Cooperative Multi-Vessel System

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5. Conclusion and future research
Background

1. Background
2. CMVS
3. Intra-CMVS
   -- VTF
4. Inter-CMVS
   -- WIS
5. Conclusion

- Problem
  - Safety
    - Misunderstanding
    - Unexpected incidents
  - Efficiency
    - Congestion at locks and ports
  - Task performing
    - Tasks which cannot be fulfilled by individual vessels, such as towing large structures, searching, etc.
Background

- Cooperation as a solution
  - Safety:
    - Efficient decision making
    - Fast reaction to unexpected incidents
    - Organized traffic
  - Efficiency:
    - Improve the utilization rate
    - Saves line-up time
  - Task performing:
    - Cooperation of a group of vessels can carry out tasks more efficiently and effectively
Cooperative Multi-Vessel System

1. Background
2. CMVS
3. Intra-CMVS -- VTF
4. Inter-CMVS -- WIS
5. Conclusion
Cooperative Multi-Vessel System

1. Background
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5. Conclusion

• Intra-CMVS Vessel-to-Vessel cooperation
  – Vessel Train Formation

• Inter-CMVS Vessel-to-Vessel cooperation
  – Waterway Intersection Scheduling

• Vessel-to-Infrastructure cooperation
Cooperative Multi-Vessel System

• Method: Model Predictive Control
  – Consider conflicts at an early stage
  – Up-to-date information
  – Control of large-scale networked systems

1. Background
2. CMVS
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Intra-CMVS V2V cooperation -- Vessel Train Formation

- **Path following:**
  - attempt to follow the predetermined paths;

- **Aggregation:**
  - attempt to stay close to nearby vessels;

- **Collision avoidance:**
  - avoid collisions with nearby vessels.
Intra-CMVS V2V cooperation -- Vessel Train Formation

- Centralized & distributed control
Intra-CMVS V2V cooperation  
--- Vessel Train Formation

• Centralized formulation

\[
\text{minimize } \sum_{i=1}^{n} J_i (\tilde{u}_i(k)) = \sum_{\tau=1}^{H_p} \sum_{j \in N_i} \left( \alpha \| y_i(k + \tau | k) - w_i(k + \tau) \|_I + \beta \| d_{ij|i}(k + \tau | k) + \delta_{ij|i}(k + \tau | k) \|_I + \gamma \| u_i(k + \tau - 1 | k) \|_I \right) 
\]

Path following  
Aggregation  
Control efforts

subject to  \( \forall i \in N, j \in N_i, \forall k \in T, \forall \tau \in H_p : \)

\[
\text{Input constraint} \quad u_{\text{min}} \leq \| u_i(k + \tau | k) \|_2 \leq u_{\text{max}}, \\
\text{Velocity constraint} \quad q_{\text{min}} \leq \| q_i(k + \tau | k) \|_2 \leq q_{\text{max}}, \\
\text{Collision avoidance} \quad d_{ij|i}(k + \tau | k) \geq d_{\text{safe}}, \\
\text{Aggregation constraint} \quad -r \leq \delta_{ij|i}(k + \tau | k) \leq r, \\
\quad r = \min(r_1, r_2, \ldots, r_n).
\]
Intra-CMVS V2V cooperation
-- Vessel Train Formation

• Distributed formulation
  – ADMM-based serial iterative algorithm

a) Each vessel solves a local problem and sends the predictive trajectory to others.
b) Information updates in sequence
c) Iterations stop when

\[ u_s^i = z_s^i = z_s^{i-1} \]
1. **Background**

2. **CMVS**

3. **Intra-CMVS V2V -- Vessel Train Formation**

   - Simulation experiments
     - Influencing factors
     - Updating sequence

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![Diagram](image-url)
Intra-CMVS V2V cooperation
-- Vessel Train Formation

• Simulation experiments
  – Influencing factors
  • Responsibility

\[
z_i^s(k) = u_i^s(k) + \lambda_i^{s-1}(k)/\rho_i
\]
\[
\therefore z_i^s(k) = \varphi_i u_i^s(k) + (1 - \varphi_i)z_i^{s-1}(k) + \lambda_i^{s-1}(k)/\rho_i,
\]
\[
\sum_{i=1}^{n} \varphi_i \geq 1, \quad 0 \leq \varphi_i \leq 1.
\]
Intra-CMVS V2V cooperation
-- Vessel Train Formation

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TU Delft
1. Background

Intra-CMVS V2V cooperation

-- Vessel Train Formation

- Simulation experiments
  - Influencing factors
- Responsibility

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Intra-CMVS V2V cooperation
-- Vessel Train Formation

• Simulation experiments
  – Scalability
Intra-CMVS V2V cooperation
-- Vessel Train Formation

1. Background
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5. Conclusion
1. Background
2. CMVS
3. Intra-CMVS

• Simulation of a CMVS

Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

- **Time-space occupation**
  - a vessel passing through an intersection can be regarded as occupying some blocks for a certain period.
Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

• **Sequential constraint:**
  – a vessel passes through the blocks in a predetermined sequence;

• **No-wait constraint:**
  – a vessel has to enter the next block immediately when it leaves a block;

• **Disjunctive constraint:**
  – other vessels cannot enter a block until the one inside leaves the block.
Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

1. Background
2. CMVS
3. Intra-CMVS -- VTF
4. Inter-CMVS -- WIS
5. Conclusion
Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

- Simulation experiments

<table>
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<th>P₂</th>
<th>P₃</th>
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</table>
Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

- **Simulation experiments**
  - Scenario I: Non-cooperative case
    - Arrivals -- Poisson distribution
    - Intersection Crossing -- Artificial Potential Field
  - Scenario II: Partially-cooperative case
    - Arrivals -- VTF
    - Intersection Crossing -- Artificial Potential Field
  - Scenario III: Fully-cooperative case
    - Arrivals -- VTF
    - Intersection Crossing -- WIS
Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

1. Background
2. CMVS
3. Intra-CMVS

• Simulation Results

Inter-CMVS V2V cooperation -- Waterway Intersection Scheduling

• Simulation Results
  – Overall makespan and the passing time

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<th>Vessel</th>
<th>Scenario I</th>
<th>Scenario II</th>
<th>Scenario III</th>
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<td>295</td>
<td>270.98</td>
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</table>
Conclusion and Future research

• Conclusion
  – The concept of CMVSs
  – A serial iterative ADMM-based DMPC algorithm for VTF of a CMVS
  – WIS for V2V interaction between CMVSs

• Future research
  – Intra-CMVS Vessel-to-Vessel cooperation
    • Task Performing Formation
  – Vessel-to-Infrastructure cooperation
    • Predictive scheduling for locks
More...


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