CNC Tool Path Planning and Machining Simulation on GPU

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CNC machining

Introduction

It is not possible to imagine the modern world without products of a contemporary manufacturing which has slowly morphed from manual work and handmade goods to huge factories controlled by computers that produce millions of items every day. Nearly every artificial item we touch in this world is the result of numerous machines and advanced technologies. One of the most important tools in modern production is the Computer Numerical Control (CNC) milling machine. These machines are used to manufacture complex mechanical devices like engines or turbines, molds and dies, tools for many manufacturing processes, complex shaped furniture, medical implants and many other items. CNC machines provide high precision (up to 0.002 mm), cheap and fast operation and the ability to produce thousands of parts with the same quality. This is made possible by computer controlled paths which allow a cutting tool to perform the same motion for all parts. But the programs used for tool movement control is also one of the most significant limitations of modern CNC machines due to the fact that tool path planning requires large investments of time as well as highly qualified personnel. Although modern Computer Aided Manufacturing (CAM) packages have resulted in a decrease in the tool path planning time there is still a huge gap in productivity.

Automated tool path planning

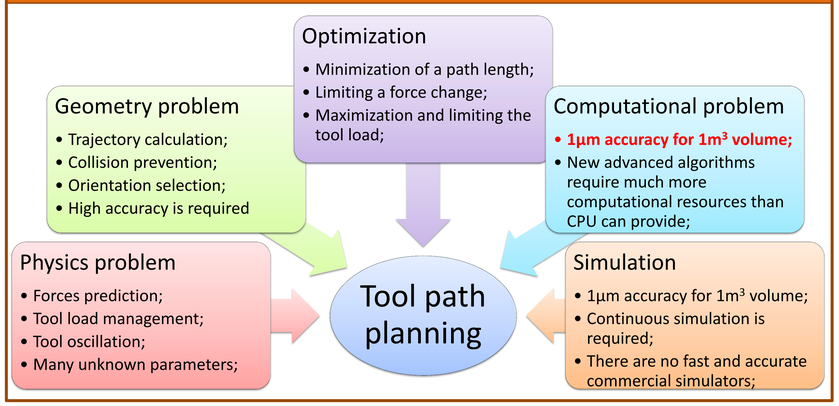
How it works today

What we would like to have

The global goal is to have a fully automatic tool path planning because:

- It takes ~4 hours to make an average program;
- For low-volume production a program cost can be as much as 90% of a product;
- It is too complicated process now and the industry is looking for easier solutions;
- Optimization is extremely important for massive production, automated tool path optimization may save billions of dollars;

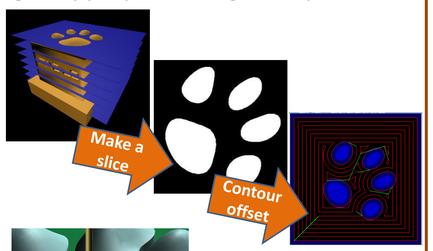
Why it is a hard problem

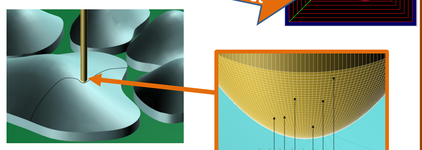


Completed research

Part I: 3-axis path planning and machining simulation

- Geometry is represented as a height map;
- Simulation is implemented by calculating cutter surface distance from each height map point and updating of appropriate heights in parallel:
- A contour offset approach is used for a roughing tool path:
  - Implement as a set of image processing operations;
- A zigzag tool path is used for finishing:
  - Initial 2d tool path is generated on a host;
  - Height position is generated based on the maximum intersection distance between tool and model surfaces;





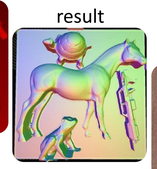
Original

Simulation result

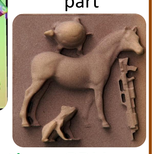
Machined part

Original model

Simulation result



Machined part



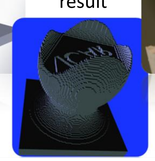
- Simulation and path planning on GPU work 32X times faster than CPU (GTX480 & i7-2600) without extensive optimization;
- Height map representation works only for 3-axis machining and is limited by resolution 8192^2 with a reasonable memory usage;

Part II: 5-axis path planning and machining simulation

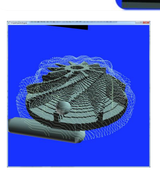
- Geometry is represented is a voxel model with resolution up to 1024^3;
- Simulation is implemented by testing intersection of each cell with a cutter;
- Path planning is based on a 3d contour offset approach;
- All path planning and simulation calculations are done on GPU; in a reasonable time (~3 minutes);
- Orientation is selected based on accessibility maps rendered in OpenGL for each tool point;

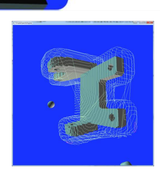
Original

Simulation result



Machined part





- The proposed set of algorithms for 5-axis tool path planning, orientation selection and simulation works and allows to machine many parts without any path planning done by an operator;
- Much higher accuracy (1µm) is required for machining industry models;

Current and future research

Global research objectives

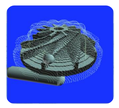
Computational problem

- New solid geometry representation
- Set of parallel geometry processing algorithms optimized for GPGPU

Simulation

- Fast and accurate 5-axis GPU-accelerated CNC machining **simulator**
- Simulator will become a base for path planning

Automatic tool path planning



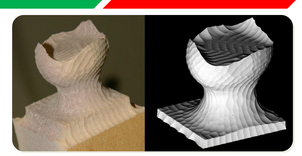
- **Platform** for tool path planning based on developed geometry representation
- Iterative human-like path planning approach

Current research

- Modern CAM software does not support parallel processing mainly because the current solid geometry representation were developed tens years ago and were designed for slow serial processors with low amount of available memory;
- A new solid geometry representation based on a discreet space approach and designed for parallel processing, data level parallelization, iterative rendering and support of GPGPU is developed in this research;
- The latest version supports resolution 4096^3 and a next version will support unlimited resolution:

8192^2 → 1024^3 → 4096^3 → unlimited

- To verify the proposed solid geometry representation a fast and accurate 5-axis machining simulator which performs all calculations on GPU is developed;



Conclusion

- New geometry representation designed for GPGPU will break the current limitation in performance of traditional CPUs:
  - Researchers will get much more performance and will be able to develop algorithms which are not possible today;
  - Software developers will be able to use existing advanced path planning algorithm which require too much performance today;
- The next step for the current research will be development of a system which will try multiple possible path planning strategies, simulate their results and select the best sequence;
  - A similar approach is used by a human;
  - This approach may compete with a human but requires huge amount of computational resources which is not available for machine shops;
- Automatic path planning will change the manufacturing industry;