CPS: Synergy: CNC Process Plan Simulation, Automation and Optimization

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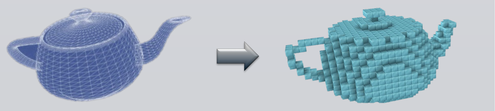
SculptPrint: The Print Button for 5-axis CNC Machining

CNC Toolpath Planning with the Ease of Programming of 3D Printing and Precision of Subtractive Manufacturing

Discrete Geometry Representation for Computer-Aided Manufacturing

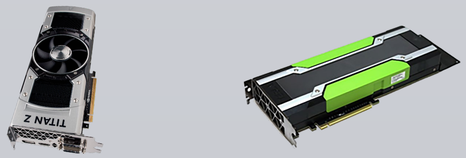
- 3D Pixels
- Alternative to B-rep or CSG



CAD Representation

Parallel Processing

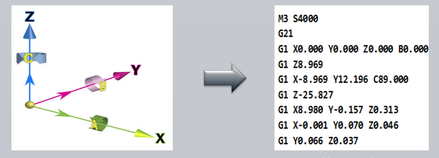
- Use of high performance computing (HPC) with GPUs to accelerate operations on voxel model
- GPGPU for sparse 3D matrices



GPUs for Compute

Toolpath Automation

- Automatic tool accessibility determination based on machine configuration
- G-Code generation



Axis Configuration G-code

CAM Toolpath Generation

CNC Machine Machined Part

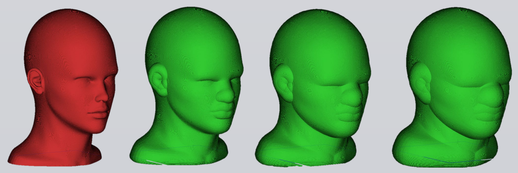
Multi-Axis Machining

Automation in Toolpath Planning

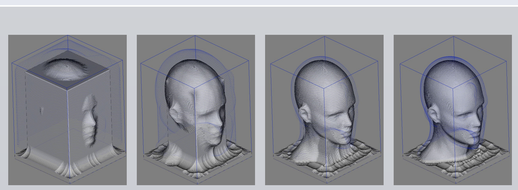
Offsetting and Tool Accessibility Analysis

Contact Volume Generation

- Discrete surface offsetting using CUDA
- Contact volumes provide the surfaces where a tool of a certain radius can reside without cutting too deeply
- Successive offsets provide XYZ points for the cutting tool



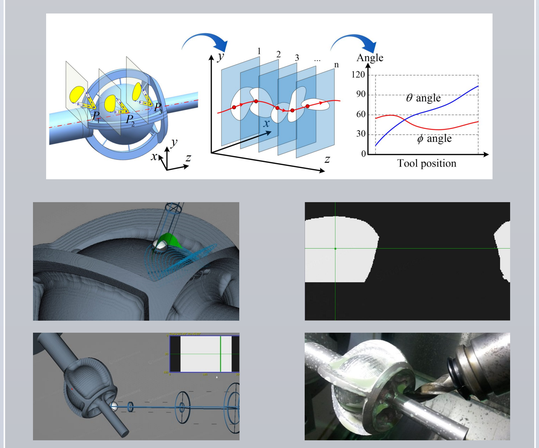
Incremental Volume Offset Computation



Iterative Volume Removal

Tool Accessibility Analysis

- A tool positioned on the offset volume must assume an orientation that avoids collisions
- An “accessibility map” provides allowable orientations for the tool.
- Stacked in sequence, the accessibility maps form an accessibility space.



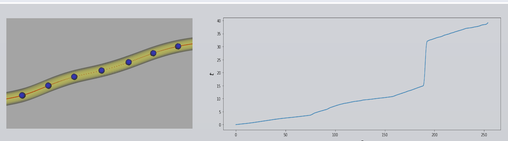
Accessibility Analysis with 2 RDoF

Trajectory Planning

Dynamic Modeling of Machine Motion for Cutting Time Reduction

Toolpath Optimization

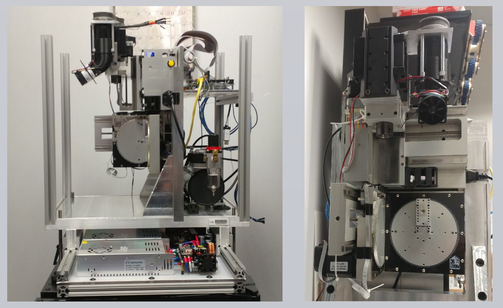
- Discrete position samples converted to motion (time parameterized paths) using B-Splines
- Travel time minimization, subject to material removal and machine kinematic constraints
- Smoothing of angular positions in accessible space
- s and t values give improvement comparison for original and optimized path



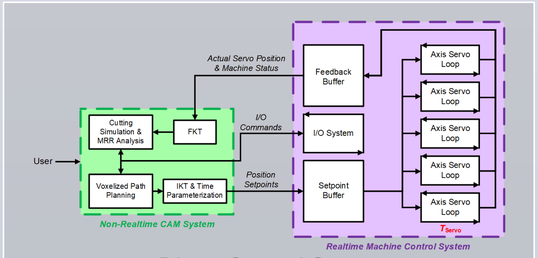
Smoothing & Result of Toolpath Optimization

Open-Source 5-Axis CNC Development

- Modification of Machinekit for direct read and write of servo loop feedback and setpoint
- Instrumentation of machine tool
- Network control of machine tool using TCP/IP
- Interactive realtime plotting in HMI



Research Platform Based on PocketNC



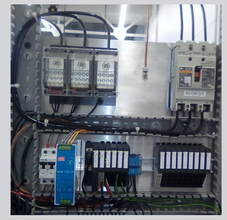
Direct Control System

Open Source Industrial Implementation

Integration of SculptPrint and trajectory planning research on retrofitted 1986 CNC

Hardware Retrofit

- Modern computation and communications
- Modern motors, drivers and IO



Power distribution

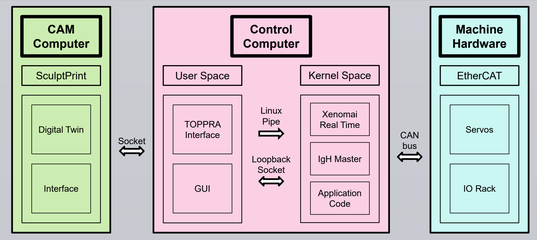
Servo amplifiers

Motor drivers

The control PC

Open Source Controller Development

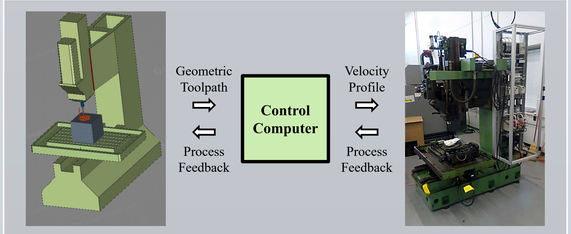
- Patched real time Linux on a PC
- Python, C, CAN bus, TCP/IP



Software components in open source controller

Digital Twin in CAM

- Direct connection of SculptPrint and CNC
- Digital Twin for remote monitoring and control



Digital Twin in SculptPrint

Acknowledgements

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