


Figure 7. Sliding mode action (Chattering).



4 CONCLUSIONS

In this paper we performed the design and implementation in Real Time of a Takagi-Sugeno fuzzy sliding mode compensator for a second order two tanks liquid level system. In general, it is not easy to determine a control law using classical control to stabilize a nonlinear system. The fuzzy compensator achieved the objective of estimating and control with which the output reaches a constant reference, while the sliding mode fuzzy observer accelerated the process of convergence with the states.

The LMI tools allows to perform a stability analysis and at the same time obtain the compensator's gains.

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SOBRE OS ORGANIZADORES

Jorge Rodrigues é economista. Licenciado, mestre e doutor em Gestão (ISCTE-IUL), com Agregação (UEuropeia). Mestre e pós-doutorado em Sociologia – ramo sociologia económica das organizações (FCSH NOVA). Professor coordenador com agregação no ISCAL – *Lisbon Accounting and Business School* / Instituto Politécnico de Lisboa, Portugal. Exerceu funções de direção em gestão (planeamento, marketing, comercial, finanças) no setor privado, público e cooperativo. Contabilista certificado. É investigador integrado no Instituto Jurídico Portucalense. Ensina e publica nas áreas de empresa familiar e família empresária, estratégia e finanças empresariais, gestão global, governabilidade organizacional, marketing, planeamento e controlo de gestão, responsabilidade social e ética das organizações.
https://orcid.org/0000-0001-7904-0061

Maria Amélia Marques, Doutora em Sociologia Económica das Organizações (ISEG/ULisboa), Mestre em Sistemas sócio-organizacionais da atividade económica - Sociologia da Empresa (ISEG/ULisboa), Licenciada (FPCE/UCoimbra), Professora Coordenadora no Departamento de Comportamento Organizacional e Gestão de Recursos Humanos (DCOGRH) da Escola Superior de Ciências Empresariais, do Instituto Politécnico de Setúbal (IPS/ESCE), Portugal. Membro efetivo do CICE/IPS – Centro Interdisciplinar em Ciências Empresariais da ESCE/IPS. Membro e Chairman (desde 2019 da ISO-TC260 HRM Portugal. Tem várias publicações sobre a problemática da gestão de recursos humanos, a conciliação da vida pessoal, familiar e profissional, os novos modelos de organização do trabalho, as motivações e expectativas dos estudantes Erasmus e a configuração e dinâmica das empresas familiares. Pertence a vários grupos de trabalho nas suas áreas de interesses.
https://orcid.org/0000-0002-7196-3838

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