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Real time implementation of non linear observer-based fuzzy sliding mode controller for a twin rotor multi-input multi-output system (TRMS)

Samir Zeghlache[a,*], Nourredine Amardjia[b,c]

[a] LASS Laboratory, Department of Electronics, Faculty of Technology, University of Msila, BP 166 Ichbilia, Msila, Algeria
[b] Department of Electronics, Faculty of Technology, University Ferhat Abbas – Setif 1, Algeria
[c] LIS Laboratory, University Ferhat Abbas – Setif 1, Algeria

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ABSTRACT

Control of the helicopter includes nonlinearities, coupling and external perturbations. This paper presents a control strategy for TRMS (twin rotor mimo system), based on the coupling of the fuzzy logic control with the so-called sliding mode control to make its beam track accurately a reference signal, or reach desired positions in 2 DOF (degree of freedom). Only yaw and pitch angles are considered available for measurement. A non linear observer is used to estimate the unmeasured states. The proposed control scheme can be attenuating the chattering effect of the sliding mode control. Exponential stability is guaranteed by using the Lyapunov method.

To show the effectiveness of the proposed observer-based robust controller is illustrated by simulation and experimental results. The real time implementation has been effectuated to the real TRMS system using MATLAB real-time tool box and Advantech PCI1711 card.

1. Introduction

Sliding mode control (SMC) techniques [1–5] have been widely applied to the field of robust control, especially in a nonlinear system. The SMC provides discontinuous control laws to drive the system states to a specified sliding surface and to keep them on the sliding surface. The dynamic performance of the SMC has been adopted as an effective robust control approach for the problems of system uncertainties and external disturbances. However, this control strategy produces some drawbacks associated with large control chattering that may wear coupled mechanisms and excite undesirable high-frequency dynamics.

Several methods of chattering reduction have been reported. One approach [6] places a boundary layer around the switching surface such that the relay control is replaced by a saturation function. Another method [7] replaces a max-min type control by a unit vector function. These approaches, however, provide no guarantee of convergence to the sliding mode and involve a tradeoff between chattering and robustness.

Recently, the fuzzy sliding mode control (FSMC) proposed in [8–13] is a hybrid of the SMC and fuzzy logic control (FLC), gives a simple way to design the controller systematically and provides the asymptotical stability of the system. In general,

* Corresponding author.
E-mail addresses: zegsam5@gmail.com (S. Zeghlache), amardjia_nour@yahoo.fr (N. Amardjia).

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the FSMC can also reduce the rule number in the FLC and still possess robustness in the face of model uncertainties, external disturbances and the elimination of the chattering phenomenon.

The helicopter are being used more and more in civilian such as traffic monitoring, recognition and surveillance vehicles, search and rescue operations [14].

The twin rotor multi-input multi-output system (TRMS) is an aero-dynamical system similar to a helicopter, the TRMS can rotate freely both in the horizontal and vertical planes responding to yaw and pitch moments, respectively over a beam. At such end of the beam there are two rotors driven by DC motors. The main rotor produce a lifting force allowing the beam to raise vertically (pitch angle) and the tail rotor is used to control the beam to turn left or right (yaw angle). Both of the motors produce aerodynamic force through the blades and also provide the coupling effect. Thus, from the control engineering point of view, TRMS is a higher order non-linear system with prominent cross-couplings between the main rotor and the tail rotor [15,16]. The control objective is to make the beam of TRMS to follow the desired trajectory.

Many efforts have been made to control the TRMS and some strategies have been developed to solve the path following problems for this type of system. First of this works is in [17] authors presented the evolutionary computation based on the genetic algorithm for the parameters optimization of the proportional-integral-differential (PID) control to the TRMS system. The hybrid intelligent controller based on real-valued genetic algorithm (RGA) and fuzzy logic inference system to stabilize the TRMS system has been proposed in [18], in the work presented in reference [19], authors have presented an adaptive neural fuzzy inference system and fuzzy subtractive clustering method were used to solve the interaction and the cross-couplings problems of TRMS system, in [20], authors focused on dynamic nonlinear inverse-model based control of the TRMS is developed using an adaptive neuro-fuzzy inference system, a composite nonlinear feedback control law is designed for TRMS system where the control law is composed of linear and nonlinear components is designed in [21]. [22] Presents a robust H_∞ control strategy is designed for TRMS system, a suboptimal tracking controller using a linear quadratic regulator (LQR) with integral action is proposed in [23]. parallel distributed fuzzy LQR controllers are designed to control the position of the pitch and yaw angles to cover various operating has been used in [24].

On the other hand, the sliding mode control has been applied extensively to control the TRMS system, The advantage of this approach is its insensitivity to the model errors, parametric uncertainties, ability to globally stabilize the system and other disturbances [25,26]. In [27] a terminal sliding mode control is designed to a linearized model of the TRMS system, a PID fuzzy sliding mode control is proposed in [28] to control the TRMS system, in [29] a fuzzy sliding and fuzzy integral sliding controller is designed to position the yaw and pitch angles of a TRMS system using linear surface, in [30], the authors have used an adaptive second-order sliding mode controller to control the TRMS system.

All presented works consider the states of the TRMS available for measurement, however in [31] a predictive controller is developed where the states are estimated using unscented Kalman filter.

In this paper a fuzzy sliding mode is developed to stabilize the TRMS in its complete nonlinear configuration. Thus, the coupling effects are considered as the uncertainties in horizontal and vertical subsystems and a non linear observer is introduced to deal with unmeasured states. By using Lyapunov's method, the tracking errors are proven to be exponentially stable. Compared to the techniques available in the literature, the contribution of this work is twofold. First, a new TRMS control methodology is introduced based on non linear observer. Second, in contrast to [17,18] where stability is not proven, in the proposed approach an exponential tracking error convergence is guaranteed for the TRMS in its nonlinear coupled configuration. Finally simulation and real time implementation has been effectuated on the real time TRMS using MATLAB real-time tool box and Advantech PCI1711 card.

The remainder of this paper is organized as follows. The dynamics of the TRMS is described in Section 2. In Section 3, the decomposed model of the TRMS is introduced. The non linear observer is designed in Section 4. The fuzzy sliding mode controller based on non linear observer is presented in Section 5, Section 6 presents the simulation results. the experimental results to validate the effectiveness of the proposed approach is presented in Section 7. Finally we arrive to the conclusion of the whole work in Section 8.

2. Model description of the 2-DOF helicopter (TRMS)

The behaviour of a nonlinear TRMS [23], Fig. 1, in certain aspects resembles that of a helicopter. It can be well seen as a static test rig for an air vehicle with formidable control challenges. This TRMS consists of a beam pivoted on its base in such a way that it can rotate freely in both its horizontal and vertical planes. There are main and tail rotors driven by DC motors, at each end of the beam. The two rotors are controlled by variable speed electric motors enabling the helicopter to rotate in a vertical plan (pitch noted ψ) and horizontal plane (yaw noted φ). The tail rotor could be rotated in either direction, allowing the helicopter to yaw right or left. The motion of the helicopter was damped by a pendulum, which hung from a central pivot point. The mathematical model of the TRMS is developed under following assumptions.

- The dynamics of the propeller subsystem can be described by first-order differential equations.
- The friction in the system is of the viscous type.

Based on Lagrange's equations, we can classify the mechanical system into two parts, the forces around the horizontal axis and the forces around the vertical axis.