On the Generation of a Spiral Tool Path for High Speed Pocket Machining and Related Applications

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Introduction

- Material is removed from a **workpiece**.
- Milling cutter can be regarded as a **cylindrical object**.
- Tool is positioned using multiple **axes**.
- Different types of **path control** can be distinguished.
Types of Path Control

- Most milling tasks can be carried out using 2\(^{1/2}\)D milling.
- Hybrid between 2D and 3D milling.
- Parallel **machining planes** are considered.
- **A contour** is a simple, closed curvilinear chain.
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The boundary $\partial P$ of a **pocket** $P$ consists of exactly one **outer contour** and (possibly) **inner contours** (the so-called islands).

Islands are disjoint and do not include islands themselves.

![Diagram of a pocket with contours](image)
High Speed Machining

- High spindle speeds and feeds.

\[ \partial P \]
High Speed Machining

- High **spindle speeds** and **feeds**.
- Conventional strategies introduce **sharp corners**.
- Rapid acceleration and deceleration should be avoided.
- Cornering greatly contributes to **tool wear**.
- **Engagement angle** varies highly.
- **Continuous** tool path is crucial.
Obtaining a Raw Tool Path

- A **basic version** of the tool path.
- Starts in the interior of the pocket.
- Ends on the pocket boundary.
- Does not intersect itself.
- Respects the user-specified maximum **step-over** $\delta$. 
Medial Axis Tree

- The **medial axis** $\mathcal{MA}(P)$ inside a pocket $P$ is a subset of the respective Voronoi diagram.
- $\mathcal{MA}(P)$ is union of all points whose **clearance disks** touch the border of $P$ in at least two distinct points.

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- $\mathcal{MA}(P)$ is union of all points whose **clearance disks** touch the border of $P$ in at least two distinct points.
- $\mathcal{MA}(P)$ forms a tree $T_r(P)$ inside a pocket without islands.
- It is assumed that $r$ is **height-balanced**.

\[
\partial P \\
T_r(P) \\
r
\]
Basic Concept of Clearance lines

- **Clearance lines** are the fundamental building blocks of the tool path.
- Straight-line segments starting on the medial axis.
- They end at one of the corresponding **defining sites**.
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Clearance Line Distribution

- Only a finite number of clearance lines can be handled.
- Thus, **sample points** are distributed uniformly on each edge $e$ of $T_r(P)$.
- Additionally, a sample point is placed at the start and end point of $e$.
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- Clearance lines together with the medial axis tree.
- New structure forms also a tree (the discrete medial axis tree (DMAT)).
Basic Idea of Impulse Propagation

- General idea based on [Held and Spielberger, 2009].
- An **impulse** flows through the DMAT.
- It starts at the root, splits at each vertex, and simultaneously arrives at all leaves of the DMAT.
- The impulse is active during the time interval [0, 1].
Animation: Impulse Propagation
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A wavefront is a closed polygonal chain. Consider impulse at a fixed point in time.
A Series of Wavefronts

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- Traverse the DMAT in depth-first manner.
- Wavefronts must be distributed uniformly such that $\delta$ is respected.
- This process yields a uniform decomposition of time, i.e., the interval $[0, 1]$. 
Generating a Closed Tool Path

- Initially, the first as well as the last lap is generated.
- The number of laps necessary to machine a specific pocket equals the number of sub-intervals of the respective uniform decomposition of time.
- Interpolate between first and last lap.
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Dealing with Islands

- A pocket $P$ with islands is described by multiple contours.
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- Solution: Connect the input contours through straight-line segments (so-called bridges).
- Therefore, a single, connected boundary is produced.
- Closing narrow bottlenecks results in a lower step-over variation.
Animation: Dealing with Islands
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Smoothing the Tool Path

- Tool path unsuited for high speed machining (HSM) due to discontinuities.
- Needs to be smoothed.
- \texttt{POWERAPX}-package (developed by Heimlich and Held [2008]) allows smoothing through Biarcs.
- Choose tolerance bands accordingly.
Animation: Smoothing the Tool Path
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- **Double spiral** provides an alternative approach.
- **Not** suited for pocket milling.
- May find other applications (such as spray paintings or aerial surveillance)
Thank you for your attention!

CCW  counter-clockwise
CW    clockwise
MAT medial axis tree
DMAT discrete medial axis tree
HSM high speed machining
CCL center of clearance lines
EMST Euclidean minimum spanning tree
SOV step-over variation