Journal of Advances in Computer Research
Quarterly ISSN: 2008-6148
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 5, No. 1, February 2014), Pages: 43-51
www.jacr.iausari.ac.ir

Observer based approach for a class of nonlinear systems using Rise feedback controller

Milad Malekzadeh[1 *] and Alireza Khosravi[2]

1. babol university of technology
2. Babol university of technology

milad.malekzade@gmail.com; akhosravi@nit.ac.ir

Received: 2013/07/25; Accepted: 2013/9/10

Abstract

This paper presents a new control scheme for a class of nonlinear systems. In the proposed method, an adaptive neural network observer with Rise feedback controller are applied to realize sensorless control scheme. This observer is tuned online and no exact information of nonlinear term of plant is required. So, this characteristic can compensate mismodeling phenomena. Also, a new controller called Robust Integral of the Sign of the Error (Rise) is considered to realize control purpose. This controller is inspired from 2nd order sliding mode while it can control system with different relative degree. Also, its chattering is acceptable in comparison with sliding mode strategy. This observer based control scheme is considered for modified Duffing chaotic system. The modified Duffing system is derived from Metamorphic shape-changing Underwater autonomous vehicle (MUV). The chaotic behavior of modified Duffing system has a negative impact on MUV performance. Therefore, the controlling of this system can be important. In order to assess the performance of the proposed method, this strategy is compared with observer-based sliding mode control. The comparison results confirm the advantages of proposed method.

Keywords: *Rise feedback, twisting algorithm, neural network, adaptive observer, nonlinear system*

1. Introduction

Due to complexity of nonlinear systems, sometimes modeling of these systems with exact information is not feasible. Therefore; to realize the control purpose the behavior of states must be identified. In order to solve this problem, an observer must be added to control strategy to estimate the trajectory of states.

Observer-based control is one of the famous approaches in control systems. In 1993 Ailon presented observer-based control for robotic manipulator [1]. In [2] this idea was combined with Fuzzy logic. Then Liao presented new observer-based control for chaotic system [3]. This scheme has been improved by scientist in different methods in recent years such as robust or adaptive structure, for instance Tong rendered adaptive observer-based control with Fuzzy structure [4] .And in 2009; an advanced method of observer-based control was considered for robotic system [5].

In this paper a new control strategy is used with the mentioned structure for controlling a class of nonlinear systems. The considered controller within the structure of this strategy is the new RISE feedback controller. This controller is introduced to the control science in 2004 [6]. The strategy of RISE controller is inspired from second-order sliding-mode systems namely super twisting with this difference that this controller could overcome some problems of second-order sliding mode in term of relative degree and also improve the chattering phenomenon. RISE is applied on different plants in recent years for example in [7-8] it is designed as a combination with a neural network in a feed-forward pathway. This control has been combined with Fuzzy for MIMO system and endorses the flexibility of this method [9]. Also this controller was considered for uncertain nonlinear system with delay in [10]. In [11] this strategy is applied on a UAV Rotor-craft base UAV. In 2013 the new paper about the capability of this controller in observer is published [12].

According to what explained, an observer must also be added to the control strategy. In recent years, different observers are introduced to the control science such as extended Kalman Filter and unscented Kalman filter [13-15]. One class of observers that have a good ability in control systems are adaptive controllers where the first observer from this category is introduced in [16]. In this study, we use the adaptive neural network observer in which the neural network weights are tuned online [17]. This observer has been considered for chaotic systems in [18].

The novelty of this paper is assigned to improve the performance of new controller called RISE feedback. This controller gained the derivative of error in its structure. Due to complexity of systems, if all of the states are not be available the performance of this controller will encounter problem. So we added the observer to its structure to unravel this problem. Also we present an observer-based control method that can control the states better than some of the previous method. The comparison section in paper endorses this claim. Another side of view, this controller did not implement on chaotic system while we do it in this paper.

This paper is organized as follows:

In section 2, basic definition of Rise feedback controller is presented. Section 3 deals with the description of adaptive neural network observer. In section 4, the proposed method is rendered and the performance of this control scheme is investigated on a class of chaotic systems. Also, the accuracy of proposed method is evaluated by comparing with observer-based sliding mode control. Conclusion of paper is given in section 5.

2. Robust Integral of the Sign of the Error (RISE) feedback

Consider the single input single output nonlinear system [6]:

$$\begin{aligned} & m(x)x^{(n)} + f(x) = u \\ & y = x \end{aligned} \tag{1}$$

Where $x(t) = [x(t)\ \dot{x}(t) .... x^{(n-1)}(t)]^T \in R^n$ denotes the system state, $y(t) \in R$ is the output and $u(t) \in R$ is the control input. To formulate the controller, tracking error is defined as:

$$e_1 = x_d - x \tag{2}$$

Where $e_1(t)\in R$ is reference trajectory such that $x_d^{(i)}\in L_\infty$. We need the following auxiliary error signals to achieve control low:

$$\begin{aligned} &e_2 = \dot{e}_1 + e_1 \\ &e_3 = \dot{e}_2 + e_2 + e_1 \\ &\bullet \\ &\bullet \\ &e_n = \dot{e}_{n-1} + e_{n-1} + e_{n-2} \end{aligned} \tag{3}$$

As a consequence in [6], the RISE control law is introduced as follows:

$$u(t) = (k_s + 1)e_n(t) - (k_s + 1)e_n(0) + \int_0^t [(k_s + 1)a\,e_n(t) + b\,\mathrm{sgn}(e_n(t))]dt \tag{4}$$

Where a, b, k_s are positive control gains and $\mathrm{sgn}(\bullet)$ denotes the standard *signum* function. As defined in the structure of controller, the definition of error in control effort is depended on the derivative of tracking error. Therefore sometimes for forming control effort, the estimation of some sates is needed. More detail will be presented in simulation section.

3. Adaptive neural network observer

In this section the structure of adaptive neural network will be demonstrated. This observer has been presented by Young H.kim et. al [17]. Consider single input-single output nonlinear plants with (A, C) in observer canonical form:

$$\begin{aligned} &\dot{x} = Ax + b[f(x) + g(x)u + d(t)] \\ &y = C^T x \end{aligned} \tag{5}$$

That $x\in R^n, y\in R, u\in R, b\in R^n$ and $d(t)$ is the unknown disturbance with known upper bound and $f, g : R^n \to R$ unknown smooth function.
The linear system is defined as an observer canonical form if A and C are given as follows:

$$\begin{aligned} &\dot{x} = Ax \\ &y = C^T x \end{aligned}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ & & & & \\ 0 & 0 & \dots & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad C = \begin{bmatrix} 1 \\ 0 \\ . \\ . \\ 0 \\ 0 \end{bmatrix} \tag{6}$$

The nonlinear observer state space equation is assumed as follows:

$$\dot{\hat{x}} = A\hat{x} + b[\hat{f}(\hat{x}) + \hat{g}(\hat{x})u - v(t)] + k[y - C^T \hat{x}]$$
$$\hat{y} = C^T x \qquad (7)$$

There is not any limitation for vector b .

That $\hat{x}$ denotes the estimates of state x and $K = [k_1 k_2 ....k_n]^T$ is the observer gain chosen where $(A - KC^T)$ is strictly Hurwitz. $v(t)$ is robustifying term to control disturbance.

The neural network equation that used in this observer is as follows:

$$f(x) = W_f^T s_f(x) + e_f$$
$$g(x) = W_g^T s_g(x) + e_g \qquad (8)$$

Where consist of two layers, the weight of first layer will be $V = I$ but the second layer weight must be tuned.

One of the advantages of neural network that is used in this paper is that there is no need to data for training. In fact, in [17]; an equation is proposed for training the network using the equations correspondent to the stability of system and provides the value of network weight for system at each moment. Training of this neural network for two nonlinear terms is achieved from the following differential equation:

$$\dot{\hat{W}}_f = F_f \hat{s}_f \tilde{y} - k_f F_f |\tilde{y}| \hat{W}_f$$
$$\dot{\hat{W}}_g = F_g \hat{s}_g \tilde{y} u - k_g F_g |\tilde{y}| \hat{W}_g \qquad (9)$$

Where s denotes the activation function and $\tilde{y} = y - \hat{y}$ .Activation function is applied in the neural networks in different ways. In this observer the activation function for first layer is chosen *sigmoid* and for second layer is chosen *purline.*

The observer used in the proposed method can estimate the trajectory of the states with slightly changes. As mentioned above, to estimate the states, no exact information of the nonlinear term of the system is needed. So this characteristic can cover a considerable part of various situation of the plant.

4. Simulation

The proposed method is exhibited as follows:

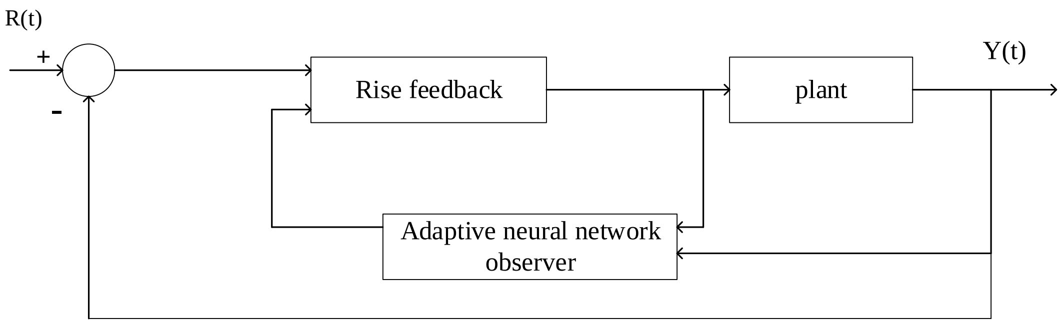

Figure 1. Block diagram of proposed control strategy

As shown above, the neural network observer estimates inaccessible states; Hence Rise feedback controller can control plant according to this sensorless scheme. This method has been implemented on single-link robot by authors [19].

To investigate the accuracy of this control scheme, this method is implemented on modified duffing chaotic system. Consider the following state space equation of modified Duffing system considering $x(0)=[2 \quad 1]$ as an initial condition [20]:

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= -p x_1 - q x_1^3 - (a + b\cos(wt)) x_2 + u(t) + d(t) \\ y &= x_1 \end{aligned} \tag{10}$$

Where $u(t)$ is the control input and $d(t)$ stands for the disturbance. Similarly the system will be of chaotic $p=-1$, $q=1, b=-1, w=1, a=-0.001$ where can be seen is the phase portrait in Fig. 2.

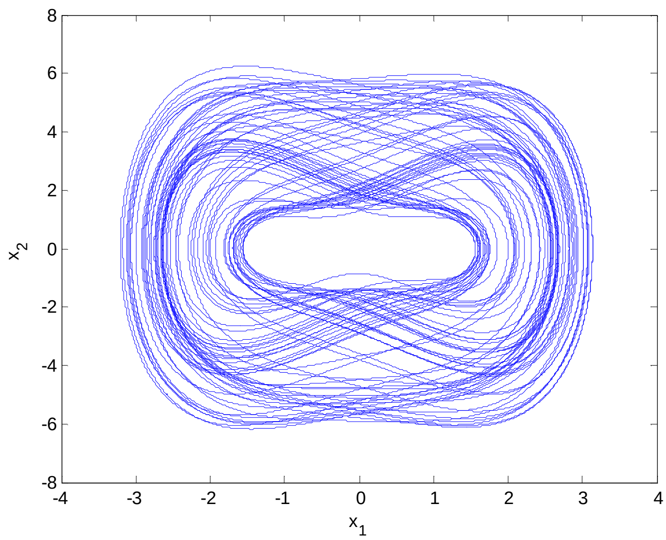

Figure 2. Chaotic behavior of modified Duffing system in 250 seconds

To control chaos phenomena, the reference input must be defined as $x_d = 0$.Then the auxiliary error of Rise feedback is achieved as follows:

$$\begin{aligned} e_1 &= x_d - x = -x_1 \\ e_n &= e_2 = \dot{e}_1 + e_1 = -\hat{x}_2 - x_1 \end{aligned} \tag{11}$$

According to auxiliary error, the second state of plant must be estimated. The derivative of tracking error needs the derivative of output, so another sate of plant that is inaccessible is needed. For this reason we employed the observer to solve this problem.

So, the simulation results of this procedure are presented as follows:

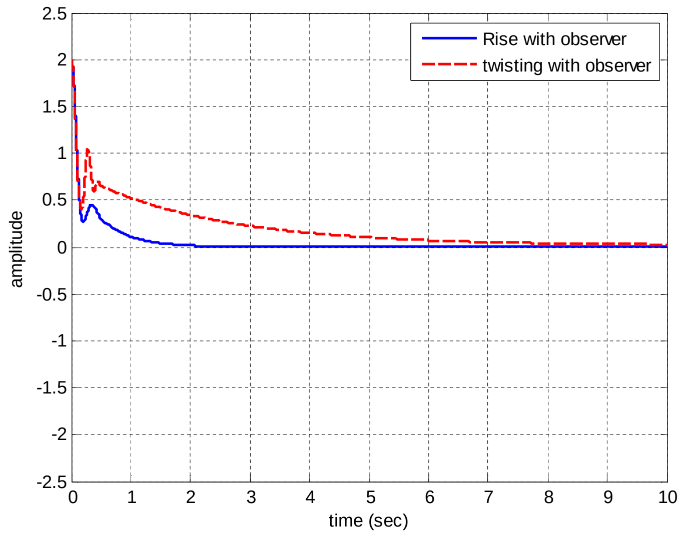

Figure 3. ***State*** x_1 ***applying Rise feedback controller in comparison with twisting algorithm***

As can be seen in Fig. 3, Rise controller could control state x_1 in desirable time in comparison with twisting algorithm. Also the transient response of Rise is more acceptable.

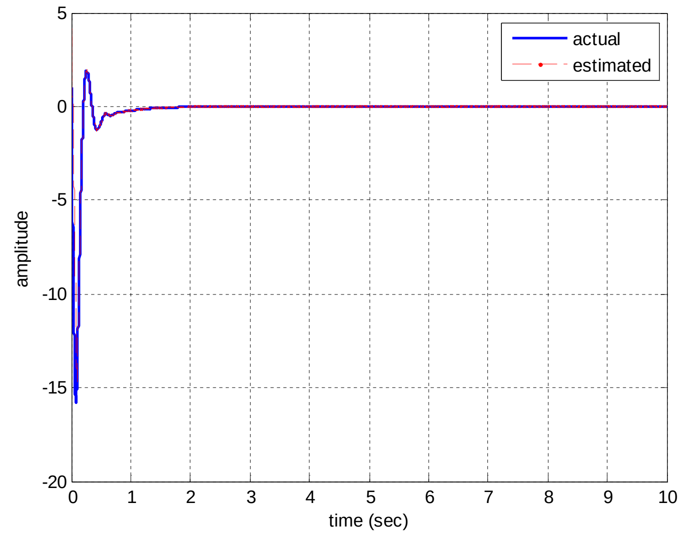

Figure 4. ***State*** x_2 ***applying Rise feedback controller and its estimation***

Similar to first state, the second state of system is controlled in desirable time and this result endorses the capability of proposed strategy. The estimation error of x_2 is presented in fig.5:

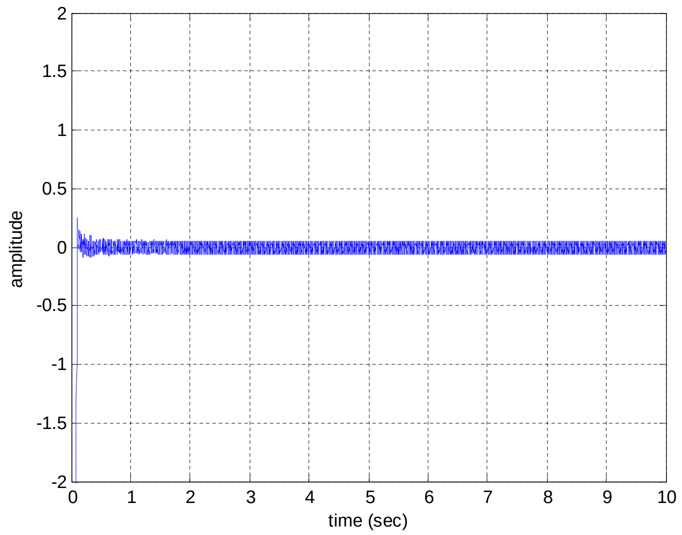

***Figure 5.* Estimation error of** x_2

And in the next figure the performance of this method is compared with twisting algorithm for second state:

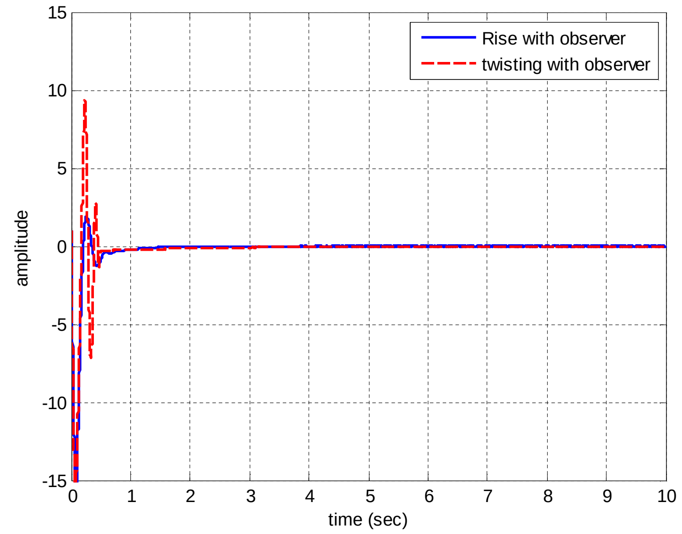

Figure 6.* State** x_2 ***applying Rise feedback controller in comparison with twisting algorithm

The convergence time of Rise feedback is slightly better than twisting algorithm while the transient response of Rise is significantly better. The control effort of Rise feedback and twisting algorithm are shown as follows:

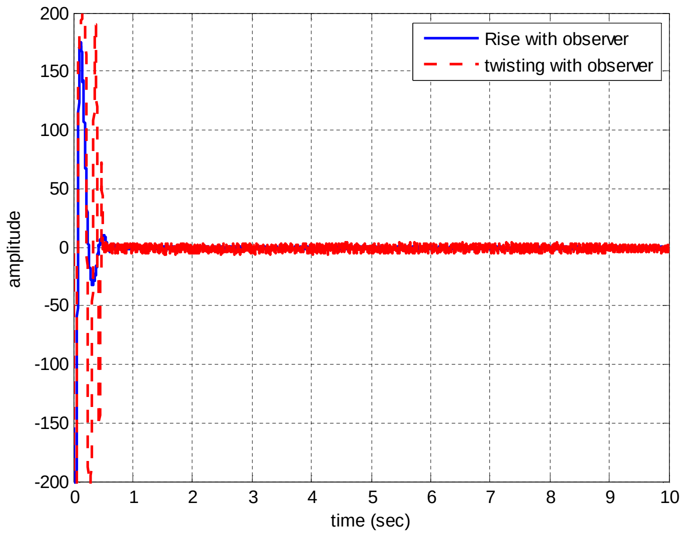

Figure 7. Control effort

As was mentioned the chattering of Rise feedback is better than sliding mode controller. Also better transient response of Rise feedback confirms the advantages of proposed method.

5. Conclusion

In this study, a new control strategy has been presented for a class of chaotic system. This control strategy applies an intelligent observer with RISE feedback controller to realize sensorless control scheme. Due to presence of neural network in the structure of the observer, its flexibility to estimate the unavailable states is desirable. Also, the controller employed in proposed scheme presents good ability to handle disturbances and uncertainties. To investigate the capability of this strategy, proposed method has been implemented on modified duffing chaotic system and the performance of this scheme has been compared with observer-based sliding mode control. The comparison results exhibit Better transient response and less chattering for proposed method in comparison with observer-based sliding mode control.

6. References

[1]. A.Ailon, R.Ortega “An observer-based set-point controller for robot manipulators with flexible joints”, System & control letters, vol. 21, pp 329-335, .1993.

[2]. H.Schneider, P.M.Frank“Observer-based supervision and fault detection in robots using nonlinear and fuzzy logic residual evaluation”, IEEE Transaction on control systems technology, vol. 4, pp 274-282, .1996.

[3]. T.Lu Liao “Observer-based approach for controlling chaotic systems”, Physical reviiew E, vol. 57, pp 1604-1610, 1998.

[4]. S.Tong, H.Xiong, W.Wang “Observer-based adaptive fuzzy control for SISO nonlinear systems”, Fuzzy sets and systems, vol. 148, pp 355-376, 2004.

[5]. N.Gole, A.Gole, K.Barra, T.Bouktir “Observer-based dynamic walking control for biped robots”, Robotics and Autonomous systems, vol. 57, pp 839-845, 2009.

[6]. B.Xian, D.M.Dawson, M.S. de Queiroz and J.Chen “A continues asymptotic tracking control strategy for uncertain nonlinear systems”, IEEE Trans.Auto.Ctrl, Vol 49, no 7, pp 1206-1211, 2004.

[7]. Parag M.Patre, William MacKunis, Kent Kaiser and Warren E.Dixon “Asymptotic tracking for uncertain dynamic systems via multilayer neural network fedforward and rise feedback control structure”, IEEE Trans.Auto.Ctrl, Vol 53, no 9, pp 2180-2185, 2004.

[8]. Travis Dierks, S.Jagannathan “Neural network control of mobile robot formations using rise feedback”, IEEE Trans. On systems, Man, and Cybernetics-Part B: Cybernetics, Vol 39, no 2, pp 332-347, 2009.

[9]. D. Kim, H.Chung , S.Bhasin , W.E.Dixon “Robust compositr adaptive fuzzy identification and control foe a class of MIMO nonlinear systems.”, American control conference, San Francisco,CA, USA, 2011.

[10]. N. Fischer, R.Kamalapurkar , N.Sharma , W.E.Dixon “ Rise-based control of an uncertain nonlinear system with time-varying state delay”, IEEE conference on decision and control, USA, 2012.

[11]. Shin, H.Jin Kim, Youdan Kim and Warren E.Dixon “Autonomous flight of rotorcraft based UAV using rise feedback and NN feedforward terms”, IEEE Trans on Ctrl systems tech., Vol 20, no 5, pp 1392-1399, 2012.

[12]. Yang Yang, S.N.Balakrishnan L.tang, R.G. landers“ Electrohydraulic control using neural MRAC based on a modified state observer”, IEEE/ASME Transaction on Ctrl Mechatrinic., Vol 18, no 3, pp 867-877, 2013.

[13]. L.Ljung, “Asymptotic behavior of the extended kalman filter as a parameter estimator for linear systems”, IEEE Transaction.Automat.Contr.AC-24, pp. 36-50, 1979 .

[14]. Y.Song and J.W.Grizzle, “The extended Kalman filter as a local asymptotic observer for nonlinear discrete-time systems” , in Proc.Amer.Contr.Conf.pp.3365-3369.1992

[15]. J.Julier and K.Uhlmann, “A new method for nonlinear transformation of means and covariances in filter and estimation”, IEEE Trans. Autom. Control, Vol 45, no 3, pp 477-482, 2000.

[16]. R. Marino, “Adaptive observers for single output nonlinear systems”, IEEE Trans. Auto. Cfrl, Vol 35, no 9, pp 1054-1058, 1990.

[17]. Young H.Kim, Frank L. Lewis and Chaouki T.Abdallahs, “A dynamic recurrent neural network based adaptive observer for a class of nonlinear systems”, Automatica, Vol 33, no 8, pp 1539-1543, 1997.

[18]. M.Malekzadeh, A.Khosravi, A.Ranjbar, R.Ghaderi “Application of adaptive neural network observer in chaotic systems”, IJISA, Vol 6, no 2, pp 37-43, 2014.

[19]. M.Malekzadeh, A.Khosravi, P.Sarhadi, R.Ghaderi “Rise feedback controller design of single-link robot with an adaptive neural network observer”, IJMEC, Vol 4, pp 126-137, 2014.

[20]. Dongchuan Yu, Dongqing Wang, Ninhua Xia “A class of nonlinear PID control for modified Duffing system”, Proceeding of the 2006 American control conference Minneapolis, Minniestota, IEEE.2006