Path Planning for Multiple Marine Vehicles: Foundations and Future Trends

Andreas J. Häusler, António M. Pascoal and A. Pedro Aguiar

Dynamical Systems and Ocean Robotics Laboratory
Institute for Systems and Robotics
Instituto Superior Técnico
Lisbon, Portugal
{ahaeusler,antonio,pedro}@isr.ist.utl.pt

FREE$_{\text{sub}}$*NET* Montpellier
March 27, 2009

Path Planning for Autonomous Marine Vehicles

- Widening fields of application
- Robots become increasingly sophisticated
- Presence of stringent limitations (dynamical constraints, energy, external disturbances)
- Multiple vehicle missions
- Robust path planning methods required

Path Planning for Autonomous Marine Vehicles

- Widening fields of application
- Robots become increasingly sophisticated
- Presence of stringent limitations (dynamical constraints, energy, external disturbances)
- Multiple vehicle missions
- Robust path planning methods required

Path Planning for Autonomous Marine Vehicles

- Widening fields of application
- Robots become increasingly sophisticated
- Presence of stringent limitations (dynamical constraints, energy, external disturbances)
- Multiple vehicle missions
- Robust path planning methods required

Path Planning for Autonomous Marine Vehicles

- Widening fields of application
- Robots become increasingly sophisticated
- Presence of stringent limitations (dynamical constraints, energy, external disturbances)
- Multiple vehicle missions
- Robust path planning methods required

Path Planning for Autonomous Marine Vehicles

- Widening fields of application
- Robots become increasingly sophisticated
- Presence of stringent limitations (dynamical constraints, energy, external disturbances)
- Multiple vehicle missions
- Robust path planning methods required

Examples & Applications

- Simultaneous arrival and rendezvous problem
- E.g. Go-To-Formation maneouvre and information exchange

Examples & Applications

- Simultaneous arrival and rendezvous problem
- E.g. Go-To-Formation maneouvre and information exchange

Examples & Applications

- Simultaneous arrival and rendezvous problem
- E.g. Go-To-Formation maneouvre and information exchange

Path Planning in General

Describing the paths

Lines-and-arcs, Splines, Dubins Paths, Pythagorean Hodographs, Bézier Curves

Online Path Generation & Replanning

Replanning Existing Paths, Step-wise advance planning & refinement

Multiple Vehicle Approaches

Different sensor/actuator capabilities, Voronoi cells around threats, Lyapunov-based optimal solutions

Path Planning in General

Describing the paths

Lines-and-arcs, Splines, Dubins Paths, Pythagorean Hodographs, Bézier Curves

Online Path Generation & Replanning

Replanning Existing Paths, Step-wise advance planning & refinement

Multiple Vehicle Approaches

Different sensor/actuator capabilities, Voronoi cells around threats, Lyapunov-based optimal solutions

Path Planning in General

Describing the paths

Lines-and-arcs, Splines, Dubins Paths, Pythagorean Hodographs, Bézier Curves

Online Path Generation & Replanning

Replanning Existing Paths, Step-wise advance planning & refinement

Multiple Vehicle Approaches

Different sensor/actuator capabilities, Voronoi cells around threats, Lyapunov-based optimal solutions

Path Planning for Marine Vehicles

Describing the paths

Polynomial-based with geometrical abstraction, Metrics for optimal paths

Optimization for Multiple Vehicles

High mission performance, Energy minimization, simultaneous arrival

Path Planning for Marine Vehicles

Describing the paths

Polynomial-based with geometrical abstraction, Metrics for optimal paths

Optimization for Multiple Vehicles

High mission performance, Energy minimization, simultaneous arrival

Our Approach

Spatial Deconfliction

$$||p_i(\tau_k) - p_j(\tau_l)||^2 \geq E^2; E > 0,$$
$$\forall\ i,j = 1,\ldots,n;\ i \neq j \text{ and } (\tau_k, \tau_l) \in [0, \tau_{f_i}] \times [0, \tau_{f_j}],$$

Temporal Deconfliction

$$||p_i(t) - p_j(t)||^2 \geq E^2, \forall\ i,j = 1,\ldots,n;\ i \neq j \text{ and } t \in [0, t_f],$$

Our Approach

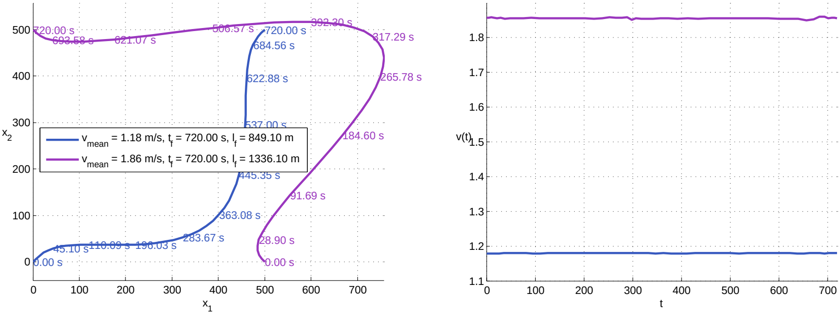
Spatial Deconfliction

$$||p_i(\tau_k) - p_j(\tau_l)||^2 \geq E^2; E > 0,$$
$$\forall\ i, j = 1, \ldots, n; i \neq j \text{ and } (\tau_k, \tau_l) \in [0, \tau_{f_i}] \times [0, \tau_{f_j}],$$

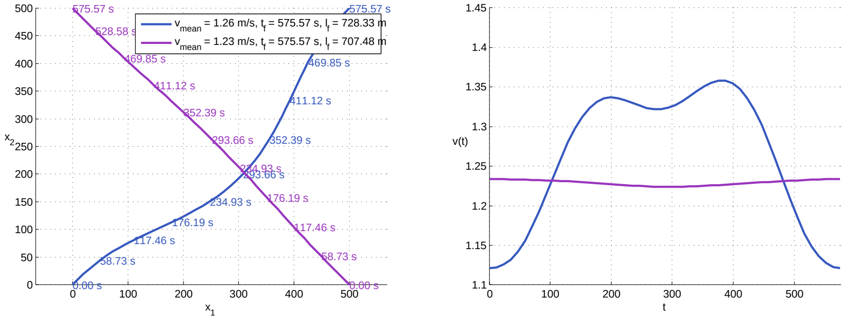
Temporal Deconfliction

$$||p_i(t) - p_j(t)||^2 \geq E^2, \forall\ i, j = 1, \ldots, n; i \neq j \text{ and } t \in [0, t_f],$$

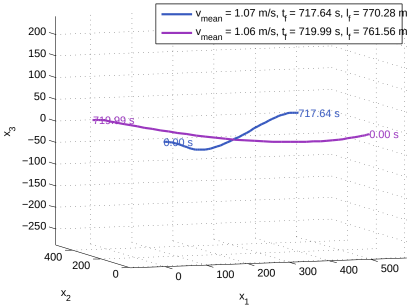
Simulation Examples

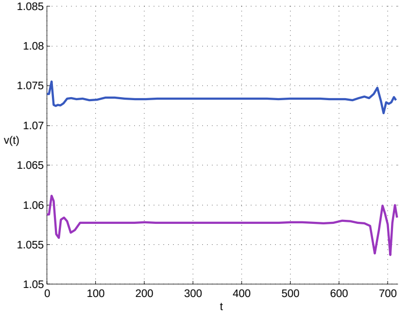


Simulation Examples



Simulation Examples





Future Trends

- Clean mathematical separation from geometrical path and time-dependent trajectory
- Allows for different mapping functions from path to trajectory
- Allows for easily switching between spatial and temporal deconfliction

Future Trends

- Clean mathematical separation from geometrical path and time-dependent trajectory
- Allows for different mapping functions from path to trajectory
- Allows for easily switching between spatial and temporal deconfliction

Future Trends

- Clean mathematical separation from geometrical path and time-dependent trajectory
- Allows for different mapping functions from path to trajectory
- Allows for easily switching between spatial and temporal deconfliction

Selected Literature I

J.-P. Laumond, Ed.
Robot Motion Planning and Control.
Laboratoire d'Analyse et d'Architecture des Systèmes (LAAS), 1998.

S. M. LaValle.
Planning Algorithms.
Cambridge University Press, 2006.

R. Ghabcheloo, I. Kaminer, A. P. Aguiar, and A. Pascoal.
A General Framework for Multiple Vehicle Time-Coordinated Path Following Control.
American Control Conference (to be published), 2009.

Selected Literature II

I. Kaminer, O. A. Yakimenko, V. Dobrokhodov, A. Pascoal, N. Hovakimyan, C. Cao, A. Young, and V. Patel.
Coordinated Path Following for Time-Critical Missions of Multiple UAVs via $\mathcal{L}_1$ Adaptive Output Feedback Controllers.
AIAA Guidance, Navigation and Control Conference and Exhibit, Aug. 2007.

R. M. Murray.
Recent Research in Cooperative Control of Multi-Vehicle Systems.
Journal of Dynamic Systems, Measurement and Control, 2007.

Selected Literature III

N. E. Leonard, D. Paley, F. Lekien, R. Sepulchre, D. Fratantoni, and R. Davis.
Collective Motion, Sensor Networks and Ocean Sampling.
Proceedings of the IEEE, Special Issue on the Emerging Technology of Networked Control Systems, Jan. 2007.