Temporally Deconflicted Path Planning for Multiple Marine Vehicles

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Objectives

The overall objective of this thesis is aiming at proposing a multiple vehicles path planning algorithm which avoids inter-vehicle collision and performs simultaneous arrival, for underactuated USVs and ASVs. To achieve this goal, a set of sub-objectives has been set as following to guarantee the main success:

- Perform background literature survey on multiple path planning algorithms, BÃĺzier curves formulations and optimization algorithms.
- Research on the general framework of temporally and spatial deconfliction for multiple vehicle scenario, and its formulation and methods.
- Develop an arbitrary number of path planning algorithm, and mark the intersection points which would geometrically presented in the route map.
- Assign the speed for the whole path, and formulate temporal deconfliction constraints and cost functions within the framework of optimization problems.
- Include the vehicle dynamics like acceleration and velocity, to constrain the velocity and ensure the continuity of the motion.
- Simulate in Matlab and improve the functions basing on the result. Discuss the final result and analyze.

Introduction

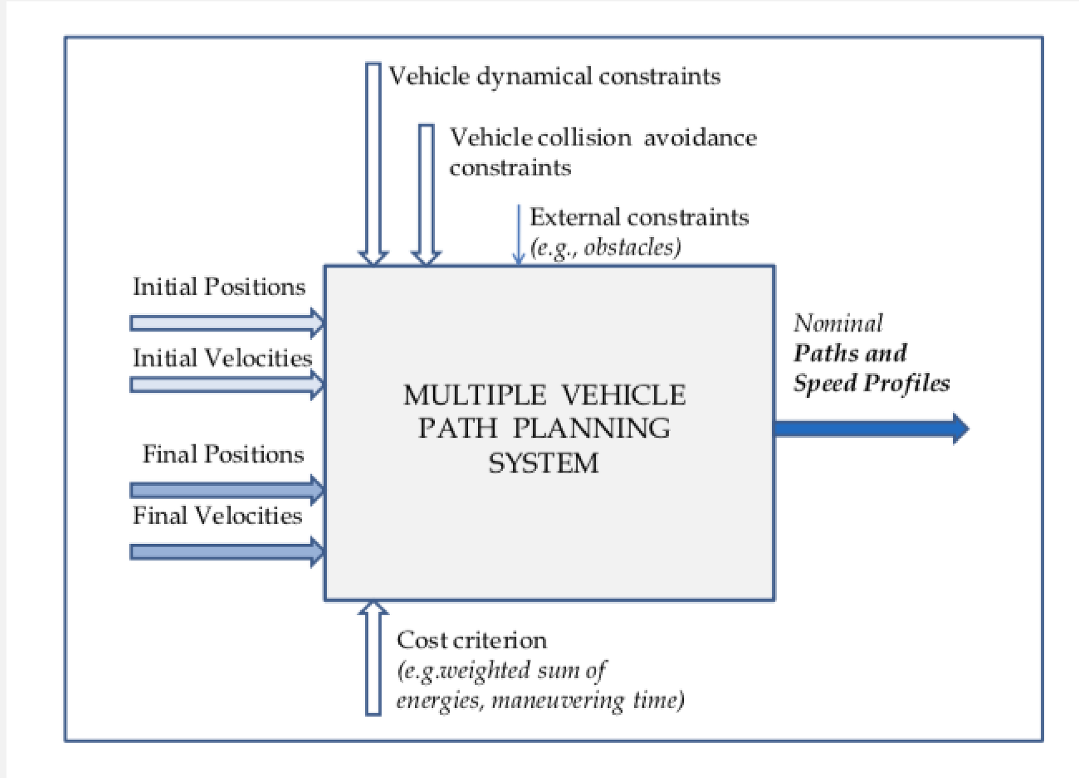
Over the past few years, growing interests and demands have been witnessed in the development of ASV operation, especially in controlling fleet of vehicles to perform complex missions. Basing on the single path planning algorithm which generates path between two points, guiding multiple vehicles to their own ends while avoiding all possible inter-vehicle collisions brings more challenges and thus requires more versatility. In the path planning algorithm, most of the time plenty of feasible solutions that satisfy all the constraints could be proposed in the end. In order to make the final choice a criteria should be set for the optimization purpose. Usually the whole operating duration of the craft is expected to be as much short as possible, to save energy or increase the efficiency,which however may lead the robots to operating under high speed and steep path following. This would expose the craft to the risk of damaging, such as vibration of machine structures, wear and tear of actuators, and inaccuracy and unstable of the system as well.Such a trade-off process leads to the need of proper path planning and trajectory generation algorithm, paving a smooth path avoiding excessive accelerations and sharp curvature,while minimize the duration cost. For such reasons, path planning algorithm has been pro-posed, generating a geometric path from the initial point to the destination, and by passing all the obstacles along the way. The crucial tasks further asks for the cooperation between multiple robots operating in the same scenario and avoid collisions between each other.To deal with this kind of problem from the aspect of temporal deconfliction, time profile for the whole process is required additionally, compared to path planning algorithms. And because of this time coordinate augment, the path could then be related to motion dynamics like velocity, therefore could be analyzed numerically. Besides, it could be resolved in another different way, that all the vehicles need to keep a fixed minimum safe distance between each other, and their routes would never cross or get close in the two dimensional space, despite of the operating time. This method is called spatially deconflicted path planning algorithm.

Contribution

This thesis is mainly contributing a method in multiple marine vehicle path planning with temporal deconfliction. Firstly, related background theories is introduced, including the topic of Bezier curve, vehicle mathematical modeling, temporal and spatial deconfliction. Basing on the path planning algorithm for one path, arbitrary number of paths are generated and speed assignment is proposed to obtain time profile along the path. The crossing points which consequently presented would be taken special care of. Specifically, constraints are formulated within the vicinity of every intersection point in the frame of optimization problem, to get staggered time of passing crossing point and avoid inter-vehicle collisions. Further, final target arriving time for each vessel is constrained, as well as vehicle dynamics like velocity and acceleration allowed in a certain range, in order to obtain smooth speeding process. The total operating time is minimized as well, at the final stage.
Thus the proposed multi-path planning algorithm could lead arbitrary number of vehicles to arrive at assigned destinations respectively, with inter-vehicle collisions avoidance. It would provide solutions in time to form smooth and continuous velocity profiles, with reasonable velocity and acceleration constraints taken into account. Finally, despite the different length of every path, each vehicle would arrive at target simultaneously with same shortest operation time. The behavior is discussed at last by presenting sets of numerical simulation results, and to present the efficiency of the algorithm.

Methods

1. Multiple Path planner : Developing a multiple path planning algorithm as extention to the single path planning using Bezier curve.



2. Temporal deconfliction : Assigning speed for the whole path and applying time as optimization variables, to obtain the speed profile which is time deconflicted and satisfing all constraints.

Important Result

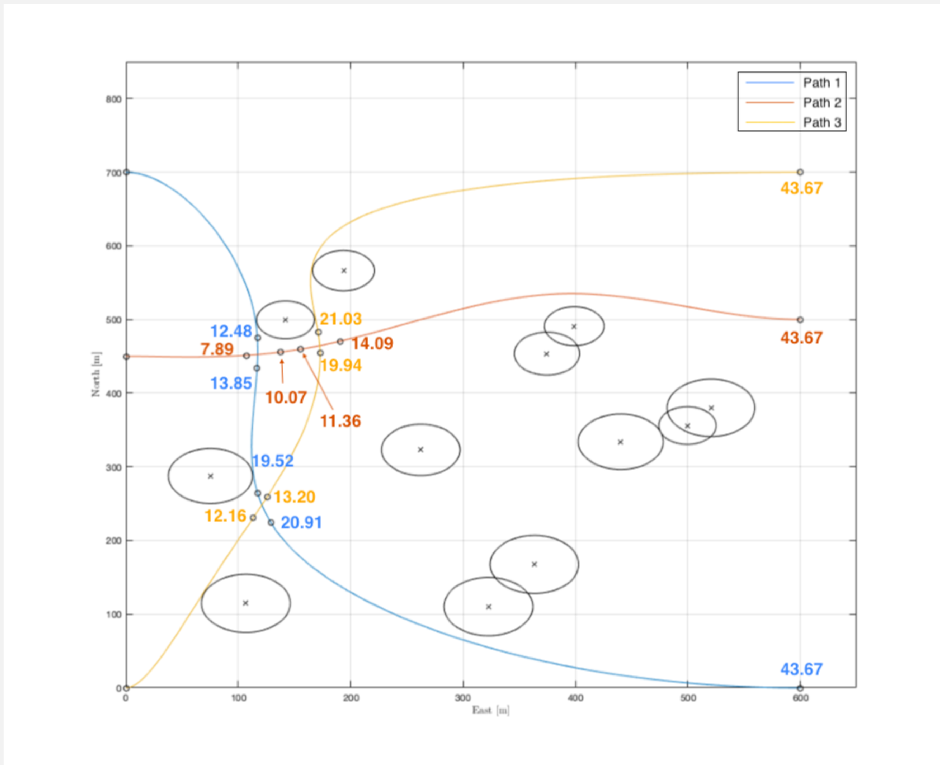


Figure: Multiple path

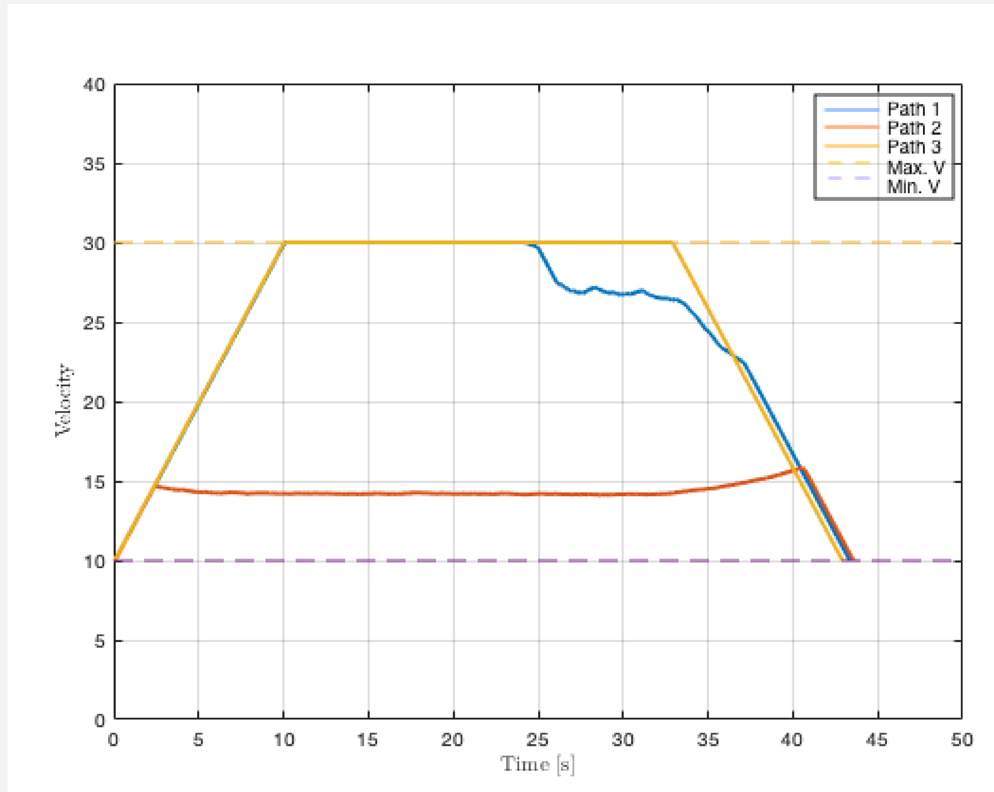


Figure: Velocity profile for each path

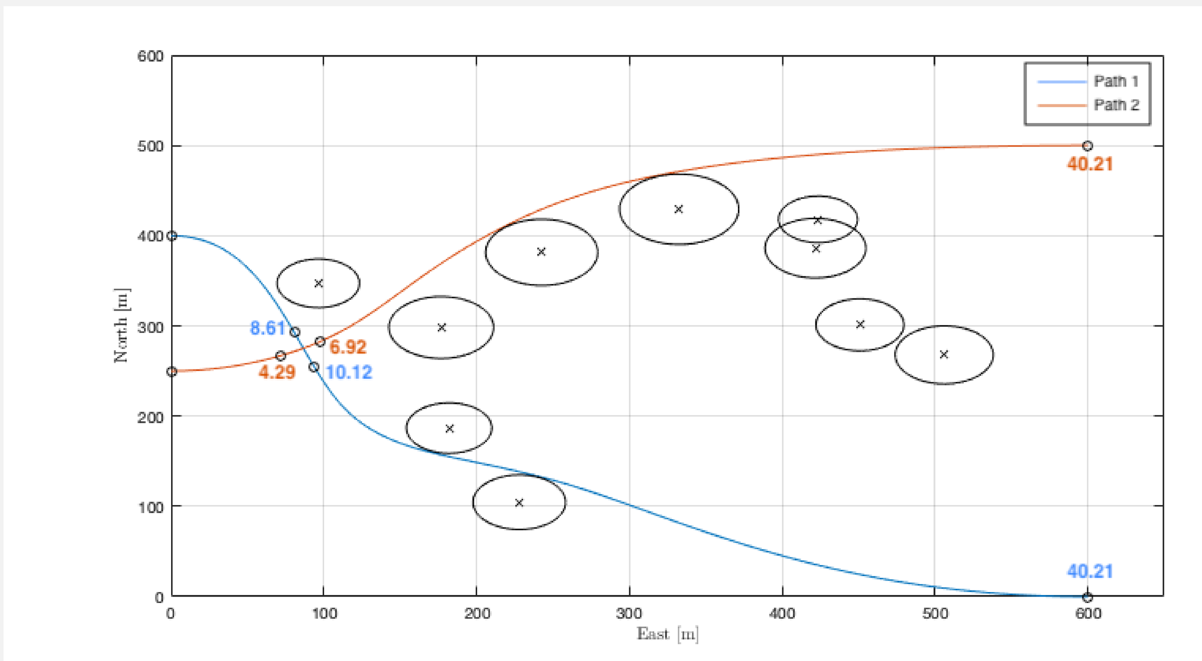


Figure: Multiple path

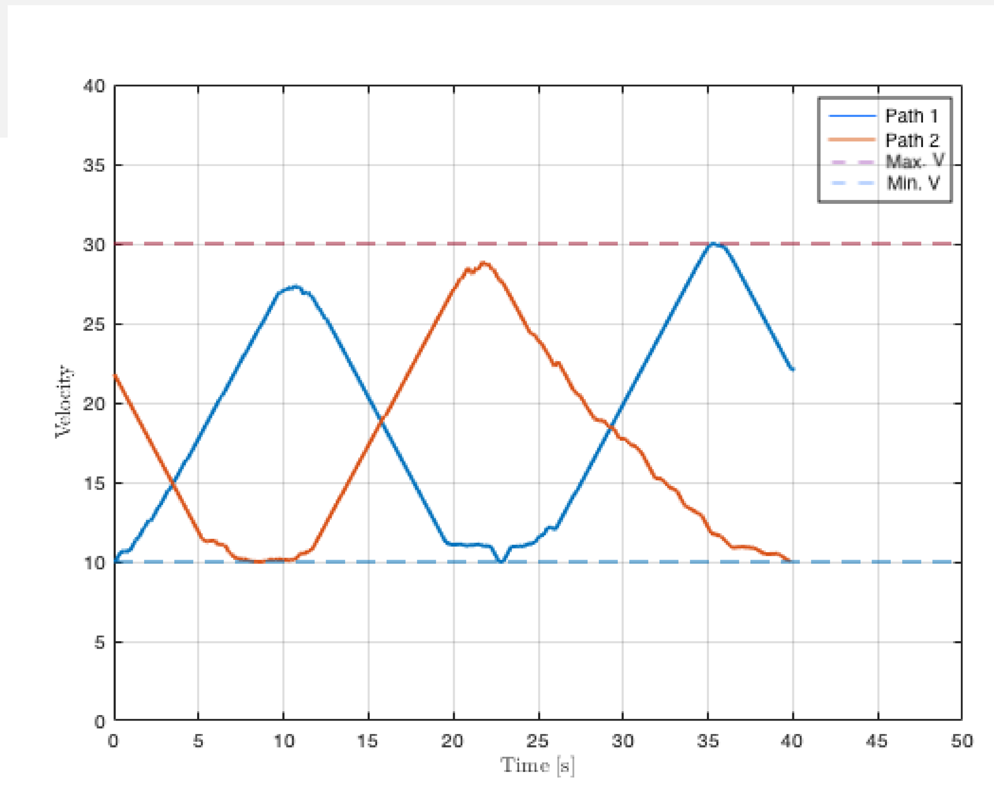


Figure: Velocity profile for each path

Conclusion

In this thesis, a temporal deconflicted path planning algorithm for multiple vehicles has been developed, using BÃĺzier curve as the basic path generation tool. It mainly deals with the problem of inter-vehicle collision avoidance when multiple vehicles are operating in the same space cooperatively and closely. Basing on the single path generation algorithm, spatial multiple path planning and deconfliction work have been decoupled and formulated separately. Basing on the concept of temporal deconfliction and augmenting the time coordinate, the mathematical formulation of the deconfliction property is proposed as well as the vehicle dynamic restrictions and simultaneous arrival requirement. Further constructing the constraints and objectives within the optimization framework and utilizing proper optimization algorithm, the problem is solved and a temporal deconflicted solution with arrival synchronized and operation time minimized is obtained.
This algorithm is able to plan path for arbitrary number of vehicles, and the physical dynamic restrictions are taken into consideration during the whole process. The vehicle motion near the crossing points on the path are specially taken care of and staggered, ensuring that two vehicles would never appear at the intersection point and its close vicinity at the same time. Moreover the operation time is minimized and final arriving time is constrained as the same and quantitatively presented in the numerical simulation.
The result has shown that the temporal deconfliction work can be implemented basing on the BÃĺzier curves and it is efficient for arbitrary number of vehicles, while taking the vehicle dynamic constraints into consideration. The proposed algorithm is able to solve a multiple path planning problem, and restrict the length of the operation duration by constraining it as simultaneous. This can also be changed such as specifying each vehicle's operating time length respectively, and thus provides more versatility for real practice. Although there are some problems existing in the obtainment of the satisfactory result, for which the reason and improving methods have been discussed before, it can be concluded that this temporal deconfliction method for multiple path planning is efficient and useful. The result of the numerical simulations presented could demonstrate this, and also indicate the efficiency and potential of this method to be improved in the further work.

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