Title:
NC Simulation for Adaptive Look-Ahead Interpolator with On-line Collision Detection

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Introduction:

CNC machining has become the standard of producing precise components for manufacturing industries. As products become more complex in geometry, CNC machining also evolves from 3-axis/5-axis machining to more complex multi-axis turn-mill machining. In addition, to achieve flexible manufacturing and increase automation level, multi-function CNC machining center further integrates machining, grinding, polishing, and even laser sintering (additive manufacturing) into one single CNC machine platform. However, as the complexity and cost of the machine increase, the issue of on-line collision detection and avoidance becomes more and more important.

This issue is particularly critical for high-speed multi-axis machining. With the advancement of the CNC and machine tool technology, multi-axis machining has become the main processing method for producing everyday products. Compared with three-axis machining, multi-axis machining has high precision, efficiency, and better surface quality in short machining period. It is used for machining complex and contour free-form product. But since the tool path is complex, interference or collision is easy to occur and can damage the machine or part. Traditionally, off-line simulation is used to detect collision before machining. But it becomes out-of-date because the demand for real-time simulation of the CNC machining process is increasing for the purpose of saving time and money.

The CNC controller is the key of the multi-axis machine tools. The function of the controller includes NC code interpretation, look-ahead feedrate scheduling, tool-path interpolation, and servo motion control. To maintain feedrate continuity and avoid undesired vibration, the controller has to look ahead the path and plan the feedrate. D. Kim [3] applied feedrate planning to produce smoother interpolation processing. G. C. Han [2] proposed the look-ahead interpolation of high-speed machining algorithm. The controller could upgrade the cutting speed without increasing the hardware cost. Yong and Narayanaswami [13] detected the sharp corner in off-line system to reduce contouring error. However, none has integrated the look-ahead interpolation with the collision detection process.

In traditional controller, linear and circular NC segments are mostly used. When a sculptured surface is being machined, a great amount of linear segments are generated to approximate the contour geometry. As a result, the processing workload is significantly increased [4] [5]. Koren [6] used parametric spline to represent the machining curve. He solved the problem of using the great amount of short lines to fit the curve. Yeh and Hsu [12] proposed adaptive feedrate interpolation to control the chord error and improve the precision of the parametric interpolation. C. C. Lo [7] used iso-feedrate to derive the implicit function and parametric curve interpolation. Compared with linear interpolation, it improves the precision in curve interpolation. In recent years, NURBS interpolation has gained much popularity in PC-based controller.

The aim of this work is to develop an on-line collision detection system that can be integrated with CNC controller to look ahead the multi-axis tool path in real-time and stop the machine execution when a collision is detected before it really happens.

Main Idea:

Fig. 1 shows the research flowchart proposed by this paper. First of all, the virtual multi-axis machine needs to be modeled by analyzing the kinematics and dynamics of the CNC machine. Using this virtual machine information, the second step is to perform the collision efficiency analysis. We separate the machine moving axes into relative pairs. Those pairs which may not collide with each are excluded from the collision detection during simulation. This will increase the collision detection efficiency significantly. Moreover, look-ahead function will be used to calculate feedrate intelligently by reading a block of data before it is ready to be executed. Then, the relations of feedrate and time can be established in advance by calculating the acceleration and deceleration of machining in path planning. Finally, the machining path can be interpolated by Taylor series according to feedrate and time information obtained from the look-ahead function. For each path segment, knowing the speed and distance, the algorithm will calculate the suitable collision detection number (or detection steps) adaptively. The collision detection and simulation will therefore be carried out at a safety distance ahead of the real machining steps. The safety distance is the distance that is at least larger than the minimum distance the machine can stop from the maximum feedrate. This proposed intelligent machining system equipped with adaptive look-ahead function and online collision detection function can be integrated with machine tool controller for on-line simulation and collision detection/avoidance to protect expensive multi-axis machine tools from being damaged by undesirable collisions.

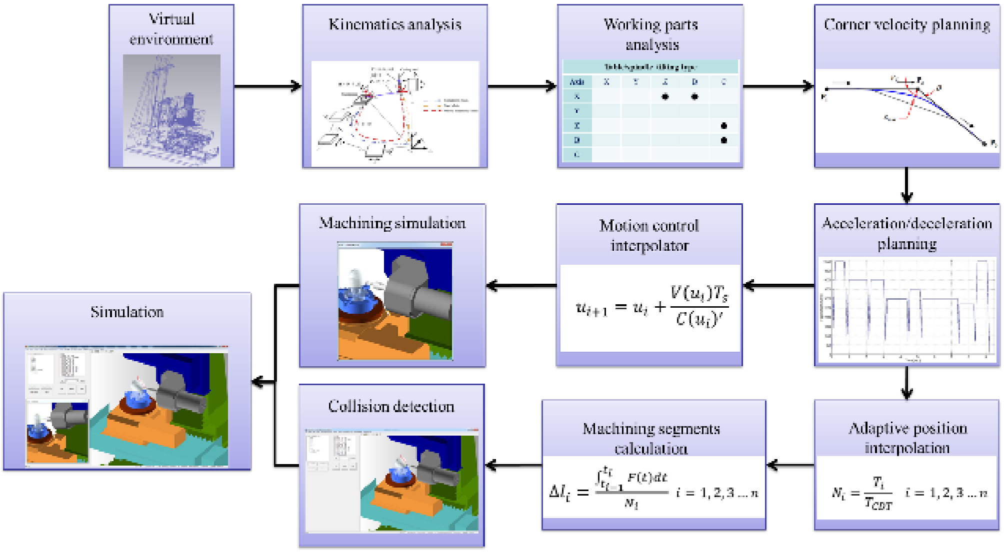

Fig. 1: Flow chart of the system.

Conclusions:

We develop a NC machining simulation system with adaptive look-ahead interpolator and on-line collision detection function. The interferences between working parts can be detected by looking ahead at a safety distance during machining. In order to provide reliable safety, the machining can be stopped before the collision taking place to avoid machine or part damages. The simulation system proposed in this paper is described as follows:

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1. Look-ahead function integration. Adaptive feed rate can be calculated according to tool path information and feedrate planning. The trapezoidal or S-curve acceleration and deceleration principle can be adopted to enhance the machining simulation accuracy.
2. Motion control interpolator. The natural machining simulation can be achieved by integrating look-ahead velocity planning with machine dynamic modeling.
3. Adaptive collision detection. Collision detection number or steps can be calculated automatically by analyzing the processing path interval and detection efficiency.

The purpose is to perform the most allowable precise collision detection during a limited time. Furthermore, the efficiency of collision detection is closely dependent on the triangle number of the machine and part models in the virtual environment. Therefore, parallel computing using GPU is adopted to speed up the collision detection efficiency. Currently, material removal simulation has not been integrated into this system. Further integration will make the system more realistic and increase system versatility. In the future, the adaptive collision detection simulation system proposed in this paper can be integrated with the real machine to validate the feasibility and improve machining safety.

References:

[1] Gottschalk, S.; Lin, M. C.; Manocha, D.: OBBTree: a hierarchical structure for rapid interference detection, in Proceedings of the 23rd annual conference on Computer graphics and interactive techniques, 1996, 171-180.
[2] Han, G. C.; Kim, D. I.; Kim, H. G.; Nam, K.; Choi, B. K.; Kim, S. K.: A high speed machining algorithm for CNC machine tools, in Industrial Electronics Society, IECON'99 Proceedings. The 25th Annual Conference of the IEEE, 1999, 1493-1497.
[3] Kim, D. I.: Study on interpolation algorithms of CNC machine tools, in Industry Applications Conference. Thirtieth IAS Annual Meeting, IAS'95, Conference Record of the IEEE, 1995, 1930-1937.
[4] Koren, Y.: Computer control of manufacturing systems, McGraw Hill, New York, NY, 1983.
[5] Koren, Y.: Control of machine tools, Journal of Manufacturing Science and Engineering, 119(4B), 1997, 749-755. http://dx.doi.org/10.1115/1.2836820
[6] Koren, Y.; Lo, C. C.; Shpitalni, M.: CNC interpolators: algorithms and analysis, ASME Manufact. Sci. Engng., 64, 1993, 83-92.
[7] Lo, C. C.; Hsiao, C. Y.: CNC machine tool interpolator with path compensation for repeated contour machining, Computer-Aided Design, 30(1), 1998, 55-62. http://dx.doi.org/10.1016/S0010-4485(97)00053-5
[8] Sørby, K.: Inverse kinematics of five-axis machines near singular configurations, International Journal of Machine Tools and Manufacture, 47(2), 2007, 299–306. http://dx.doi.org/10.1016/j.ijmachtools.2006.03.011
[9] Tang T.; Bohez, E. L.; Koomsap, P.: The sweep plane algorithm for global collision detection with workpiece geometry update for five-axis NC machining, Computer-Aided Design, 39(11), 2007, 1012-1024. http://dx.doi.org/10.1016/j.cad.2007.06.004
[10] Wang, J. B.; Yau, H. T.; Universal real-time NURBS interpolator on a PC-based controller, The International Journal of Advanced Manufacturing Technology, 71(1-4), 2014, 497-507. http://dx.doi.org/10.1007/s00170-013-5460-5
[11] Yau, H.T.; Kuo, M.J.; NURBS Machining and Feed Rate Adjustment for High-Speed Cutting of Complex Sculptured Surface, International Journal of Production Research, 39(1), 2001, 21-41. http://dx.doi.org/ 10.1080/00207540010002360
[12] Yeh, S. S.; Hsu P. L.: Adaptive-feedrate interpolation for parametric curves with a confined chord error, Computer-Aided Design, 34(3), 2002, 229-237. http://dx.doi.org/10.1016/S0010-4485(01)00082-3
[13] Yong, T.; Narayanaswami R.: A parametric interpolator with confined chord errors, acceleration and deceleration for NC machining, Computer-Aided Design, 35(13), 2003, 1249-1259. http://dx.doi.org/10.1016/S0010-4485(03)00043-5