Advanced Coordination of Multi-AGV Systems

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Problem Statement

Route map Design

Segment
Path
Global Navigation
Problem Statement

Traffic Rules
Problem Statement

Route map + Traffic Rules + Global Navigation

Design

manual

manual

Route map

Traffic Rules

Global Navigation
Problem Statement

Route map Design + Traffic Rules + Global Navigation

manual + manual

Segment Path

Route map

PAN ROBOTS
Plug & Navigate robots for smart factories
Problem Statement

Automatic Route map Design AND Global Navigation AND Coordination AS A WHOLE!
Hierarchical Architecture

• **Topological Layer**
  – Divided in *sectors*
  – Dynamic Path Planning

• **Route map Layer**
  – Deadlocks and conflicts avoidance
  – Decentralized Coordination
Topological Layer

**SECTOR**

- Particular geometric space
- Topology
- Property: position, AGVs number, links ...

Diagram:
- Obstacle/rack
- Sectors
Topological Layer

SECTOR

Particular geometric space

Topology

Property: position, AGVs number, links ...

Graph
Properties of the Route map

Directed graph

- Edge = segment
- Node

Start/end segment

Interest point

sector’s border
Properties

**Intersection**

- Cross point
- Attention point
GLOBAL NAVIGATION & COORDINATION
Global Navigation & Coordination

Topological Navigation
- BEST PATH

Route map Coordination
- DECENTRALIZED COORDINATION
Global Navigation on Topological Layer

D* Algorithm
- Shortest Path
- Re-planning

MPC
- Sector Check
- Moving Horizon

Only one shared information: Number of AGVs
Each AGV autonomously computes its path (A*) towards the next sector.
Decentralized Coordination

- Local communication inside the sector

- Data exchanged:
  - AGV Priority
  - Intersection Request
  - Intersection Allocation
ROUTE MAP DESIGN
The route map has to:

- Cover the free space
- Be as redundant as possible
- Be strongly connected and maximal connected
- Be admissible (w.r.t. the AGV’s kinematics)
Approach

Idea

1. Find corridors and intersections in the free space
2. Fill the corridors
3. Build the intersections
4. Assign Directions
5. Smooth the route map
Find corridors and intersections
Find corridors and intersections
Find corridors and intersections

Medial Axis Transformation (MAT)
Find corridors and intersections

From MAT Q

- **Corridor**: the set of points bounded by at least two obstacles and such that $Q$ is a segment of line parallel to the boundary of the obstacles.

- **Intersection**: the set of points bounded by corridors and whose medial axis $Q$ is not parallel to the boundary of any of the obstacles.
Find corridors and intersections
Fill the corridors
Build the intersections
Assign Directions

- Topological graph T
Assign Directions

- Corridor num. roads > 1 => bi-directional edge
- Corridor num. roads = 1 => mono-directional edge
Direction Assignment Problem

A direction has to be assigned to each road in the route map $G$ in such a way that the topological graph $T$ is strongly connected and the algebraic connectivity is maximized.

Method:
- Randomized direction assignment
- Strong connectivity verification
- Algebraic connectivity evaluation
Randomized direction assignment

\( n = \text{num. of roads in corridor} \)

- \( \left\lfloor \frac{n}{2} \right\rfloor \) roads with direction \( i \rightarrow j \)
- \( \left\lfloor \frac{n}{2} \right\rfloor \) roads with direction \( j \rightarrow i \)
- \( n - 2 \left\lfloor \frac{n}{2} \right\rfloor \in \{0,1\} \) roads with random direction
Strong connectivity verification

$\overline{T}$ is the balanced version of the graph $T$

$\overline{T}$ is strongly connected if and only if $T$ is strongly connected

$\overline{T}$ is strongly connected if $\text{Real}\{\lambda_{\overline{T}}^2\} > 0$
Assign Directions

Algebraic connectivity evaluation
Maximize the Algebraic connectivity of T (heuristic to maximize the traffic flow)

*binary non-linear optimization problem:*

\[
\text{Maximize } \text{Real} \{\lambda^T_2(x)\} \\
\text{Subject to } x \in \{0,1\}
\]

X is a vector of directions

Solve with a local search approach: Monte Carlo and Tabu Search approach
Smooth the route map

Straight lines

+ 

Bezier Curves
Results

<table>
<thead>
<tr>
<th>Class</th>
<th>Dimension</th>
<th>Manual Route</th>
<th>Automatic Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>5 AGVs</td>
<td>0.0031</td>
<td>0.0043</td>
</tr>
<tr>
<td>Medium</td>
<td>25 AGVs</td>
<td>0.0002</td>
<td>0.0027</td>
</tr>
<tr>
<td>Big</td>
<td>50 AGVs</td>
<td>0.00075</td>
<td>0.0019</td>
</tr>
</tbody>
</table>

Conclusion

• Coordination strategy for a fleet of AGVs (2-Layer Approach)

• Global Navigation
  – Simple
  – Scalable
  – Only 1 traffic rule: Priority
  – Dynamic
  – Decentralized coordination

• Automatic Route map generation process
Current Work

• Integration of the Coordination algorithm with the Automatic Route map design process
  – Define the route map properties (attention/cross points)
  – Sector division based on the route map design

• Mapping the route map layer on the topological layer in a better way
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