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Discrete-time model predictive contouring control for biaxial feed drive systems and experimental verification

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ABSTRACT

In this paper we present a novel algorithm to model predictive contouring control for biaxial feed drive systems. model predictive control (MPC) refers to a class of model-based controllers that uses an explicit process model and tracking error dynamics to predict the future behavior of a plant, making it effective for machine tool feed drive systems that must achieve high-precision motion and are severely affected by friction, cutting force and changes in the workpiece mass. To improve contouring performance, we propose a new performance index in which error components orthogonal to the desired contour curve are given more importance than tracking errors with respect to each feed drive axis. Controller parameters are calculated in real time by solving an optimization problem. The parameters depend on the instantaneous slope of the reference trajectory and thus vary with time for curved reference trajectories, resulting in a time-varying controller. Weighting factors for the error components in orthogonal and tangential directions are used to adjust the error importance in each direction. In addition, to consider the required feed drive energy, the control inputs in both directions are included in the performance index. The effectiveness of the proposed control approach is demonstrated with an experimental biaxial feed drive system for circular and non-circular trajectories. The proposed contouring controller allows the feed drive to follow smooth curves and reduces contouring error.

1. Introduction

High-precision machining requires multi-axis feed drive systems to accurately follow specified contours. Tracking errors usually appear in many industrial applications such as *X–Y* tables, computer numerical control (CNC) machines and industrial manipulators. For machining, error components orthogonal to the desired contour curve represent better indicators of the precision of machining, and are defined as contouring error. Tracking and contouring errors are important aspects that significantly affect machining accuracy. Two main control approaches are used to improve contouring performance: tracking control approach and contouring control approach. For the tracking control approach, the control law of each drive axis control loop attempts to minimize the tracking error independent of other control loops. In addition, disturbances in one control loop are compensated only by that particular loop. Other control loops do not receive any information about the disturbance, and they run as if the disturbed control loop is functioning normally. This lack of coordination causes error in other axes. However, the contouring error of the desired path is evaluated in real time and this error is eliminated by feedback control in contouring control systems.

To improve the tracking accuracy in each individual axis by elimination of the servo-lag phenomenon, Masory proposed a feedforward controller [1], and Tomizuka proposed the zero phase error tracking control [2]. The above approaches can be applied to effectively reduce tracking errors for single axis or decoupled motion applications. However, they do not guarantee contouring performance when applied to multi-axis contour-following tasks. To reduce contouring error, researchers have developed a variety of alternative control approaches. By calculating the contouring error from the tracking error in biaxial contour-following tasks, Koren proposed a cross coupled controller (CCC) [3]. Yeh et al. employed a cross-coupled fuzzy logic controller for improving the contouring accuracy [4]. They utilized a new fuzzy rule-generated method which is based on a performance index of the contouring error model. Ho et al. decomposes the contouring error into normal tracking error and advancing tangential error, following which a dynamic decoupling procedure is applied to the system dynamics [5]. By transforming the machine tool feed drive dynamics into a moving-task coordinate frame attached to the desired contour, Chiu and Tomizuka proposed the task coordinate frame approach [6]; Cheng et al. [7] proposed an integrated control scheme that consists of a feedback controller, a feedforward controller and a

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