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SUPEROPT Project and Sense Constraints

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The Project

• **SUPEROPT** – Supervision of Route Optimizers

• Find trajectory optimizers that are suitable for human interaction
  – Selecting and applying optimizers
  – *Not* developing new ones or HMI
The Project

Useful inputs
“Constraint playbook”
Prioritized constraints

Meaningful outputs
Sensitivity
Distinct alternatives
So Far

- Main body of work just about to start

- Today: initial results
  - Constraining the sense of a conflict resolution

- Who is the supervisor?
  - Big question: for now, executive controller
Constraining the Sense

- Tricky to formulate
- Constraint: integrated angular change $\geq 0$
  - Or $< 0$ for opposite
- Angle change robustly captures the sense
  - Independent of direction or aircraft ordering
MILP Separation Constraints

\[ x_1 - x_2 \geq R - Mb_1 \]
and \[ x_2 - x_1 \geq R - Mb_2 \]
and \[ y_1 - y_2 \geq R - Mb_3 \]
and \[ y_2 - y_1 \geq R - Mb_4 \]
and \[ \sum_{k=1}^{4} b_k = 3 \]
MILP Separation Constraints

\[ x_1 - x_2 \geq R - Mb_1 \]
\[ \text{and } x_2 - x_1 \geq R - Mb_2 \]
\[ \text{and } y_1 - y_2 \geq R - Mb_3 \]
\[ \text{and } y_2 - y_1 \geq R - Mb_4 \]
\[ \text{and } \sum_{k=1}^{4} b_k = 3 \]

Sense can be related to the sequence of binary settings.

b=(1,1,0,1)

b=(1,0,1,1)

b=(0,1,1,1)

b=(1,1,1,0)
MILP Sense Constraints

- New binary decision variables
  - $m_{CW}(i,k)=1$ if move is clockwise from quadrant $i$ at time $k$
  - $m_{ACW}(i,k)=1$ if move is anticlockwise from quadrant $i$ at time $k$
  - $m_{NR}(i,k)=1$ if no move from quadrant $i$ at time $k$

- Choice of $m$ fixes $b$
MILP Sense Constraints

- For clockwise resolution, number of clockwise moves > number of anticlockwise moves
  \[ \Sigma m_{CW} > \Sigma m_{ACW} \]
  - Vice versa for anticlockwise
Demonstration
Demonstration

Simple circular sector with six E-W flows

Control of constraints
Two crossing aircraft in conflict
Resolve anti-clockwise
Resolve anti-clockwise
Resolve clockwise
Resolve clockwise
Three Aircraft
Three Aircraft

Resolve all 3 pairs anticlockwise
## Computation

<table>
<thead>
<tr>
<th>Sense constraint</th>
<th>Computation (s)</th>
</tr>
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<tbody>
<tr>
<td>3 v 2</td>
<td>11.1</td>
</tr>
<tr>
<td>2 v 1</td>
<td>ACW 44.9</td>
</tr>
<tr>
<td>3 v 1</td>
<td>CW 13.2</td>
</tr>
<tr>
<td>ACW</td>
<td>CW 11.7</td>
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<td>CW ACW</td>
<td>CW ACW ACW 52.2</td>
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<tr>
<td>CW ACW CW</td>
<td></td>
</tr>
</tbody>
</table>
Ahead or Behind

Two aircraft fixed. Third enters.
Ahead or Behind

Solve for #3: goes behind #1
Ahead or Behind

Request #3 ahead of #1: generate sense constraint
Summary

• Expressed sense constraints in terms of total angle change between aircraft

• Captured and constrained sense within MILP optimization

• Offers an intuitive control of conflict resolution optimization
Next Steps (1 of 2)

- More constraint trials
  - Corridor relative to nominal
  - Deviation from nominal

- Jump to 3-D
  - Easily done in the code
  - Expand possibilities for constraints
    - Resolve above/below
    - Deviate above/below
Next Steps (2 of 2)

• Switch to alternative nonlinear optimizer
  – Core methods available and understood
  – Incorporate new constraint forms
    • Compare with MILP

• Move on to prioritization
  – New idea for cost weight generation
  – Easily done in MILP
  – B&B idea for generic inclusion in any opt.