TRACKING ERROR REDUCTION IN CNC
MACHINING BY RESHAPING THE KINEMATIC
TRAJECTORY

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Abstract  In this paper, a method of reducing the tracking error in CNC machining is proposed. The structured neural network is used to approximate the discontinuous friction in CNC machining, which has jump points and uncertainties. With the estimated nonlinear friction function, the reshaped trajectory can be computed from the desired one by solving a second order ODE such that when the reshaped trajectory is fed into the CNC controller, the output is the desired trajectory and the tracking error is eliminated in certain sense. The proposed reshape method is also shown to be robust with respect to certain parameters of the dynamic system.

Keywords  CNC controller, robustness, structured neural network, tracking error.

1 Introduction

Traditionally, the CNC machine programming is divided into three major levels: path planning, trajectory planning, and trajectory control. The path planning phase aims to define the geometric cutting path without timing information[1]. The trajectory planning considers the kinematic information, such as velocity, acceleration, jerk, and jounce, to generate a velocity profile along the specified geometric path (Jamhour and André[2], Dong and Stori[3], and Smith, et al.[4], Fan, et al[5]). Time optimal trajectory generation process plays an important role in
maximizing productivity in CNC machining. The trajectory control is in the closed-loop real-time process, which aims to respond swiftly to ensure the actuators moving along the specified trajectory accurately.

In the trajectory control phase, due to the inherent dynamics limits, it is impossible to respond instantaneously to variations in the commanded path. Moreover, high feedback gains cannot be used to eliminate all tracking errors, for that will prohibit compliant control and make the system less safe for the environment. As a result, the actual machine motion deviates from the desired motion inevitably and the contour error may emerge as well.

Hence, whatever algorithm is adopted for trajectory planning, tracking errors exist in each axis. A number of different approaches have been proposed to ensure high tracking accuracy. Renton and Elbestawi\cite{6} developed a method to reduce cycle time and path error, which uses the axis performance envelope as well as instantaneous position, velocity, and acceleration information of the target path to improve servo performance in the presence of disturbances. Dong and Stori\cite{7} brought the dynamic information into the trajectory planning level by reducing the tracking error to a linear combination of velocity and acceleration approximately. Lo\cite{8} presented a new servo control method for axis machining which conducts a direct elimination of the deviation error, the orientation error, and the tracking error. Dong, et al.\cite{9} presented a synchronization approach to trajectory tracking of multiple mobile robots. The main idea is to control each robot tracking its desired trajectory while synchronizing its motion with other robots to keep the relative kinematics relationship. Ernesto and Farouki\cite{10} solved the problem of compensating for inertia and damping of the machine axes by a priori reshaping the commanded path geometry for CNC machines governed by typical feedback controllers.

In this paper, the idea of reshaping the original cutter path with kinematic information is used to reduce tracking errors. This idea was first proposed in the robot community\cite{11} and recently used in CNC controlling\cite{10}. The principle of these work is the same which aims to modify the input signal to the CNC controller so that when the modified signal is fed into the controller, the output is exactly the desired cutter path and thus there exists no tracking error comparing to the original cutter path. The contributions of this paper are as follows. A more general and practical model with the PID controller and nonlinear uncertainty frictions is considered, while previous work only considers the PD controller and simpler friction models. The nonlinear friction is learned through an SNN (structured neural network), which can approximate discontinuous functions with jump points nicely. Each continuous piece of the friction is approximated by the powerful BPNN (back propagation neural network) model. Compared with the method of approximating the friction with a given explicit expression, the SNN/BPNN model can cope with a broad range of unknown disturbances regardless of their specific structure. After the friction is estimated with SNN, the reshaped trajectory can be computed from the original one by solving a second ODE. We also show that the proposed method is robust with respect to certain parameters of the dynamic system. Finally, a practical case from CNC machining is used to verify the approach by Matlab/Simulink.

The paper is organized as follows. Section 2 describes the basic CNC controller and dynamic models. Section 3 introduces the SNN model used to estimate the friction. Section 4 presents the