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Chaotic satellite synchronization using neural and nonlinear controllers

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ABSTRACT

In this paper, two master and slave chaotic satellites will be synchronized acceptably using two different control methods. The first method is based on the neural networks in which two neural controllers called NARMA-L2 and Predictive controllers will be designed. In the second method a Nonlinear controller is designed by the Feedback linearization approach. The simulation results of the designed controllers have been compared with a performed control method called Active control to verify the effectiveness of the proposed controllers and to show the advantages and disadvantages of each one.

1. Introduction

Satellites may exhibit chaotic behavior in gravitational and geomagnetic fields and solar radiation pressure [1,2]. On the other hand, it is so difficult or impossible to do some missions by only one satellite. These missions include the Earth observation and space observation missions that can become more accurate by several synchronized satellites. Some of the other benefits of the satellite synchronization are the decrease in the risk of total mission failure that is critical for important missions, to solve more difficult and expensive assignments and to reduce the launch costs by deploying small satellites in clusters [3,4]. The synchronization and attitude control of the chaotic satellites is an essential subject in the formation flying field. The attitude dynamics of the chaotic satellite is kind of extreme nonlinear dynamics with fast and chaotic behaviors [5]. Chaos is a very complex and nonlinear phenomenon that its most important feature is extreme sensitivity to initial conditions [6]. Over the past two decades, the control and synchronization of chaotic dynamic systems have attracted the interest of many researchers. The chaos has been applied in many subjects such as laser [7], electronics [8], secure communications [9], synchronization of chaotic gyroscopes [10], synchronization and control of chaotic satellites [5,11,12], cryptography [13] and medical applications [14].

The synchronization of chaotic dynamic systems means applying some changes to one of the systems or both of them thus both of them will act the same. In 1990, Pecora and Carrol showed that the chaotic systems can be synchronized under some special conditions [15]. After that, several techniques were evaluated for the synchronization of chaotic dynamic systems such as adaptive control [3,16], fuzzy control [10], impulsive control [17] and backstepping control [18]. Up until recently, the synchronization controlling in complex networks has been studied extensively. In [19–21], some of the recent studies about the synchronization controlling in complex networks have been presented.

In this paper, two different control methods have been presented that in the first method, two neural network controllers called NARMA-L2[1] and Predictive controllers are applied. This approach is inspired by nature and has been applied very successfully in the identification and control of dynamic systems. In the second method, a Nonlinear controller is designed by the Feedback linearization approach and finally a stabilization proof will be done.

2. The attitude dynamics of the chaotic satellite

In this paper, two satellites are considered as two rigid bodies with three degrees of freedom and the rotational kinetics equations called Euler equations have been considered as the satellite

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[1] Nonlinear Autoregressive-Moving Average L2.

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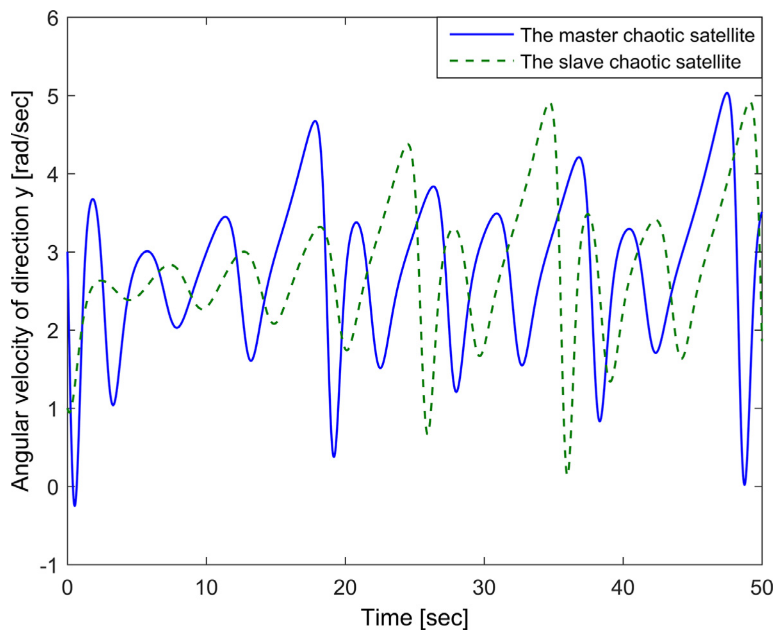

Fig. 1. The angular velocities of two chaotic satellites in y axis using no controllers.

plant, which are as follows [22].

$$\vec{T} = \vec{T}_c + \vec{T}_d = \dot{\vec{h}}_I = \dot{\vec{h}}_B + \vec{\omega} \times \vec{h} \Rightarrow \begin{matrix} T_x = I_x\dot{\omega}_x + \omega_y\omega_z(I_z - I_y) \\ T_y = I_y\dot{\omega}_y + \omega_x\omega_z(I_x - I_z) \\ T_z = I_z\dot{\omega}_z + \omega_x\omega_y(I_y - I_x) \end{matrix} \quad (1)$$

where T is the applied torque to the satellite, h is the angular momentum, I is the moment of inertia and ω is the angular velocity of the satellite. The indices of $_I$, $_B$, $_c$ and $_d$ respectively show the inertial and body coordinate systems and control and disturbance torques. Eq. (2) is the rearrangement of the Euler equations in which the indices of $_S$ and $_M$ respectively show the slave and master satellites. They are different only in the initial conditions of the angular velocities.

$$\begin{cases} \dot{\omega}_{xS} = 1/I_x \times \left(Tc_x + Td_{xS} - \omega_{yS}\omega_{zS}(I_z - I_y)\right) \\ \dot{\omega}_{yS} = 1/I_y \times \left(Tc_y + Td_{yS} - \omega_{xS}\omega_{zS}(I_x - I_z)\right), \\ \dot{\omega}_{zS} = 1/I_z \times \left(Tc_z + Td_{zS} - \omega_{xS}\omega_{yS}(I_y - I_x)\right) \end{cases}$$
$$\begin{cases} \dot{\omega}_{xM} = 1/I_x \times \left(Td_{xM} - \omega_{yM}\omega_{zM}(I_z - I_y)\right) \\ \dot{\omega}_{yM} = 1/I_y \times \left(Td_{yM} - \omega_{xM}\omega_{zM}(I_x - I_z)\right) \\ \dot{\omega}_{zM} = 1/I_z \times \left(Td_{zM} - \omega_{xM}\omega_{yM}(I_y - I_x)\right) \end{cases} \quad (2)$$

By applying different values of the torques to the systems, different behaviors will be observed. By applying the chaotic torques that have been used in [5,12], two satellites will become chaotic. An example of these chaotic behaviors has been shown in Fig. 1. The chaotic torques are obtained according to (3).

$$\begin{cases} Td_{xS} = -1.2\omega_{xS} + \sqrt{6}/2 \times \omega_{zS} \\ Td_{yS} = 0.35\omega_{yS} \\ Td_{zS} = -\sqrt{6}\omega_{xS} - 0.4\omega_{zS} \end{cases}, \begin{cases} Td_{xM} = -1.2\omega_{xM} + \sqrt{6}/2 \times \omega_{zM} \\ Td_{yM} = 0.35\omega_{yM} \\ Td_{zM} = -\sqrt{6}\omega_{xM} - 0.4\omega_{zM} \end{cases} \quad (3)$$

The goal is to design controllers to make synchronization errors approach zero. In the following, three appropriate controllers will be designed.

3. Controller design

3.1. Neural network controllers

The universal approximation capabilities of the multilayer neural networks make it a popular choice for modeling nonlinear systems and for implementing general-purpose nonlinear controllers [23]. There are typically two steps involved when using neural networks for control, which include system identification and control design [24]. In the system identification stage a neural network model of the satellite plant (Euler equations) is defined by training and then in the control design stage the neural network will be used to control the satellite plant. The system identification process is identical for both of the NARMA-L2 and Predictive neural controllers, but the control design stage is different for each of them. In the NARMA-L2 neural controller, the controller is simply a rearrangement of the neural network plant model. In the Predictive neural controller, the neural network plant model will be used to predict future behavior of the plant and an optimization algorithm is used to select the control input that optimizes future performance of the plant [24].

3.1.1. The NARMA-L2 neural controller

The idea of this control method is to estimate the Euler equations by training of a neural network model. So the output of the trained neural network model is the estimated angular velocity of the chaotic satellite. The structure of this estimated Euler equations is the NARMA-L2 model. One standard model that has been used to represent general discrete-time nonlinear systems is the NARMA model that is as follows [24].

$$y(k+d) = F[y(k), y(k-1), ..., y(k-n+1), u(k), u(k-1), ..., u(k-n+1)] \quad (4)$$

where $u(k)$ is the system input (torque), $y(k)$ is the system output (angular velocity), k is the time, d is the dead time (delay) and n is the order of the SISO[2] nonlinear system. This model implies that an input at time k produces the output at time d later. In the

[2] Single-Input Single-Output System.