Dynamics analysis and fuzzy logic controller design of atomic force microscope system with uncertainties

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In this paper a nonlinear rule based fuzzy logic controller is proposed to control the nonlinear dynamic behavior of the probe tip of an atomic force microscope system (AFMs). At first, we use the bifurcation diagram to analysis the complex dynamic behavior of the atomic force microscope system, and show that the chaotic behaviour exists in the region of $A_3 > 2.54$. Next, in order to suppress the undesired motion in AFMs with uncertainty, we address the design schemes of fuzzy logic controller to stabilize the slave AFMs with parameter uncertainty to the master AFMs. Based on Lyapunov stability theory and fuzzy rules, the nonlinear controller and some generic sufficient conditions for global asymptotic synchronization are attained. We directly construct the fuzzy rules subject to a common Lyapunov function such that the error dynamics of master and slave AFMs satisfy stability in the Lyapunov sense. It overcomes the trial-and-error tuning for the membership functions and rule base in traditional fuzzy logic control. The effectiveness of presented method is numerically investigated by synchronizing slave AFMs which has chaotic motion or exceeding vibration amplitude to the master AFMs which is periodic motion or has small vibration amplitude.

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1. Introduction

Atomic force microscope (AFM) provides a powerful tool for surface analysis applications in the nanoelectronics, materials and biotechnology fields. The mechanism of AFM basically depends on the interaction of a microcantilever with surface forces. The tip of the microcantilever interacts with surface through a surface-tip interaction potential. One approach to measure the surface forces is to monitor the deflection of the microcantilever through a photodiode. This approach is named “contact mode” . Another approach termed “tapping mode”, is performed by vibrating the microcantilever close to its resonance frequency and monitoring the changes in its effective spring constant. In this method, the driving amplitude is set to a constant value and typical resonant frequencies are in the range from a few kilohertz to some megahertz [2].

The nonlinear dynamic behavior of an AFM system is a major concern since any irregular motion of the AFM probe tip inevitably degrades the precision of the measurement results. Burnham et al. [1-2] showed that the microcantilever of an AFM performed chaotic motion under specific physical conditions. Ashhab et al. [3] modeled the microcantilever of an AFM using a single-frequency mode approximation and analyzed the chaotic dynamics of the cantilever-sample system using the Melnikov method. Lee et al. [4] analyzed the effects of van der Waals and Derjaguin-Muller-Toporov forces on the tip-sample interactions induced in dynamic force microscopy (DFM). The authors also presented detailed experimental results which provided valuable new perspectives and insights into DFM. Ruetzel et al. [5] applied the Galerkin method to investigate the nonlinear dynamics of an AFM probe tip under the assumption that the tip-surface interactions were governed by Lennard-Jones potentials. Based upon their analysis, the authors showed that a microcantilever in tapping mode exhibited a broad range of dynamic phenomena, including both periodic and chaotic motion.

The existence of chaotic motion in AFMs is highly undesirable for its performance since this type of complex irregular motion causes the AFM to give inaccurate measurements and low resolution of the achieved sample topography. Accordingly, it is always required to ensure good performance of the microscope and to eliminate the possibility of chaotic motion of the microcantilever either by changing the AFM operating conditions to a region of the parameter space where regular motion is ensured or by designing an active controller to remove the chaotic motion. In 1999, Ashhab et al.[6] applied a proportional and derivative controller to AFMs, firstly. It computes the Melnikov function in terms of the parameters of the controller. Using this relation it is possible to design controllers that will remove the possibility of chaos in AFMs. Besides, In 2008, Arjmand et al. [7] used a nonlinear delayed feedback control to control chaos in AFMs. It showed that the chaotic behaviour of the AFMs is suppressed by stabilizing one of its first-order Unstable Periodic Orbits via sliding mode control.

Many methods have been presented for the control and synchronization of chaotic system [8-11]. However, none of the studies reviewed above presented a fuzzy