Supplementary file: Benchmark tests under environments with cluttered islands and narrow water ways

In this file, simulations have been carried out to evaluate the performance of our proposed method under some challenging path planning cases. We have selected some other state of the art methods from existing reliable references for comparison, i.e., Improved artificial fish swarm algorithm (Zhao et al., 2022), D* lite (Yao et al., 2021), Hybrid A* (Hemmat et al., 2017), and Batch informed Trees* (Xu et al., 2020). The selected environment maps are presented in Fig 1, the start and goal points are marked as blue and red dots respectively. Table 1 shows the dimensions and coordinates of the given points. To focus on the effectiveness, the current movement is assume to be zero. The simulations are conducted via MATLAB environment with a PC configured with Intel (R) Core (TM) i7-8700 CPU and 8-GB RAM. Furthermore, to obtain reliable results, it should be noted that 20 runs are conducted for each case.

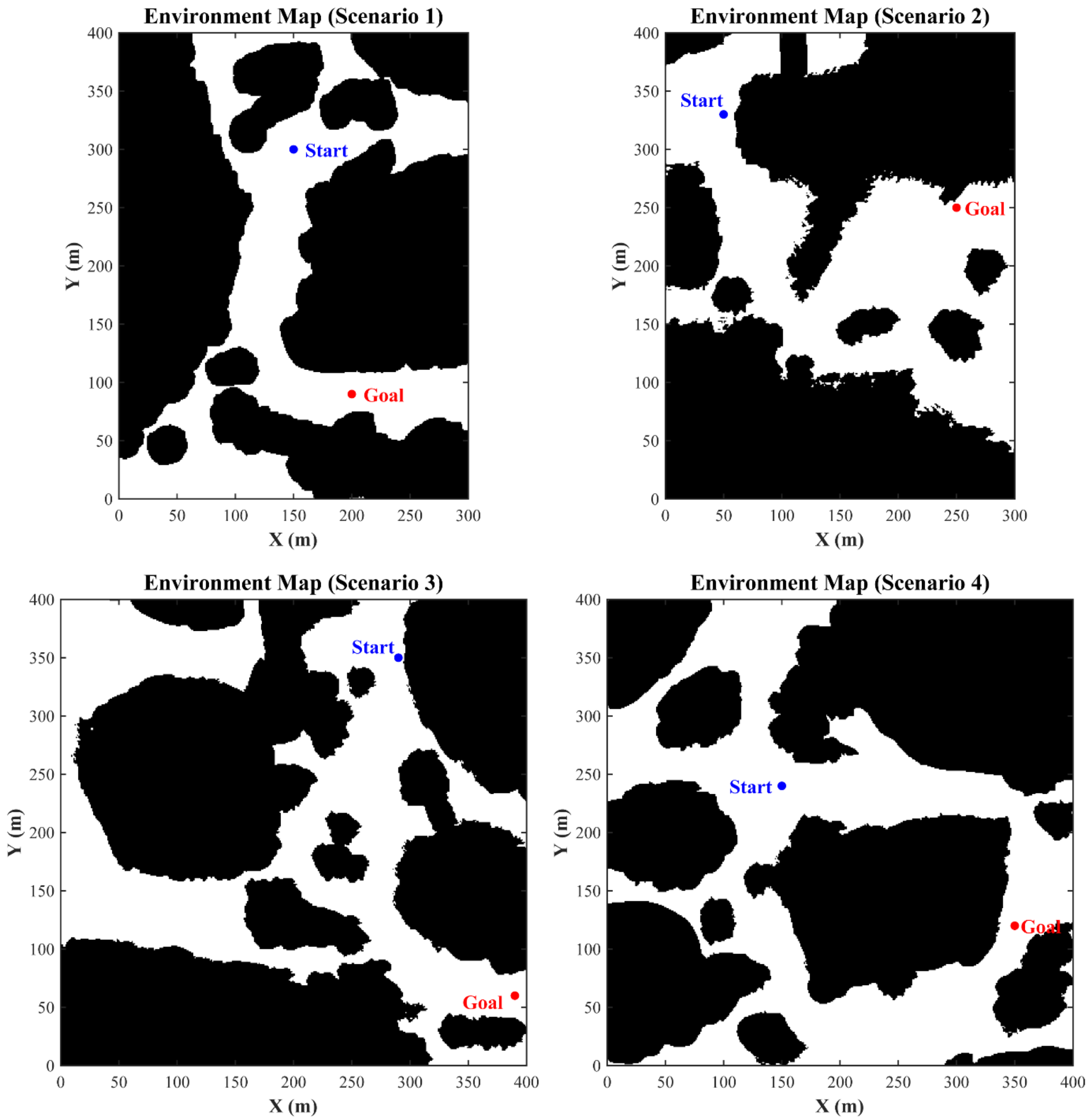

Fig. 1. Environment settings

The parameters are set as follow:

- AENSGA-II: $N = 100$, $T_{max} = 200$, $p_c = 0.9$, $p_m = 1/\text{n}$, $\eta_c = 10$, $\eta_m = 20$, $R_{min} = 6$ m, $d_{min} = 5$ m, $d_{max} = 25$ m.

- IAFSA: $N = 50$, $\delta = 0.618$, $step = 1$; $visual = 5$, $try\_number = 8$.
- D* lite: No hyperparameters
- Improved Hybrid A*: Minimum turning radius = 4 m; Motion primitive length = 4 m.
- BIT *: Max-Connection distance = 4 pixels.

Since the parameter tuning is not the core topic of this article, we chose these values suggested by the corresponding literature.

Table 1. Environment setting

	Map size	Start	Destination
Scenario 1	300*400	(150, 300)	(200, 90)
Scenario 2	300*400	(50, 330)	(250, 250)
Scenario 3	400*400	(290, 350)	(390, 60)
Scenario 4	400*400	(150, 240)	(350, 120)

Quantitative results have been presented in Table 2. As can be seen from the data, AENSGA-II yields the time cost with 10.254 s, 11.023 s, 12.144 s, and 11.689 s for the four scenarios respectively. It has shown advantages on computational efficiency over IASFA and D* lite. Batch informed RRT* calculates the results with the highest speed because it reduces the computational burden by using a sampling connection rule. It is also observed that grid-based approaches like D* lite and Hybrid A* are very sensitive to map size. For the path quality, AENSGA-II outperforms the other methods with more reasonable solutions. As denoted by Table 2, it presents the lowest smoothness values as well as the safest routes in all the cases, although at some expense of path length. It is mainly attributed by the fuzzy selector which could find the balance between different objectives. However, the other methods have failed to present high-quality paths in our tests because these paths are either too close to the obstacles or contain many zigzag turnings. This is because they mainly focus on reducing the path length with less regard on the safety level and path quality. Same conclusions can be drawn by observing the visualized results on Fig. 2. As can be seen from the figure, the curve is smooth with no existence of abrupt turnings and keep a sufficient distance to the nearby obstacles.

Table 2. Statistical measurements (objective values)

Methods	Performance	Scenario 1	Scenario 2	Scenario 3	Scenario 4
AENSGA-II	Time (s)	10.254	11.023	12.144	11.689
	Path length (m)	271.125	365.172	371.998	312.896
	Smoothness (deg)	174.547	149.454	129.088	211.538
	Safety (m)	10.050	6.083	5.831	5.000
IAFSA	Time (s)	15.254	14.543	14.683	15.245
	Path length (m)	252.051	355.347	351.976	321.834
	Smoothness (deg)	590.291	343.702	528.768	227.737
	Safety (m)	1.000	1.414	1.414	2.236
D* lite	Time (s)	10.065	10.463	18.024	18.452
	Path length (m)	253.297	356.718	353.480	299.841
	Smoothness (deg)	945.000	720.000	720.000	450.000
	Safety (m)	1.000	1.000	1.000	1.000
Improved Hybrid A*	Time (s)	8.157	8.433	18.024	18.452
	Path length (m)	253.676	351.758	369.485	303.112
	Smoothness (deg)	1222.300	1404.700	1912.500	1263.100
	Safety (m)	1.000	1.000	1.000	1.000

BIT*	Time (s)	5.647	6.542	7.213	7.496
	Path length (m)	307.989	501.574	444.771	523.964
	Smoothness (deg)	303.395	555.388	426.283	762.342
	Safety (m)	1.414	1.000	1.414	2.236

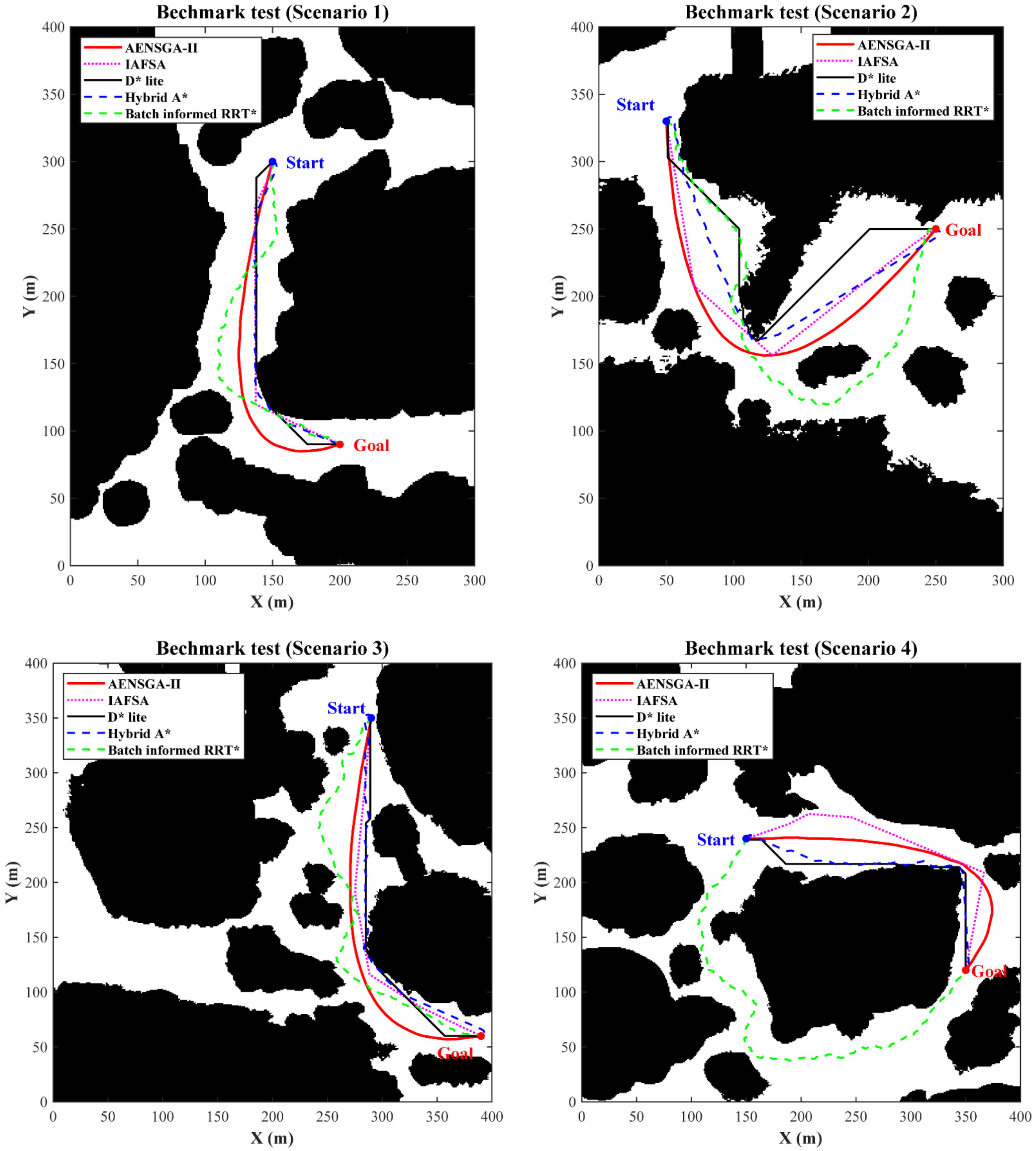

Fig. 2. Visualized results

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