Quick NC Simulation & Verification for High Speed Machining

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Abstracts: Numerical Control (NC) machining is the cutting edge of modern manufacturing technology. NC errors could break cutter edges, destroy work pieces and even damage the machine tool. In recent years, more and higher speed cutting is applied in the industry due to the advancement of machine tool technology and the demand of shorter production time. However, checking the NC codes for high speed machining is difficult due to the lack of information on material removal rate and the large size of NC blocks. In this paper, a novel high speed NC simulation method in an extended Z-map approach is presented, which offers higher simulation accuracy of the resulted geometry and with reasonable cutting load calculation. In conclusion the authors propose the pervasive manufacturing modeling and simulation for multi machining and layered manufacturing processes.

Keywords: NC verification; NC simulation; NC post-processing; Collaborative machining

1. INTRODUCTION

Comparing with the sharp decline of the computing cost, worldwide material and machine tool prices have up surged significantly. Saving material and making efficient use of machines through pervasive computing become important in the midst of increasing raw material and energy costs. One NC error could make the work piece a scrap; and it could take days to reproduce another work piece. Due to the work piece's material and processing costs, machining errors could erode the profit considerably. In the age of small batch production, there is no time for "trials and errors" approach. Therefore, verifying and optimizing precision NC machining have significant impacts on the profitability of a company. The manufacturing industry demands "First Part Correct".

In the case of High Speed Machining (HSM), the fast feeding movements can break the expensive cutter easily. Traditional NC simulation is not good enough because it only checks geometrical errors and most of them checks cutting process graphically without an in process model. Hence, they have built-in difficulties to calculate the exact cutting load. We believe that the dynamic machining load has to be taken into consideration as it greatly affects cutter life, geometry accuracy and the surface finish. Further, the huge tool path data files for HSM give challenges as well where millions of lines of NC code are commonly encountered. The traditional NC verification is so slow that even HSM itself is faster than verification. The size of the program combined with a high feed rate makes it almost impossible to run test simulations prior to cutting.

In recent years, Singapore Institute of Manufacturing Technology (SIMTech) has developed a more efficient approach based on a geometry representation which has been patented.

The system starts with a solid model of the machined part, and can simulate and optimize machining processes quickly. NC codes could be reversely post-processed into graphical 3-D tool paths, and interactively viewed, edited, and optimized. The user can highlight or hide operations, tool paths, or layers. The user can also edit the tool paths in a certain layer. Tool paths and cutting results can be viewed from any viewpoint and checked graphically. The machined part and the design part are compared for the remaining stock and the over-cut areas. Error-free optimized tool paths can be achieved. Hence this application eliminates the need for a time-consuming test cut. A quick and simple post processor is used to translate the error-free tool paths into NC codes. This technology is suitable for machine tool NC tool path simulation, verification and optimization in the precision engineering, automotive, aerospace, and electronics industries.

Based on this technology, SIMTech has developed several practical applications for mould manufacturers. These include QuickSeeNC (a machining simulation and verification tool) and PartingAdviser (a plastic part analysis tool, which is to be introduced in a separate paper). Both of them provide "What You See is What You Cut" (WYSWYC) functionality for CADCAM engineers and shop floor machine operators. They could be integrated with other CAM software through a native APT adapter.

2. NC PROGRAM ERRORS

The average scrape rate for local mould maker is 15%. There are different kinds of NC program errors. Some of them are caused by human errors which depend on the NC programmer's experience. These errors can be classified as: (1) Inaccurate results in the patching up of surfaces; (2) Inappropriate selection of machining process; (3) Mistakes with the references to the part face, the checking face and the selection of boundaries; (4) Incorrect machining set-up; (5) Unusable cutting parameters. However, a large amount of errors are caused by the systems or the algorithms deployed in the shop floor machining.

In the current industry practice, different CADCAM systems are used among business partners. One of the main problems that cause low quality in solid models in the current CADCAM approach is the data translation process which is required due to the poor interoperability among different CADCAM platforms. The low quality of solid models cause low quality NC programs with following three reasons: (1) The post-processor generates arcs with large radius (several meters), which will cause errors in some CNC controllers; (2) The surface deformation during to data exchange problem; (3) The surface tolerance is too low in surface model translation; for example, it may be larger than 0.1mm. Figure 1 shows a set of typical parallel tool paths which generates uneven water level cutting. (4) The data defects cause unexpected NC problems. For example very often, there are gaps between surface patches after data translation. Due to such patch gaps in the part surface geometry model, sudden plunge could be generated as also shown in Figure 1.

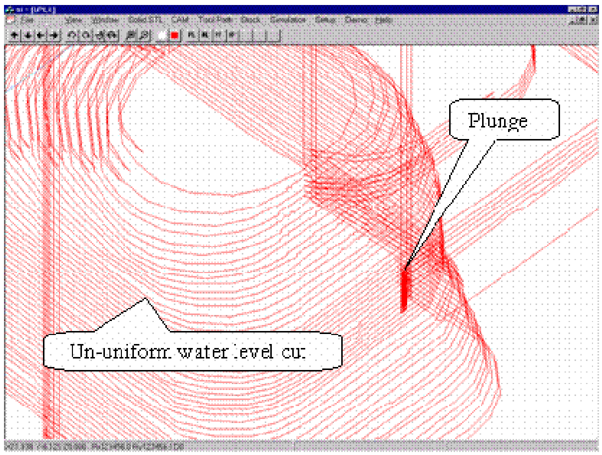


Fig. 1 Typical NC toolpath errors

In another aspect, the NC tool path generation algorithms are unstable because that (1) the tool path planning is a very difficulty task; (2) the tool path sampling method varies considerably from one CAM package to another; and (3) there are no exact offset solutions for curves and curved surfaces.

However, comparatively, the most significant problem for NC optimization is the lack of

In-Process Model (IPM), so the tool path generation with the CAM application does not consider the real cutting geometry. This causes a lot of process problems, such as air cut and gouging. It can be observed that with the tool paths directly generated from CAM application, the cutter moves through remaining stock too fast, or too many conservative air cuts in semi-finishing and finishing cut, or near-touch cutting conditions occur which cause fast cutter wearing. The recent development of high speed machining (HSM) requires huge tool path in order to realize the constant load. The constant load is a very important factor in HSM. The cutter will break under uneven cutting force. As the feed rate is already very high, it does not reflect the sensitive cutting situation to verify the NC program with the traditional test cutting. It is highly demanded to check the dynamic cutting forces before the operation. Hence, there are strong requirements from industry for a real dynamic simulation. The simulation results can be used to optimize feed/speed. Graphics-based visual tool path checking is difficult as the tool path overlapping with each other. Besides, it takes a long time to run traditional simulation software.

3. FUNCTIONAL REQUIREMENTS FOR AN IDEAL NC SIMULATOR

Theoretically, NC Simulation should feature the full 3-D solid model of the entire NC machine tool with detailed simulation for the manufacturing (e.g. material removal) process. There are four aspects to be covered by a comprehensive NC simulator:

(1) NC tool path visualization. The simulator enables programmers and machinists alike to preview exactly what will happen on the machine, especially for the cutter movements, or even for the shop floor. Many users apply NC simulation for electronic shop floor planning and documentation.

(2) NC verification. This function detects problems in the NC tool path program. It is a powerful visual inspection tool, which highlights fast feed errors, gouges, and potential crashes/collisions. Programmers can detect and correct problems before prove-cut. Ideally, with NC Verification you can virtually eliminate NC program mistakes, greatly reduce the time spent on prove-outs, and make the move to "lights-out" machining.

(3) NC analysis. This simulation function identifies the tool path records responsible for an error. You can quickly verify the dimensional accuracy of the entire part with a full array of 3-D measurement tools. NC analysis function compares the simulated in-process part model to the designed part model and checks if the machined part matches to the design. One of the sub-function for NC analysis is to perform constant gouge checking.

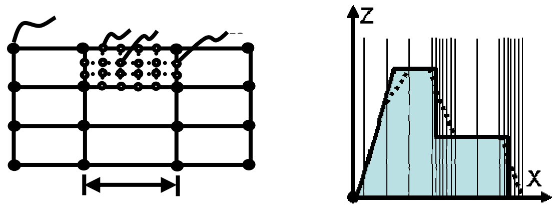
(4) NC optimization. This function automatically determines the best feed rate for each segment of the tool path based on the machining conditions and amount of material removed. Optimizing NC feed rates can greatly reduce the time it takes to machine the part, assure the cutting safety, and improve the quality of surface finish.

4. Quick NC SIMULATION METHODS

Z-Map [1] geometrical representation is widely used for NC simulation verification. A map of Z values represents the object geometry. Z-Map representation can be effectively used for the surface that is always visible from above in the direction parallel to the Z axis. Since 3-axis milling parts are composed of surfaces visible in the z direction, they can be effectively expressed by the Z-Map representation. With the Z-Map representation, the machining process can be simulated by intersecting the Z-Map vectors with the cutter profile.

Since the precision of Z-Map is decided mainly by the XY resolution along the vertical walls, how to increase the resolution along these walls and reduce memory becomes a critical issue. An important feature of 3-axis milling came into play. Viewing from the top, the vertical walls only cover a relatively small percentage of Z direction projection, can we use finer resolution along the vertical walls while maintain a rough resolution in the planar area? This was the initial motivation for our extended Z-Map method [2].

The size of the grid can be reduced through using sub-cells. In this study, at least one grid on a Z-Map is segregated into sub-cells. Only grids corresponding to intricate features on the surface of an object are assigned sub-cells to improve representation of object features. Figure 3(a) illustrates the plan view of the z-map grid with sub-cells 52 (a level finer than 44) while Figure 3(b) hows the front sectional view.



(a) (b)

Fig. 3 Extend Z-Map sub-cells along vertical walls

However, the precision of XY dimension is still limited by the size of sub-cells. For a sub-cell of 0.1mm, the best precision is 0.1mm in XY plane. There is a need to represent XY dimension more precisely. Instead of using vectors in the sub-cells, we use sticks in the sub-cells that have volumes and surface geometry (see Figure 4). A B-rep surface model can be represented precisely using a map of B-rep sticks.

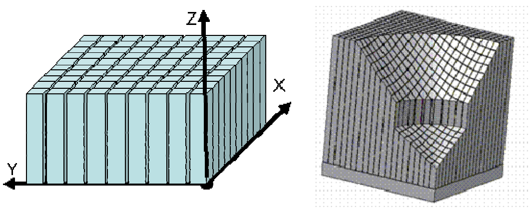


Fig. 4 Stick geometric representation method

Milling simulation in stick method involves Boolean subtraction operation of the cutter from each stick. Figure 5 shows different stick shape after cutting. The experiments with B-rep stick model are very slow and create a huge B-rep model. To simplify the stick representation and Boolean operations, a wire frame polygon instead of a real solid with surfaces is used in a stick cell. This could greatly increase simulation speed. The data structure of polygon is much simpler than that of B-rep which needs a group of complicated pointers to maintain a double wing data structure.

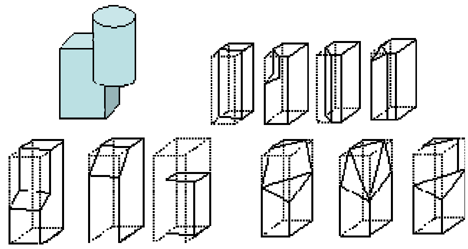
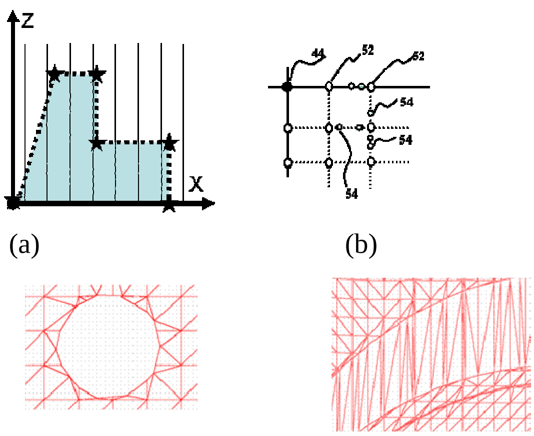


Fig. 5 Different shapes of stick elements

In the real world, part surface objects are not always uniform in XY dimension but can be any shape (see Figure 6(a)). Nodes can be flexibly used to enhance sub-cell's precisions in representation of object face. For example, one edge of the sub-cell may have two overlapping nodes to represent a vertical face. The nodes of a sub-cell may not be uniformly distributed over XY plane. Figure 6(b) shows a close-up view of a portion of the Z-Map grid with nodes labeled with 54 (level number). Figure 6(c) shows how a circular hole is represented with adjusted nodes. Figure 6(d) shows the stick method that has more sub-cells over the vertical walls.



(a) (b)

(c) (d)

Fig. 6 Extend sub-cells to approximate a vertical wall

Based on this patented geometry representation, we developed a more efficient NC simulation system. The system starts with a solid model of the machined part and quickly simulates and optimizes machining processes. NC code could be reversed by a generic post process into 3D tool paths, which can be further graphically displayed and interactively viewed, edited, and optimized. The user can highlight or hide an operation, tool path, or layer. The user can also display and edit a certain layer of the tool paths. Tool paths and cutting results can be viewed from any viewpoint and checked automatically. The machined part and the designed part are compared for calculating the remaining stock and any over cut. Error-free tool paths are created, eliminating the need for a time-consuming test cut. Quick and simple post processors are developed to export the optimized tool paths into NC codes.

Figure 7 shows an application example of a steel insert of ‘discman’ (a portable CD audio player) mould from a company. There are 16 operations in this CLS file. The resulted NC codes contains almost half million of NC blocks. QuickSeeNC loaded in half million lines in seconds and displayed tool paths in different colours according to operations (see Figure 7-9).

NC Program Data Sheet core_insert_nc

No.	Name	Cutter	SOL	Time
1	V64C61CA	D20.00 R0.000	L75	96m
2	V61CA1	D20.00 R0.000	L75	11m
3	V64C61CB	D12.00 R6.000	L75	31m
4	V64C61CC	D6.000 R3.000	L75	45m
5	V64C61CD	D6.000 R3.000	L75	153m
6	V64C61CE	D4.000 R2.000	L75	33m
7	V61CE1	D4.000 R2.000	L75	11m
8	V64C61CF	D20.00 R0.000	L75	2m
9	V61CF1	D20.00 R0.000	L75	1m
10	V64C61CG	D8.000 R0.000	L75	6m
11	V61CG1	D8.000 R0.000	L75	7m
12	V61CG2	D8.000 R0.000	L75	7m
13	V61CG3	D8.000 R0.000	L75	7m
14	V61CG4	D8.000 R0.000	L75	7m
15	V64C61CH	D16.00R0.000	L75	13m
16	V61CH1	D16.00 R0.000	L75	14m

Total NC Program = 16

Machine time = 7 hours 23 minutes

Fig. 7 An example of 16 milling operations

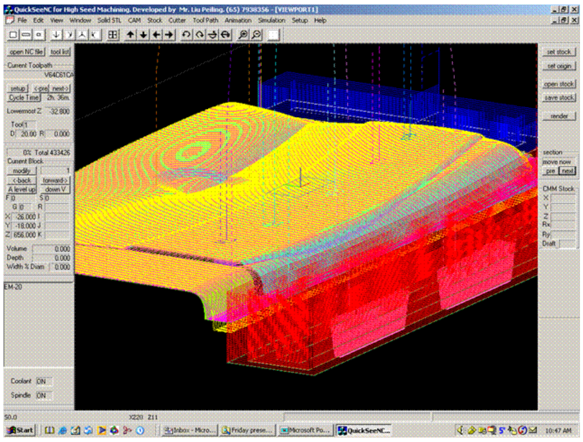


Fig. 8 Toolpath of half million NC blocks

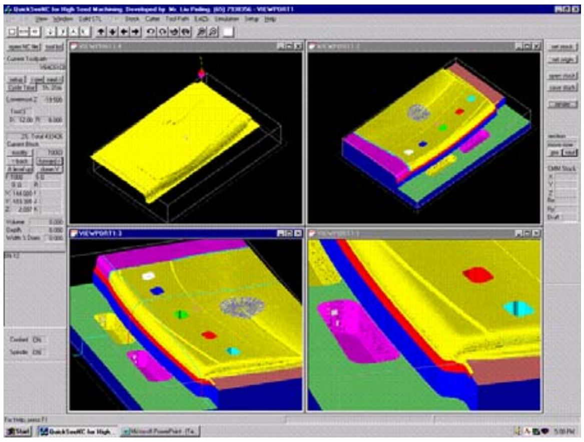


Fig. 9 Extended Z-Map simulation

Another patent [3] has been filed to use this extended Z-Map representation for quick plastic mould design and rapid tooling application. A CAD-independent mould design toolkit has been developed based on this patent.

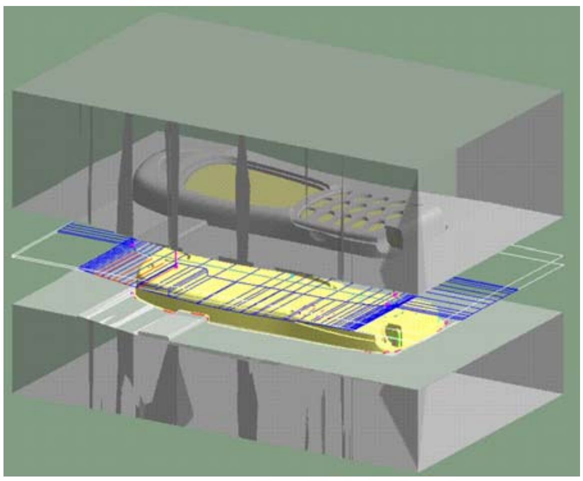


Fig. 10 PartingAdviser for quick concept mold design

5. TOWARDS PERVASIVE SIMULATION

Despite the fact that simulations are becoming more widely used, there is a lack of integration of simulations of manufacturing processes. Most work focuses on an individual process being simulated. Significant gaps remain in M&S technology – particularly in the provision of a general in-process model (IPM) that can be integrated across diverse manufacturing processes [4]. To overcome the data exchange problem between different models, we extended the concept of the IPM from machining process to other manufacturing process and intend to develop a unified in-process geometrical model for multiple machining and layered manufacturing simulations. Figure 11 shows an application example of a voxel model.

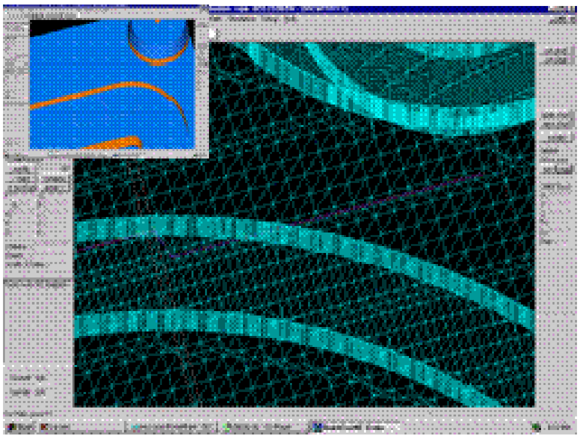


Fig. 11 Experiment result of voxel model

Further analyzing the voxel model, the authors of this paper believe the voxel-based volume modeling is a very promising approach to the unified IPM for multiple machining and layered manufacturing (LM) simulation [5-6]. As a natural clone of the LM technology, the voxel model of an object and the object fabricated using an LM closely resemble each other since both are made of layers of small cells It eliminates the STL format and eases accomplishments of tasks such as estimation of errors in the physical parameters of the fabricated objects, tolerance and interference detection. Furthermore, voxel based models permit the designer to analyze the LM object and modify it at the voxel level leading to the design of custom composites of arbitrary topology.

6. CONCLUSION

NC errors could destroy work pieces, even damage machine tool. In the age of small batch production, there is no time for trials and errors. The challenges also come from huge tool path of HSM. The traditional NC verification is so slow that even HSM itself is faster than verification. The size of the program combined with a high feed rate makes it almost impossible to run test simulations prior to cutting metal.

In this paper, we introduced our recent research results on the quick NC simulation, which can generate finished machining geometry efficiently and accurately; at the same time, in-process cutting volumes are calculated which allows for cutting conditions optimization.

The novel hybrid multiple machining and layered manufacturing processes posed a new challenge to process planning and verification. It seems that the voxel-based approach could be a promising solution. More research work is to be carried out. More detailed description will be introduced in future papers.

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