Deconflicted Path Planning for Multiple AMVs

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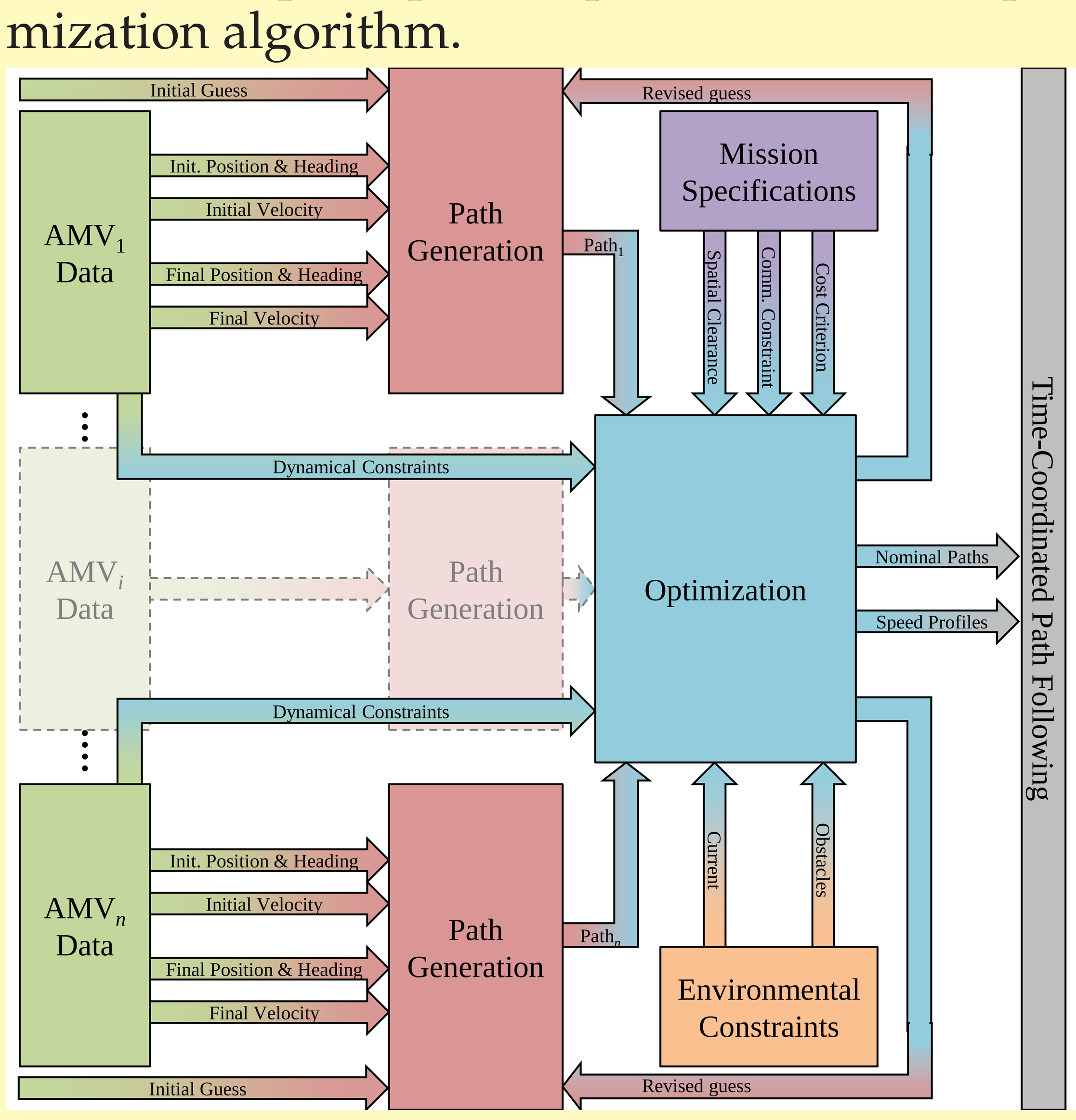
Contribution

We developed a versatile path planning algorithm for deconflicted multiple auonomous marine vehicle (AMV) missions at sea, incorporating single vehicle dynamical constraints as well as inter-vehicle communication constraints and conditions imposed onto the mission through sea currents. This was done by employing a polynomial-based approach, originally described by Yakimenko and further developed by Häusler et al.
The approach allows us to describe the polynomial in terms of the mission's boundary conditions (such as vehicle start and end poses) and employ a zero-order method, e.g. Hooke & Jeeves, to find a time-minimal path, taking into account environmental constraints.

The Path Planning System

The abstract layout of the planning system is shown in the figure below. In the first stage, paths are generated for single vehicles. The inputs are initial and final poses (positions and headings), the "boundary conditions", and an initial guess vector I of the parameters to optimize, e.g. joint arrival time and acceleration at the boundaries. The output is a path between the given positions, which is, together with an associated speed-profile, passed on to the optimization algorithm.



The second stage finds the optimal values of the parameters in I, according to an evaluation of the generated paths according to vehicle dynamic constraints (e.g. minimum and maximum permitted speed), constraints imposed by the mission (e.g. spatial clearance, a cost criterion like minimum energy usage, or minimum simultaneous arrival time), and environmental constraints (e.g. sea current speed and direction and obstacles). The new guess vector is passed back to stage one, until a global optimum has been reached.

References

[1] A. J. Häusler et al. Multiple Marine Vehicle Deconflicted Path Planning with Currents and Communication Constraints In 7th *IFAC Symposium on Intelligent Autonomous Vehicles 2010*

[2] A. J. Häusler et al. Temporally and Spatially Deconflicted Path Planning for Multiple Autonomous Marine Vehicles In *Proceedings of the 8th Conference on Manoeuvring and Control of Marine Craft (MCMC 2009)*

[3] A. J. Häusler et al. Path Planning for Multiple Marine Vehicles In *Proceedings of the IEEE Oceans 2009*

Polynomial Path Planning

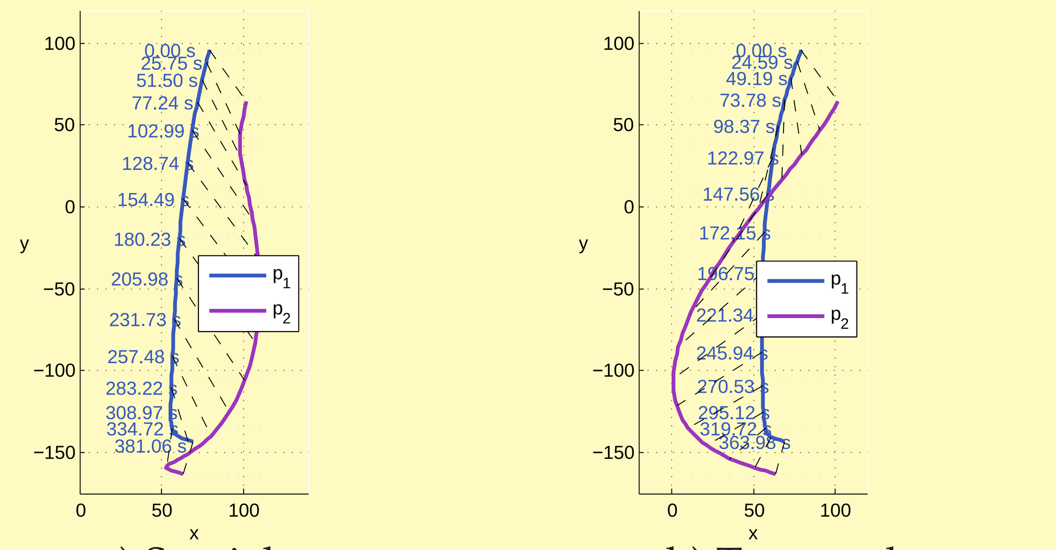
The key point of our technique is the separation of spatial and temporal path description: the optimization process can be viewed as a method to produce paths $\bar{p}_i(\tau_i)$ with timing laws $\eta_i(\tau)$ in terms of an abstract parameter τ, that describe how the nominal speed of vehicle i should evolve along the path. Hence, spatial and temporal constraints are decoupled and captured in the descriptions of $\bar{p}_i(\tau_i)$ and $\eta_i(\tau) = d\tau_i/dt$, respectively. Adopting polynomial approximations for $\bar{p}_i(\tau_i)$ and $\eta_i(\tau)$ keeps the number of optimization parameters small and makes real-time computational requirements easy to achieve.
The path of a vehicle, denoted by $\bar{p}(\tau) = [\bar{x}(\tau), \bar{y}(\tau), \bar{z}(\tau)]^\top$ with a parameterization $\tau = [0, \tau_f]$ can be represented by an algebraic polynomial of degree N, i.e. $\bar{x}(\tau) = \sum_{k=0}^{N} a_{\bar{x}k}\tau^k$. Shaping the speed profile can be achieved by choosing $\eta(\tau) = d\tau/dt$, which describes the evolution of τ in time, giving us equations for temporal speed $v(\tau(t))$ and acceleration $a(\tau(t))$

$$v(\tau) = \eta(\tau)\sqrt{\bar{x}'^2(\tau) + \bar{y}'^2(\tau) + \bar{z}'^2(\tau)}$$
$$a(\tau) = ||\bar{p}''(\tau)\eta^2(\tau) + \bar{p}'(\tau)\eta'(\tau)\eta(\tau)||$$

that later on can be used to check the vehicles' dynamical constraints.

Deconfliction

These pictures show simulation results illustrating the difference between the two types of deconfliction. It can be achieved either spatial (Fig. (a), paths are separated "geometrically") or temporal (Fig. (b), paths are allowed to intersect or violate the clearance distance condition if the vehicles are not within the conflicting region at the same instance of time).



a) Spatial b) Temporal

Spatial deconfliction can be formulated as solving, as part of the overall cost function, the optimization problem

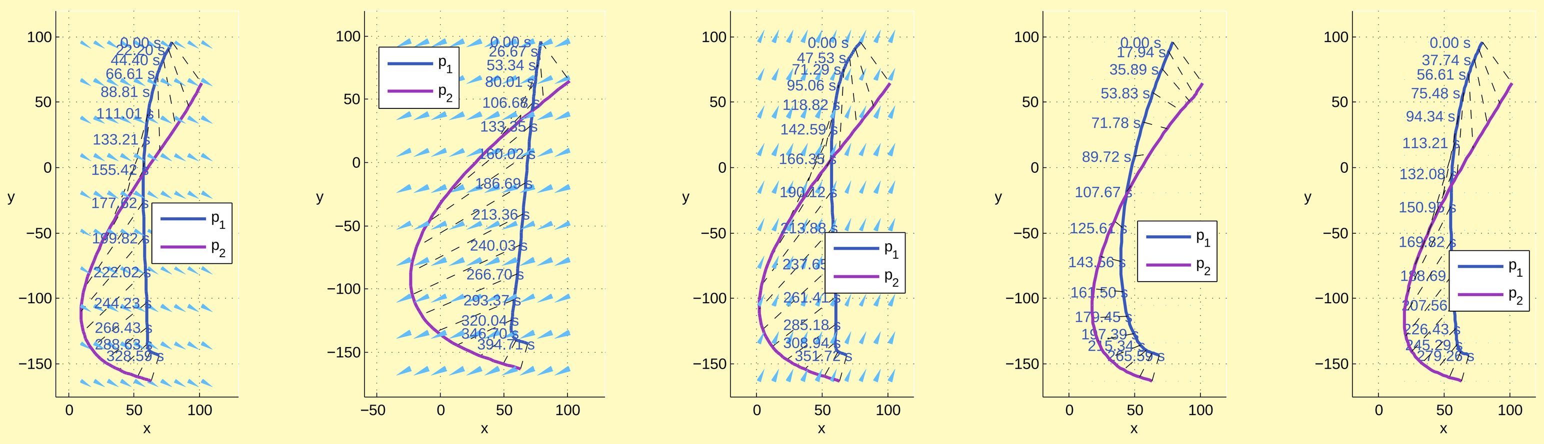
$$\min_{j,k=1,\ldots,n, j\neq k} ||\bar{p}_{c_j}(\tau_j) - \bar{p}_{c_k}(\tau_k)||^2 \geq E^2$$

for any $\tau_j, \tau_k \in [0, \tau_{f_j}] \times [0, \tau_{f_k}]$, where E is the spatial clearance. For temporal deconfliction, this changes to $||p_i(t) - p_j(t)||^2 \geq E^2$ for all $i, j = 1, \ldots, n; i \neq j$ and $t \in [0, t_f]$.

Results

Spatial and temporal deconfliction. Spatial deconfliction is a problem that is especially hard to solve for surface vehicles, i.e. in two dimensions. However, it reduces the risk of collisions, and might be preferred for groups of submersibles that are not under constant human supervision. Simulation results are shown above in the box "Deconfliction".

Influence of currents. Naturally, the vehicle's path following controller has to compensate for currents. However, although the vehicle might be able to track a given path correctly, this path might not be the most energy efficient one for facing a given current. The effect of ocean currents onto the planned paths is shown in figures (a)-(c) for varying current speeds and directions.



(a) (b) (c) (d) (e)

Communication constraints. Figures (d) and (e) show first results where the communication constraint has been implemented in a way that defines a loss of communication between both vehicles as exceeding the maximum permissible distance C, which here was 40m and 80m, respectively.

Open Questions

Although the path planning system shows increasing versatility, there remains a number of problems that still have to be tackled. Better results can be expected to be achieved using a second-order solver like Newton's method. Current work with *Prof. John Hauser* (Univ. Boulder, Colorado) aims towards solving this problem as well as extending it towards obstacle avoidance. Furthermore, a currently used rough approximation to the vehicles' energy usage has to be refined to reflect reality. The communication constraint an be improved in various ways; for example, a penalty could be put on the number of communication losses, so that short interruptions would be allowed.

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