Autonomous docking of a feeder vessel

Bas J. de Kruif
Introduction - EU Moses project
Introduction

Aim:
• autonomously sail from quay to quay

Approach:
• split operation
• guidance - navigation - control
• simulate
Split operation
Split operation

docking

undocking

transit

approaching

rest
Approaching - GNC

Guidance - Navigation - Control framework

Trajectory → Guidance → Control → Ship

required pose → required heading speed → actuators

(estimated) pose

Navigation
Ship model

- two azimuthing pods
- two bow thrusters
- course unstable ship manoeuvring model from CFD calculations

→ available in time domain simulator

<table>
<thead>
<tr>
<th>Lpp</th>
<th>71.0 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>13.0 m</td>
</tr>
<tr>
<td>t</td>
<td>4.5 m</td>
</tr>
<tr>
<td>$\nabla$</td>
<td>$2.8 \times 10^3 \text{ m}^3$</td>
</tr>
<tr>
<td>m</td>
<td>$2.9 \times 10^6 \text{ kg}$</td>
</tr>
</tbody>
</table>
Approaching - GNC

Trajectory \rightarrow Guidance \rightarrow Control \rightarrow Ship

required pose \rightarrow required heading speed \rightarrow actuators

(estimated) pose \rightarrow Navigation
Approaching - Bézier trajectory
Approaching - Bézier trajectory
Approaching - guidance

Convert earth-fixed trajectory → to ship-fixed heading/speed

Constant bearing

- copies velocity vector of ‘target’: $v_{sp}$
- adds velocity vector to reach it: $v_c$
Approaching - guidance

Convert earth-fixed trajectory
→ to ship-fixed heading/speed

• Constant bearing
  • copies velocity vector of ‘target’
  • adds velocity vector to reach it
Approaching - GNC

1. Trajectory
2. Guidance
3. Control
4. Ship
5. Navigation

- required pose
- required heading speed
- actuators
- (estimated) pose

Flowchart: Trajectory → Guidance → Control → Ship → Navigation
Approaching - control

- Cascade control
  - inner loop: rate-of-turn
  - outer loop: course
- Stabilises unstable inner loop
- Counters fast disturbances in inner loop
Approaching - control

- Cascade control - inner loop
  - controls rudder to obtain rate-of-turn
  - feedback $\rightarrow$ counter disturbances / instability
  - feedforward $\rightarrow$ control what you know
Approaching - control

- Cascade control - inner loop
  - controls rudder to obtain rate-of-turn
  - feedback → counter disturbances / instability
  - feedforward → control what you know
Approaching - control

- **Cascade control - inner loop**
  - controls rudder to obtain rate-of-turn
  - feedback $\rightarrow$ counter disturbances / instability
  - feedforward $\rightarrow$ control what you know
• Cascade control - outer loop
  • calculates required rate-of-turn to control course
Approaching - control

- Cascade control - outer loop
  - calculates required rate-of-turn to control course
  - pole-zero cancellation at yaw/course conversion
Approaching - control

- Cascade control - outer loop
  - calculates required rate-of-turn to control course
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  - pole placement for rest
Approaching - control

- Cascade control - outer loop
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  - pole placement for rest
Approaching - control

- blue: measurement no bow thrusters
- orange: measurements with bow thrusters
- dotted: trajectory required
Approaching - control

- blue: measurement no bow thrusters
- orange: measurements with bow thrusters
- dotted: trajectory required
- dashed: replanned

![Diagram showing control system with symbols sp, C, Δsp, mv, Δu, u]
Simulate
Summary

• controller designed and tested
  • cascade control for course control
  • course unstable ship
  • bow thrusters included at low speed
• divide-and-conquer approach for quay-to-quay operation
• guidance-navigation-control framework used

Acknowledgment:

MOSES project has received funding from the European Union’s Horizon 2020 research & innovation programme under grant agreement No. 861678. Content reflects only the authors’ view and the Agency is not responsible for any use that may be made of the information it contains.