ARTICLE IN PRESS
JID: CAEE [m3Gsc;November 14, 2017;20:57]

Computers and Electrical Engineering 000 (2017) 1–18

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

Backstepping terminal sliding mode control of robot manipulator using radial basis functional neural networks☆

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ARTICLE INFO

Article history:
Received 30 April 2017
Revised 28 October 2017
Accepted 7 November 2017
Available online xxx

Keywords:
Robot manipulator
Neural network (NN)
Backstepping terminal sliding mode control
Adaptive control
Position tracking
Disturbance rejection

ABSTRACT

This paper examines an observer-based backstepping terminal sliding mode controller (BTSMC) for 3 degrees of freedom overhead transmission line de-icing robot manipulator (OTDIRM). The control law for tracking of the OTDIRM is formulated by the combination of BTSMC and neural network (NN) based approximation. For the precise trajectory tracking performance and enhanced disturbance rejection, NN-based adaptive observer backstepping terminal sliding mode control (NNAOBTSMC) is developed. To obviate local minima problem, the weights of both NN observer and NN approximator are adjusted off-line using particle swarm optimization. The radial basis function neural network-based observer is used to estimate tracking position and velocity vectors of the OTDIRM. The stability of the proposed control methods is verified with the Lyapunov stability theorem. Finally, the robustness of the proposed NNAOBTSMC is checked against input disturbances and uncertainties.

1. Introduction

Transmission line icing is one of the most significant factors that affects safety and reliability of a power system. The adverse impact of icing on transmission lines can result in tower collapse, unnecessary tripping and power outages. Robot manipulator de-icing technology can mitigate icing problems without interrupting power supply on transmission lines. The exact dynamics of the robot manipulator are not available to design a perfect controller. This is due to the nonlinearities, model uncertainties, elasticity, cross coupling and frictional effects that increase the system complexity. One of the main objectives of a robotic manipulator controller is to generate a control signal that helps to track the reference trajectory [1,2]. Nonlinear control techniques, such as sliding mode control (SMC), artificial intelligence based adaptive control techniques help to enhance the performance of conventional control techniques. Many researchers have analyzed that SMC is one of the best nonlinear controllers that provides fast response in terms of trajectory tracking and disturbance rejection [3–6].

In the conventional sliding mode control, the convergence of the state is usually asymptotic due to the linearity of the switching plane. However, this convergence can only be achieved in infinite time, although the SMC parameters can be adjusted to make convergence faster. For high-precision control systems, faster convergence is the priority and can only be achieved at large control inputs. These large control inputs can lead to saturation of the actuator. The terminal sliding mode control (TSMC) includes nonlinear function in the outline of the sliding hyperplane. By using a nonlinear sliding surface,

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. A. Chaudhary.

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https://doi.org/10.1016/j.compeleceng.2017.11.007

TSMC enables the rapid convergence of the state without the need for an extensive control action. A nonsingular terminal sliding mode manifold is used to design a chattering free adaptive control scheme for the robot manipulator [7]. In [8], an adaptive TSMC regulated a 2-link robot manipulator to track the variable signals. However, the significant drawback of the TSMC is chattering phenomenon that includes high-frequency oscillations due to discontinuous control signals.

The combinations of artificial intelligence with SMC techniques to control the nonlinear systems are addressed in [9–12]. In [13], a new adaptive backstepping SMC (ABSMC) scheme with fuzzy monitoring technique is discussed for the desired trajectory tracking control of nonlinear systems. The neural network (NN) is utilized to approximate or estimate uncertainties and disturbances of the unknown model in [14,15]. Authors in [16], have developed control methodology based on output-feedback to keep up the predefined control execution for a class of uncertain MIMO nonlinear systems. In [17], a versatile control based radial basis neural network (RBFNN) is designed for a variable-pitch and variable-speed wind turbine. Fuzzy logic controller (FLC) based methodologies have been developed for the robot manipulator in the presence of structured and unstructured disturbance conditions [18,19]. The propulsive positioning and on-line levitated balancing of a hybrid magnetic levitation are achieved by fuzzy neural based backstepping SMC scheme in [20]. Several researchers proposed disturbance observer (DOB) for SMC to mitigate the chattering phenomenon and retain its desirable control behavior under the presence of mismatched uncertainties [21–23].

In this paper, we discuss different control methods of the 3 degrees of freedom (DOF) overhead transmission line de-icing robot manipulator (OTDIRM) to eliminate the effects of disturbance and uncertainty associated with direct measurements. The designing of a new controller considers the combination of modified backstepping TSMC (BTSMC) with NN identifier and NN observer. The optimal weights of the NN observer, NN identifier, and the BTSMC parameters are obtained with the help of particle swarm optimization (PSO). Estimated position and velocity vectors of the RBFNN based observer are fed to another RBFNN based identifier to approximate the auxiliary control input torque to the de-icing robot manipulator. The chattering effect is mitigated by utilizing boundary layer phenomenon, and the Lyapunov stability test ensures the stability of the anticipated control strategy.

In [5], the authors discussed conventional SMC based on the chemical reaction optimization and radial basis functional link net (CRLSMC) for the de-icing robot manipulator to achieve desired trajectory tracking performance under various operating conditions. In [12], authors have designed a conventional SMC scheme based on NN for better trajectory tracking of the mobile robot manipulator. The position control of the 2-link robot manipulator is designed by considering the combination of conventional SMC and NN based observer [14]. In [15], the wavelet neural network (WNN) based controller is designed for the de-icing robot manipulator without consideration of an observer-based control structure. This paper mainly differs from [5], [12], [14] and [15], by replacing conventional SMC with modified backstepping TSMC scheme in combination with PSO based observer and identifier. Several performance methods are examined to show the effectiveness of the proposed control technique.

The structure of this paper is dealt with as follows: Section 2 addresses the description of the robot manipulator. It also demonstrates the design of BTSMC and NNBTSMC with stability analysis. NN based versatile observer framework and control designs are discussed in Section 3. Section 4 presents simulation verification. Finally, Section 5 concludes the paper.

2. Description of controlling sytems

Dynamic equation of the robot manipulator with n-DOF can be characterized as:

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) + F(q,\dot{q}) + \tau_d = \tau \tag{1}$$

where q, $\dot{q}$ and $\ddot{q} \in R^n$ are the link position, velocity and acceleration vectors respectively, $D(q) \in R^{n\times n}$ is the symmetric positive definite inertia matrix, $C(q,\dot{q})\dot{q} \in R^{n\times n}$ is the Coriolis or centrifugal forces, $G(q) \in R^{n\times 1}$ consolidates the gravitational force, $F(q,\dot{q}) \in R^{n\times 1}$ incorporates the friction terms and τ_d represents external disturbances [24].

Dynamic equation (1) can be composed as:

$$\ddot{q} = D^{-1}(q)[\tau - (C(q,\dot{q})\dot{q} + G(q) + F(q,\dot{q}) + \tau_d)] \tag{2}$$

2.1. Design of BTSMC

The backstepping methodology is a nonlinear scheme generally utilized as a part of controller design. The mathematical model of the robot manipulator is expressed in (3)–(5) as:

$$\dot{x}_1 = x_2 \tag{3}$$

$$\dot{x}_2 = \ddot{q} = D^{-1}(q)[\tau - (C(q,\dot{q})\dot{q} + G(q) + F(q,\dot{q}) + \tau_d)] \tag{4}$$

$$y = x_1 \tag{5}$$

where x_1 and x_2 are the position and velocity vectors of the robot manipulator. The tracking error of the position is given as:

$$e_1 = q_d - q \tag{6}$$

Please cite this article as: M. Vijay, D. Jena, Backstepping terminal sliding mode control of robot manipulator using radial basis functional neural networks, Computers and Electrical Engineering (2017), https://doi.org/10.1016/j.compeleceng.2017.11.007