Applications of the Fuzzy Intelligent Systems

Z. Dong, Department of Mechanical Engineering, University of Victoria

Automated CNC Tool Path Generation in Sculptured Surface Machining

- Intelligent Rough Machining of Sculptured Parts
- Optimal Tool Path Generation for 3½-2-Axis CNC Machining

Dynamic Traffic Control

- Dynamic Traffic Control for Signalized Highways
- Real-time Traffic Contra-flow Operation at George Massey Tunnel
Automated CNC Tool Path Generation in Sculptured Surface Machining

- Intelligent Rough Machining of Sculptured Parts
- Optimal Tool Path Generation for 3½₁₂-Axis CNC Machining
Intelligent Rough Machining of Sculptured Parts for Maximum Productivity

H. Lee, Z. Dong and G.W. Vickers
A Project Supported by the Natural Science and Engineering Research Council of Canada

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Rough and Finish Machining of Dies and Injection Molds
2 1/2D Rough Machining

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Intelligent Rough Machining of Sculptured Parts

- **Objective**
  Minimize machining time given part geometry, material and machining constraints

- **Scope of Study**
  - Identification of Optimal Machining Strategy Based on Part Geometry
    - Optimal Tool Path Patterns for 2 ½ D Machining
  - Identification of Optimal Machining Parameters
    - Feed-rate, Depth and Width of Cut, Number of Cutting Layers
Various Feasible Tool Path Patterns in 2 1/2 D CNC Machining

(a) Parallel tool path pattern
(b) Stock-offset tool path pattern
(c) Parallel-hull pattern
(d) Component-hull pattern
(b) Stock Offset
(a) Component Offset
(c) Stock/Component Offset
(e) Proportional Blending Offset
(f) Max-Min Offset

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Clustering of Cutting Layers in Identifying the Optimal Tool Path Patterns
Identification of Optimal Tool Path Patterns

- **Alternatives**
  - Clustering all possible cross-section shapes
  - Clustering all cutting layers of a given part
- **Fuzzy Variables and Function**
  - Fuzzy parameters: length/width ratio, island/stock area ratio, etc.
  - Fuzzy Measure: tool path length (machining time)
- **Benefits**
  - Around 15% of machining time reduction
  - Automation in tool path pattern selection
Machining Parameter Optimization

Objective Function:

\[
\min_x \quad T = T_c + T_m + T_u + T_d \frac{T_c}{T_l} \approx T_c + T_m
\]

\[
= \sum_{i=1}^{N} t_{ci} + \sum_{i=1}^{N} t_{mi} = \sum_{i=1}^{N} \sum_{j=1}^{n_{ci}} l_{cij} + \sum_{i=1}^{N} \sum_{k=1}^{n_{mi}} l_{mik}
\]

Design Variables:

\[X = \{ N, f_i, d_i, d_{c,i}, P_i \quad (i = 1, \ldots , N); \quad S_p(x, y, z), S_s(x, y, z) \}^T\]

Machine and Process Constraints:

\[0 \leq F_{T,i}(\phi) = K_T a h_i(\phi) \leq F_{T,max}\]

\[0 \leq F_{R,i}(\phi) = K_T K_R a h_i(\phi) \leq F_{R,max}\]

... Geometry Constraints:

\[\sum_{i=1}^{N} d_i = H\]
Test Results

Higher Productivity with Reduced Machining Time:
- vs. Manual Planning: 39%
- vs. Adaptive Control: 25%
Summary

- **Two Aspects and Two Methods**
  - Identification of Optimal Machining Strategy Based on Part Geometry
    ~ Optimal Tool Path Patterns for 2 ½ D Machining (Fuzzy Intelligent System)
  - Identification of Optimal Machining Parameters
    ~ Feed-rate, Depth and Width of Cut, Number of Cutting Layers (Math Modeling and Numerical Optimization)

- **Machining Time Reduction and Automation (Benefits)**
  - Machining Strategy Optimization (15%)
  - Machining Parameter Optimization (45%)
Automated Optimal $3^{1/2}/2$-Axis CNC Tool Path Generation for Machining Sculptured Parts Using Fuzzy Pattern Clustering

Z. Chen, Z. Dong and G.W. Vickers
Advanced Manufacturing Lab.
Dept of Mechanical Engineering
Supported by NSERC

(Please see the other poster for details.)

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3½½-Axis VS. 5-Axis CNC Machining

3½½-Axis CNC Machining
- Discrete Translation and Rotation
- Reorientation for Better Machining Set-up
- Rigid and Less Chatter
- Lower Investment and Cheaper Maintenance
- Automatic and Optimal Tool Path Planning

5-Axis CNC Machining
- Synchronized Translation and Rotation
- Flexible Machining and One-time set-up
- Less Rigid and Prone Chatter
- Higher Costs and Expensive Operating
- Difficult to Generate Tool Path
Sculptured Surface Expression

To digitize the surface feature, *shape and machinability*, surface expression is needed. Non-Uniform Rational B-Spline (NURBS) surface is often used.

**NURBS Surface Expression**

\[
S(u, v) = \sum_{i=1}^{n+1} \sum_{j=1}^{m+1} C_{i,j} \cdot N_{i,k}(u) \cdot N_{j,k}(v)
\]

\[
u_{\text{min}} \leq u \leq u_{\text{max}}, \quad v_{\text{min}} \leq v \leq v_{\text{max}}
\]

**Surface Shape Types**

- Convex
- Concave
- Saddle

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Hierarchical Data Structure

Surface Grid Points

- Convex
  - Accessible & No Gouging
  - Inaccessible / Gouging

- Concave
  - Accessible & No Gouging
  - Inaccessible / Gouging

- Saddle
  - Accessible & No Gouging
  - Inaccessible / Gouging

An Example Sculptured Surface

Control Polyhedron (4 X 4)

Grid Points of A NURBS Surface
Fuzzy Pattern Clustering of Surface Points

- Subtractive Fuzzy Clustering
  - Input: Grid Points of A Surface Shape (i.e. Accessible Convex)
  - Output: The Number of Cluster Centers and Their Locations

- Fuzzy C-Means Clustering
  - Input:
    - Grid Points of A Surface Shape (i.e. Accessible Convex)
    - The Number of Cluster Centers and Their Locations
  - Output:
    - Optimized Number of Clusters
    - Locations of the Cluster Centers
Subtractive Fuzzy Clustering on Points of the NURBS Surface

Fuzzy C-Means Clustering on Points of the NURBS Surface
Voronoi Diagram of the Surface Patch Boundaries
Automatically Generated Optimal Tool Paths

Shown in the Figure:
- Surface Patches
- Surface Normal of the Cluster Centers
- Iso-parameter Tool Paths for Each Surface Patch

Five-axis Machining on Low-cost, 3-axis CNC Machine
Better Surface Quality and Higher Productivity
Dynamic Traffic Control

- Dynamic Traffic Control for Signalized Highways

- Real-time Traffic Contra-flow Operation at George Massey Tunnel
Dynamic Traffic Signal Control Using A Self-learning Fuzzy-neural Intelligent System

J. Wu and Z. Dong
Supported by Ministry of Transportation and Highways of British Columbia and Institute for Robotics and Intelligent Systems

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Major Obstacles for Dynamic Traffic Control

- Complexity of the traffic system and traffic flow conditions
- Real-time traffic control
- Self-learning and adaptability
- Implementation
Traffic Demands on Trans Canada Highway in Duncan Area

Volume (vehicles / 15 min)

Time of day (15 minute intervals)
Traffic Timing Plan Design

- Transyt - 7F (minimizing total delay)
- Passer III (maximizing bandwidth)
Intelligent Dynamic Traffic Control System Structure (software)

- Traffic Data Acquisition
- Traffic Condition Prediction
- Traffic Pattern Identification
- Timing Plan Setting
- Traffic Data Memory
- Traffic Data & Parameters Input / Output
- Traffic Data & Parameters Input / Output
- Traffic Data Clustering
- Traffic Data & Parameters Input / Output
- Timing Plan Design
- Traffic Pattern Training

On-line

Off-line

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Intelligent Dynamic Traffic Control System

Modem

LM or MDM Master Controller

LMD Local Controllers

Central Office Monitor & Intelligent Dynamic Traffic Control System (on-line)

Intelligent Dynamic Traffic Control System (off-line)

dedicated line

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Total Delay of Static and Dynamic Traffic Control

Average Total Traffic Delay Reduction: 5~30%

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Real-time Traffic Contra-flow Operation Using Artificial Neural Network, Fuzzy Pattern Recognition and Delay Minimization

D. Xue and Z. Dong
Supported by Ministry of Transportation and Highways of British Columbia

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Research Problem

- **Traffic Problems:**
  - Tunnels and bridges are often bottlenecks of a traffic system.
  - Traffic demands from the opposite directions vary periodically.

- **Contra-flow Operations**

- **Contra-flow Control Problem:**
  - Lane switch leads to a temporary capability loss.
  - Difficult to accurately predict future traffic demand.
  - Difficult to handle constantly changing traffic conditions.
A Contra-flow Operation Cycle

- Closing the selected contra-flow lane to clear up the traffic on this lane;
- Opening the contra-flow lane in the opposite direction;
- Closing the contra-flow lane when the traffic peak hours are over; and,
- Re-opening the traffic lane to its normal state.
Traffic Demand Prediction by Pattern Matching

A Traffic Pattern:

\[ P_i = (P_{i_1}, \ldots, P_{i_p}) \quad (i = 1, \ldots, c) \]

Sample every 5 min for 7 hrs:

\[ p = 1 + 7 \times 60/5 = 85 \text{ samples} \]

Collected Traffic Data:

\[ D = (D_1, \ldots, D_q) \quad (q < p) \]

Similarity Measure:

Distance \((D, P_i)\)
Two Challenging Tasks
Hierarchical Pattern Representation and Matching

- Improving search efficiency
- Utilizing available heuristics: Mon-Thur, Fri, Weekends/holidays
Traffic Demands and Capacities at the Tunnel Site

(a) One-Shift Contraflow Control

(b) Two-Shift Contraflow Control

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# Traffic Delay Reduction

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Delay (Vehicle-hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-time Schedule</td>
<td>2163</td>
</tr>
<tr>
<td>On-line Schedule</td>
<td>1416</td>
</tr>
<tr>
<td>The Optimal Schedule</td>
<td>948</td>
</tr>
<tr>
<td>Improvement of On-line Schedule</td>
<td>34%</td>
</tr>
<tr>
<td>Total Room for Improvement</td>
<td>56%</td>
</tr>
</tbody>
</table>

*(Unit of Delay: Vehicle-hours)*

Proposed System Implemented by the MOT since 1996.
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