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Cornering Error Estimation of Look-Ahead Based Tool Path Generation Algorithm

Chan-Young Lee[1,#], Seung-Kook Ro[1], Chang Kyu Song[1], Jeong Seok Oh[1], Soon-Hong Hwang[2] and Byung-Kwon Min[2]

1 Department of Ultra-Precision Machines and Systems, Korea Institute of Machinery & Materials, Daejeon, 34103, South Korea
2 Department of Mechanical Engineering, Yonsei University, Seoul, 03722, South Korea
Corresponding Author / Email: cylee@kimm.re.kr, TEL: +82-42-868-7129

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Computerized numerical control (CNC) interpolator uses a look-ahead based tool path generation algorithm for high-speed and high-precision machining. The look-ahead algorithm of the CNC interpolator calculates an optimal velocity profile to utilize the maximum kinematic constraints of the machine tool feed drive. A corner smoothing algorithm is applied to the optimal velocity profiles to reduce the cycle time and smooth the tool path. The smoothed tool path causes a cornering error near the vertex. Because the cornering error decreases the dimensional accuracy of the workpiece, it is required to limit the error of the tool path. However, because the cornering error of the commercial CNC can be calculated using the actual tool path, it is difficult to limit the cornering error considering the machining accuracy before machining. This paper proposed a cornering error estimation algorithm for the CNC interpolator based on the look-ahead algorithm. A simulation model composed of the interpreter, velocity profiler, and interpolator was constructed to generate the smoothed tool path using the look-ahead algorithm. The cornering error estimation algorithm calculates the minimum distance between the smoothed tool path generated by the simulation model and the corner transition. The proposed algorithm was evaluated experimentally using the commercial CNC (0i-MD, Fanuc). The smoothed tool path was captured to calculate the actual cornering error of the commercial CNC using a monitoring program (Servo Guide, Fanuc). The cornering error estimated by the proposed algorithm was compared with experimental results to evaluate the estimation accuracy.

1. Introduction

High-speed and high-precision (HSSP) machine tool has become essential in the aerospace and mold industry because the high machining quality and productivity has become global trends. A variety of research has been proposed for HSSP machining because the machining quality and the cycle time are directly affected by the tool path generation algorithm of a computerized numerical control (CNC).

Since the cornering error decreases the machining quality, Zhao et al.[1] proposed a corner smoothing algorithm by inserting a cubic B-splines curve within a cornering error tolerance between two adjacent blocks for high-precision machining. Beudaert et al.[2] utilized two cubic B-splines curves for the corner smoothing to smooth tool position and tool orientation for five-axis machining. If the G-code block length is not long enough to insert the curve, the cornering error becomes smaller than tolerance. It increases the cycle time. The tool path generation algorithm based on a look-ahead is generally utilized in the part program consisting of short-length G-code blocks[3]. Because the look-ahead calculates the optimal velocity profiles utilizing the forthcoming G-code paths, the cycle time can be suppressed for short-length G-code blocks. However, because kinematic constraints for the look-ahead are coupled, it is hard to estimate the cornering error before machining.

This paper proposes a cornering error estimation algorithm using a numerical control (NC) kernel model. The tool path generation algorithm with the look-ahead was modeled to implement into the NC kernel model. The cornering error of commercial CNC was estimated using the tool path. The simulation model composed of the NC kernel model and the cornering error estimation algorithm was constructed for evaluation. The cornering error estimation accuracy was evaluated experimentally.

2. Cornering error estimation using NC kernel model

This chapter presents a cornering estimation error algorithm using the tool path generated by the NC kernel model. The NC kernel model is comprised of the interpreter model, look-ahead model, and interpolator model. The interpreter model parses the G-code information to generate the velocity profile. Using the G-code information, the look-ahead model computes the optimal velocity profiles of each G-code block. The interpolator model generates the tool path by applying the corner smoothing algorithm.

The look-ahead model generates the optimal velocity profiles for HSSP. The look-ahead model is composed of a backward velocity planning algorithm and a forward velocity planning algorithm. Fig.1 shows the velocity profiles generated by the look-ahead algorithm. The backward velocity planning algorithm computes the optimal end velocity of the current G-code block utilizing the forthcoming paths and the kinematic constraints. The kinematic constraints such as the tangential acceleration, the velocity difference allowance, and the acceleration difference allowance are used for the look-ahead. The kinematic constraints values of the model can be applied to the CNC directly. The forward velocity planning algorithm computes the acceleration, jerk, and interpolation period to generate the velocity profiles of the current G-code block.

Using the tangential velocity profile information, the interpolator generates the tool path for the machine tool feed drive. The interpolator uses the finite impulse response (FIR) filter for smoothing. The jerk of the tool path can be controlled by the time constant of the FIR filter. The tool path is generated by overlapping the smoothed velocity profiles to prevent an increase in the cycle time.

The tool path is used to calculate the cornering error at each transition. The cornering error is defined by the minimum distance from the G-code path to the smoothed tool path.

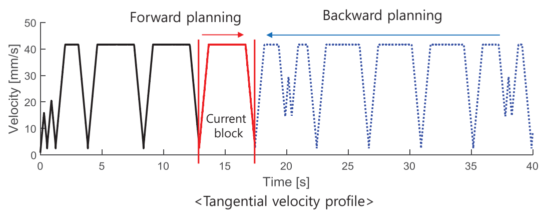

Fig. 1 Velocity profile generated by the look ahead

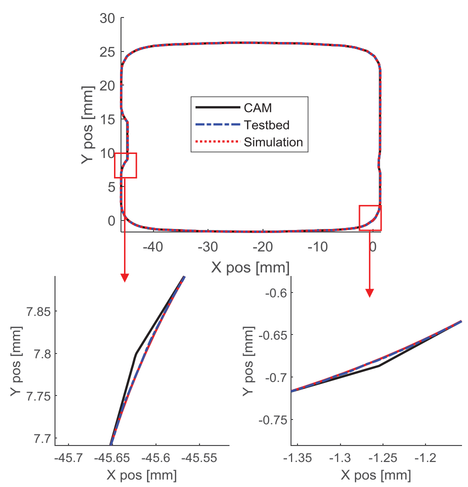

Fig. 2 Comparison of the tool path between the testbed and the simulation

3. Experimental results

The estimation performance of the proposed algorithm was evaluated experimentally. The commercial CNC (0i-MD, Fanuc) was used for evaluation. The tool path generated by the look-ahead algorithm was captured using a data monitoring program (Servo Guide, Fanuc). The cornering error estimated by the proposed algorithm was compared with experimental results to evaluate the estimation accuracy. The part program composed of G01 paths was used. The tangential acceleration, the velocity difference allowance, and the acceleration difference allowance were set to 50, 200, and 700, respectively. The time constant of the FIR filter was identified from the actual tool path of the commercial CNC.

Fig. 2 shows the tool path used for evaluation. The figure shows that the simulation can estimate the tool path of commercial CNC. Table 1 shows the comparison of the cornering error at the transitions. The estimated cornering error using the NC kernel model can predict the experimental error with an accuracy of 93.70%.

4. Conclusions

This paper presents the cornering error estimation algorithm using the NC kernel model based on the look-ahead. The NC kernel was modeled and constructed to generate the tool path using the look-ahead. The cornering error estimation performance of the proposed model was evaluated using the experiment. The experimental results demonstrated that the proposed model can estimate the characteristics of the path generation of the commercial CNC.

Corner number	Cornering error of the testbed (μm)	Cornering error of the simulation (μm)
1	6.64	7.21
5	2.00	1.82
10	10.63	10.80
15	9.41	9.63
20	9.39	9.94
25	9.33	9.21
30	1.68	2.18
35	8.83	9.89
40	8.32	8.97

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