Chapter 29
Robust Integral of NN and Error Sign Control for Nanomanipulation Using AFM

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ABSTRACT

This paper presents a novel control methodology for automatically manipulating nano particles on the substrate by using Atomic Force Microscope (AFM). The interactive forces and dynamics between the tip, particle and substrate are modeled and analyzed including the roughness effect of the substrate. Further, the control signal is designed to consist of the robust integral of a neural network (NN) output plus the sign of the error feedback signal multiplied with an adaptive gain. Using the NN-based adaptive force controller, the task of pushing nano particles is demonstrated in simulation environment. Finally, the asymptotical tracking performance of the closed-loop system, boundedness of the NN weight estimates and applied forces are shown by using the Lyapunov-based stability analysis.

INTRODUCTION

In the past decade, nanomanipulation, which aims at manipulating and handling nanometer size objects and structures with nanometer precision, has become a hot topic of research. As a first and critical step for achieving any complex functional nano devices, nanomanipulation can find numerous applications in various fields like medicine, biotechnologies (DNA and protein study) and data storage or material science (nanotube or surface film characterization) (Gauthier & Regnier, 2010; Requicha, 2008).

However, in order to manufacture nanotechnology products, the challenges in automatic nanomanipulation and handling of objects in nano scale require cross-disciplinary studies.

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Nowadays, assemblies of small nano structures built by nanomanipulation typically consist of ten to twenty components, and may take an experienced user a whole day to construct using Atomic Force Microscope (AFM) as the manipulator. To efficiently accomplish such tasks or even more complex ones, the manipulation process should be more automated with less human intervention (Liu et al., 2008).

One of the obstacles to achieve efficient and reliable nanomanipulation is that the physical and chemical phenomenon at this scale has not been well understood. Furthermore, visual feedback is not available while the AFM probe is used as a manipulation (pushing) tool (Li et al., 2003). Hence, a significant amount of work on modeling interactive forces during manipulation was introduced in Tafazzoli et al. (2005), Li et al. (2005), Yang and Jagannathan (2006). Additionally, AFM tips and some of the experimental samples used in the nanomanipulation are fragile. Improper applied force could damage these nano objects or even the tip. Thus, designing controllers for the manipulation and handling of nano scale objects poses a much greater challenge in terms of accommodating the nonlinearities and uncertainties in the system (Eslami & Jalili, 2011).

Meanwhile, the control of nonlinear uncertain dynamic systems has attracted extensive interests from the control community (Krstic et al., 1995; Qu, 1998). Among various methodologies, adaptive control techniques modify the parameters of the controller in response to the error feedback signal to pick up the prompt changes in system operating conditions (Slotine & Li, 1991). In an attempt to parameterize the unknown plant nonlinearities, either neural networks or fuzzy logic techniques have been utilized (Jagannathan & Lewis, 1996; Su & Stepanenko, 1994) due to their universal approximation ability (Lee & Tomizuka, 2000).

Typically, manipulation or pushing of micro/nano particles today is undertaken by simple open loop control strategy in Requicha et al. (2009) or by human operators in Li et al. (2005). Therefore, in this paper, an adaptive feedback controller integrating neural networks (NN) and error sign function is proposed to perform autonomous nanomanipulation tasks. A two-layer NN structure is employed to estimate the unknown system dynamics in an online manner and a robust term of error sign function is added to compensate the NN functional reconstruction errors and external unknown disturbances. Compared with traditional sliding mode designs, this method generates a continuous-time control signal while waiving the requirement of infinite bandwidth and chattering (Patre et al., 2008; Yang et al., 2011), which may deteriorate the nonlinearities of the piezoelectric actuators within AFM. Theoretically, the asymptotical stability performance and the boundedness of the NN weights and other signals in the closed-loop system are shown by using Lyapunov method.

This paper is organized as follows. First, the modeling of the nanomanipulation process is presented. Then, the robust integral of NN and error sign feedback control law is developed. The stability of the overall formation is presented and then we present numerical simulations. Finally, we will provides some concluding remarks.

NANOMANIPULATION DYNAMIC MODEL

A. Interactive Forces

In this work, consider the scenario that the AFM tip makes contact with a nano particle and moves it on the substrate. The AFM tip apex is assumed to be a spherical ball with radius R_t, and the particle radius is denoted as R_p. β is the pushing angle, which is the angle between the pushing direction and the horizontal plane. Interactive forces among the AFM tip, particle, and substrate after the tip contacts the particle can be seen in Figure 1. A_{ps} is the adhesion forces between particle and substrate. F_{ps} and F_{tp} denote the particle-substrate