A Fast Continuous-time Motion Planner for USVs in Oceanic Environments

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1. Introduction and background

The planning of trajectories in complex maritime environments plays a critical role in developing autonomous maritime platforms such as unmanned surface vehicles (USVs). Even with growing recognition of the importance of motion planning algorithms for USVs, **three major challenges** have largely hindered their progress of development including:

- The majority of mainstream motion planning algorithms do not encompass proper consideration of the environmental impacts such as winds and surface currents;
- Among the minority of algorithms that do take these environmental characteristics into account, important metrics including the computation time and path quality are not up to that minimum standard of quality required for practical applications;
- Another research bottleneck for USV development is the lack of high-fidelity environments. By developing high-fidelity simulation environments, validating the newly proposed motion planning, control and any other algorithms can be conducted in an efficient and low-cost manner.

Aim of this work

- Designing **a motion planner** that can generate a short and smooth path with a extremely high computational speed. Furthermore, the capability of dealing with ocean currents is required to be integrated into this motion planner.
- Developing **a high-fidelity simulation environment** to test the designed motion planner for USVs in an efficient and low-cost manner

2. Methods

Anisotropic Gaussian Processes Motion Planner 2 (Anisotropic GPMP2) algorithm can be formulated as a trajectory optimisation problem, and further, it applies Gaussian Processes to optimise trajectories in an efficient manner. By considering a trajectory as a function of continuous time t, such an optimisation process can be written as the standard form of an optimisation problem with continuous variables as:

$$\begin{aligned} &\text{minimise } F[\theta(t)] \\ &\text{subject to } G_i[\theta(t)] \le 0, \quad i = 1, \dots, m_{ieq} \\ &\qquad\qquad H_i[\theta(t)] = 0, \quad i = 1, \dots, m_{eq}. \end{aligned}$$

where $\theta(t)$ is a continuous-time trajectory function mapping a specific moment t to a specific robot state θ. $F[\theta(t)]$ is an objective function to find the optimal trajectory by minimising the higher-order derivatives of robot states, such as velocity and acceleration, and collision costs. $G_i[\theta(t)]$ is a task-dependent inequality constraint function and $H_i[\theta(t)]$ is a task-dependent equality constraint function that contains the desired start and goal states with specified configurations.

For the given optimisation problem, the objective function is given as:

$$F[\theta(t)] = F_{gp}[\theta(t)] + \lambda_1 F_{obs}[\theta(t)] + \lambda_2 F_{env}[\theta(t)],$$

where $F_{gp}[\theta(t)]$ is the GP prior cost, $F_{obs}[\theta(t)]$ is the obstacle collision cost and $F_{env}[\theta(t)]$ is the environment characteristic cost. λ_1 and λ_2 are the weight coefficients given to these costs. At this juncture we specifically highlight the inclusion of the environment cost $F_{env}[\theta(t)]$ as it is of particular importance when considering marine vehicles. For other types of vehicles, costs can be adjusted as required.

A high-fidelity simulation environment based upon the Robotic Operating System (ROS) has been developed and the overall structure of it is shown in the following figure:

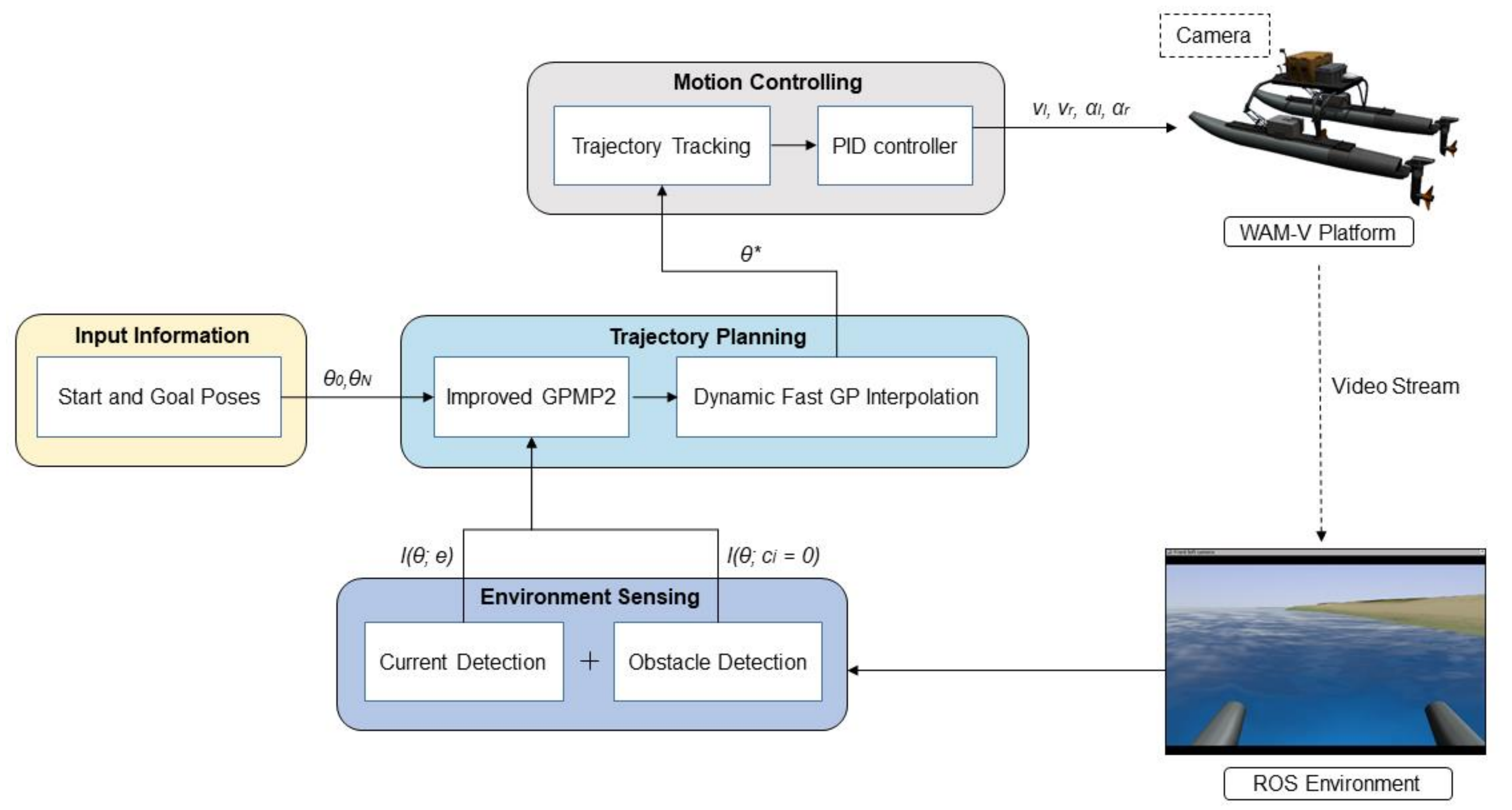


Figure 1. Overall structure of the proposed motion planning system [1].

3. Results

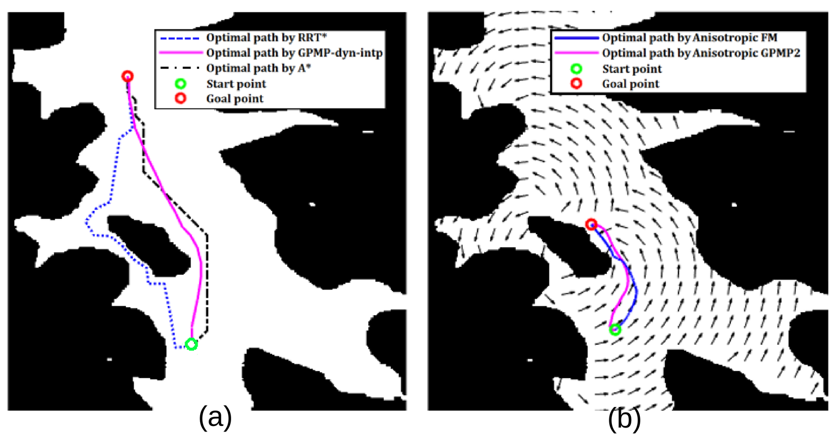
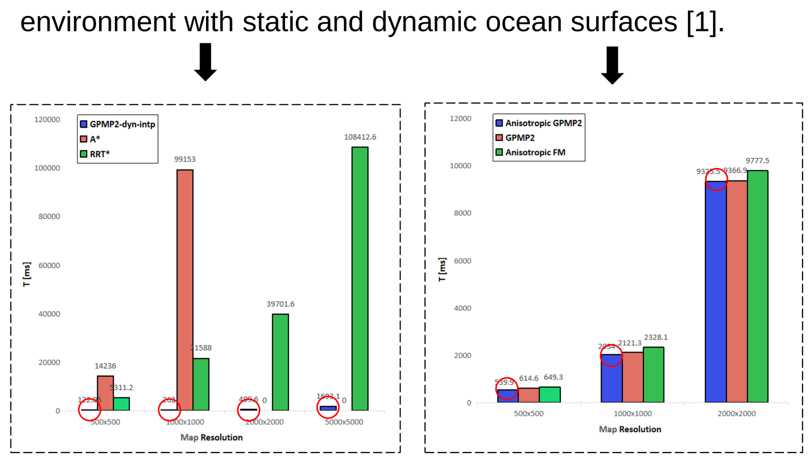


Figure 2. Comparisons about the paths generated by our method with other mainstream methods in maritime environment with static and dynamic ocean surfaces [1].



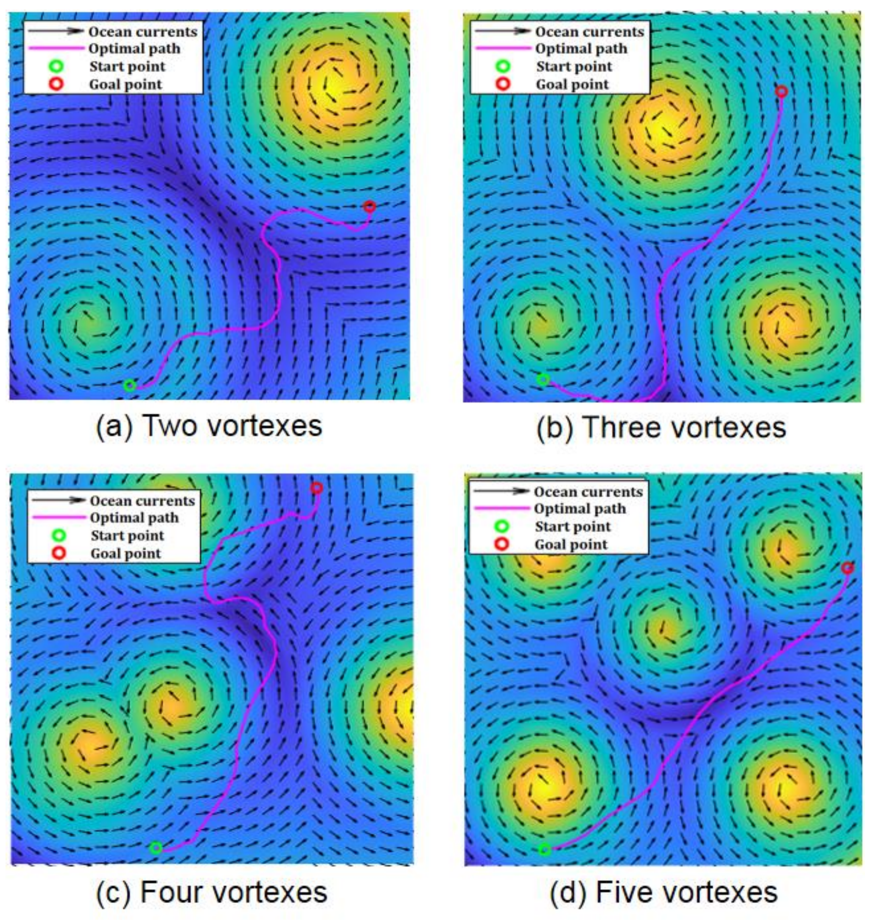


Figure 3. Anisotropic GPMP2 works in marine environments with a variety of vortexes [1].

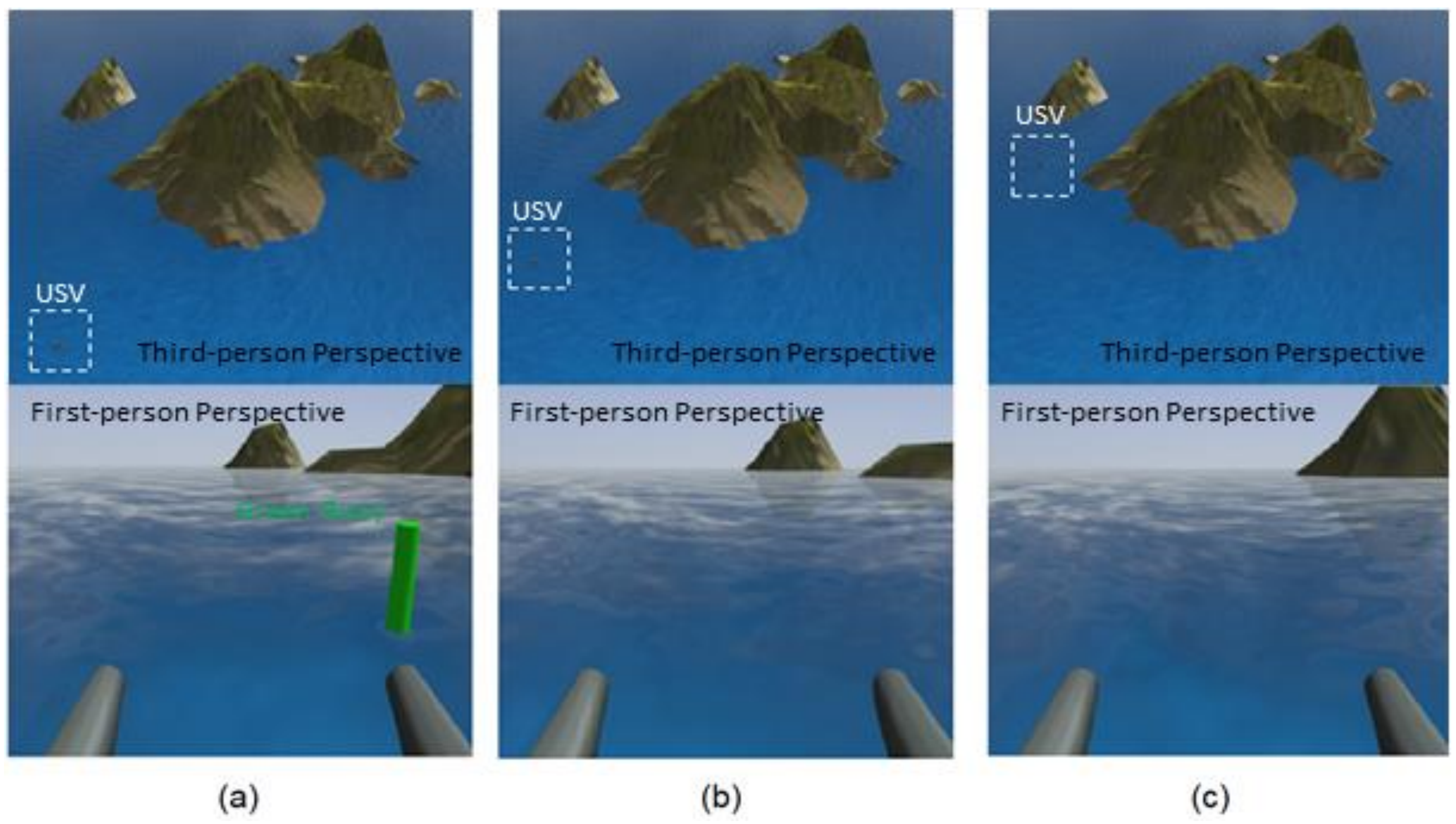


Figure 4. The storyboards of the transportation mission based on the first-person perspective (at the lower part of each figure) and third-person (at the upper part of each figure) synchronously [1].

4. Future Work

- Further optimising and enriching the ROS environment to enable USVs to perform different tasks in the environment.

References

1. Meng J, Liu Y, Bucknall R, Guo W, Ji Z. Anisotropic GPMP2: a fast continuous-time Gaussian processes based motion planner for unmanned surface vehicles in environments with ocean currents. IEEE Transactions on Automation Science and Engineering. 2022 Jan 7.

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