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Advances in Space Research 57 (2016) 367–377

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Adaptive attitude controller for a satellite based on neural network in the presence of unknown external disturbances and actuator faults

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Received 18 June 2015; received in revised form 18 October 2015; accepted 20 October 2015
Available online 26 October 2015

Abstract

In this paper, an adaptive attitude control algorithm is developed based on neural network for a satellite. The proposed attitude control is based on nonlinear modified Rodrigues parameters feedback control in the presence of unknown terms like external disturbances and actuator faults. In order to eliminate the effect of the uncertainties, a multilayer neural network with a new learning rule will be designed appropriately. In this method, asymptotic stability of the proposed algorithm has been proven in the presence of unknown terms based on Lyapunov stability theorem. Finally, the performance of the designed attitude controller is investigated by simulations.
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Keywords: Actuator faults; Adaptive control; Attitude; External disturbances; Neural network; Satellite

1. Introduction

Attitude determination and control system (ADCS) is an important subsystem of a satellite. ADCS is responsible for stabilizing and pointing satellite to a specified target in space missions. This subsystem has different parts including, sensors, actuators, control algorithm and electronic control board. The control algorithm is an important part of ADCS that provides commands for actuators.

Difficult problems in the design of control algorithm for such a complex and nonlinear dynamic system are due to the inherent nonlinearities of the model because of large angle maneuvers, uncertainties and unknown environmental disturbances. Although many classical controllers for satellite attitude control have already been proposed (Moradi, 2013; Hu and Xiao, 2012; Shahravi, et al., 2006), neural networks are promising tools for control applications because they are capable of approximating any well-behaved nonlinear function to any desired accuracy.

Always, uncertainty in complicated system is an important problem. Adaptive control is one of the important controller to overcome this problem. In Slotine and DiBenedetto (1990), Junkins et al. (1997), and Sheen and Bishop (1994) an adaptive controller was developed to estimate the model uncertainty and uncertain moment of inertia based on the feedback linearization. Most of the previous proposed adaptive control methods deal with the unknown parameters. Furthermore, the attitude control of satellite based on the feedback linearization is dependent on the initial conditions due to singularity problem (Paynter and Bishop, 1997). However, in the satellite, the uncertainties are nonlinear caused by different sources (Leeghim et al., 2009; Lee et al., 2002). In recent years, the use of intelligent systems such as neural networks, fuzzy systems, fuzzy-neural network systems and etc. have been proposed to estimate unknown variables and parameters of the satellite dynamic. A lot of works has been performed

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http://dx.doi.org/10.1016/j.asr.2015.10.026
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Nomenclature

$Ci\ (i = 0, 1, 2, 3)$	computable positive known constants	x	input vector to NN
e	tracking error	Z	matrix of all NN weights
G	constant matrix	Δ	uncertain term (external disturbances)
I	identity matrix	$\hat{\Delta}$	estimation of uncertain term
J	inertia matrix of satellite	$\tilde{\Delta}$	approximation error of uncertain term
K	positive constant	δ	disturbance term of error system equation
K_v	PD controller gain	ε	function reconstruction error
K_z	gain of robust term	υ	robust term
M	constant matrix	Ξ	activation function
N_0	mean orbital rate of the satellite	σ	modified Rodrigues parameters
$O()^2$	terms of order 2	σ_d	desired modified Rodrigues parameters
s	filtered error	Φ_d	known constant
u	control torque	$[\phi \quad \theta \quad \psi]$	Euler angles of the satellite
V	ideal first layer weight matric of NN	$[\phi_d \quad \theta_d \quad \psi_d]$	desired Euler angles of the satellite
W	ideal second layer weight matric of NN	$[\phi_0 \quad \theta_0 \quad \psi_0]$	initial Euler angles of the satellite
$\hat{V}$	actual value of first layer weight matric of NN	ω	angular velocity of the satellite
$\hat{W}$	actual value of second layer weight matric of NN	ω_0	initial angular velocity of the satellite
$\tilde{V}$	approximation error of first layer weight matric of NN	Λ	positive definite designing parameter matrix
$\tilde{W}$	approximation error of second layer weight matric of NN	$(\ )_F$	converged ideal matrix
		$(\ )_M$	upper bound of matrix

in estimation of system states by the neural network. However, minor works has been performed in estimation of the unknown parameters of the system using neural network. In Zhenning and Balakrishnan (2005) and Atenica et al. (2005), a Hopfield neural network is designed to estimate the unknown parameters of the nonlinear system of an aircraft and robotic arm. This method was based on the linearization of the system dynamic model.

Neural networks has many advantages over common adaptive controllers in providing desired system performance. Neural networks are used in various applications, especially pattern recognition, identification, estimation, and control of dynamic systems (Yesildirek and Lewis, 2001; Lee and Kim, 2001). For example, different methods have been proposed in the control and estimation of aircrafts and helicopters using neural network (Hovakimyan et al., 2002; Kim and Calise, 1997; Leitner et al., 1997). Adaptive output feedback control using a high-gain observer and radial basis function neural network was proposed for nonlinear dynamic equations represented by input–output models (Khalil, 1996). Also, a nonlinear adaptive flight control system was designed by backstepping and neural network controller (Lee and Kim, 2001). Lewis et al. designed a multilayer neural network robot controller with a novel on-line weighted tuning algorithm by filtered error approach to estimate the unknown dynamic model of a robot (Lewis et al., 1999; Lewis et al., 1996). Weighted tuning algorithms, including correction terms to the delta rule plus an added robustifying signal, guarantee bounded tracking errors as well as bounded neural network weights.

Most pervious works have capability of parameters estimation but not function estimation. Moreover, some of them use linearization to simplify the dynamic model, and some of them encountered chattering problems. In this paper we will consider external disturbances, dynamic model uncertainty and actuator fault as an uncertain function to be estimated. So, we have developed an adaptive neural network controller for attitude control of a satellite in the presence of unknown external disturbances or dynamic model uncertainty. For this purpose, the well-known modified Rodrigues parameters feedback law will be developed with the three-layered neural network based on (Lewis et al., 1996) to estimate the unknown function represent the external disturbances or dynamic model uncertainty. The proposed adaptive neural network is based on modified Rodrigues parameters controller using new weight updates rule. Advantages of using modified Rodrigues parameters representation include: (1) rotations of up to 360° are possible, (2) the parameters form a minimal parameterization (Crassidis and Markley, 1996) and (3) by using modified Rodrigues parameters, we can rewrite the dynamic equations to develop the adaptive-neural network controller. By using modified Rodrigues parameters and nonlinear model of dynamic, singularity and chattering problem have been solved and the stability of the proposed adaptive neural network controller has

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