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Robust global route planning for an autonomous underwater vehicle in a stochastic environment

Key words: Autonomous underwater vehicle; Route planning; Genetic algorithm; Orienteering problem; Stochastic path cost

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Motivation

1. Due to the complexity of the ocean, a comprehensive route-planning strategy is required to address the autonomous underwater vehicle (AUV) route-planning problem when the path cost is stochastic.

2. Despite the excellent performance of existing evolutionary algorithms, the individuals in existing methods are often of low efficiency due to the strict constraint of the total cost. The optimization is often seriously hindered because there is usually no clear boundary between the feasible and infeasible domains in the space of definition.

3. Up to now, the uncertainty of the AUV local path cost, which comes from the inconsistency between the plan and the actual operation, is often not considered.

Main idea

1. To address the individual feasibility problem in heuristic methods neglected by reported works, a novel greedy strategy based rebirth operator is proposed. It can effectively solve the problem that individuals in the infeasible domain contribute little under the total time constraint, thereby tremendously improving the efficiency of the optimization.

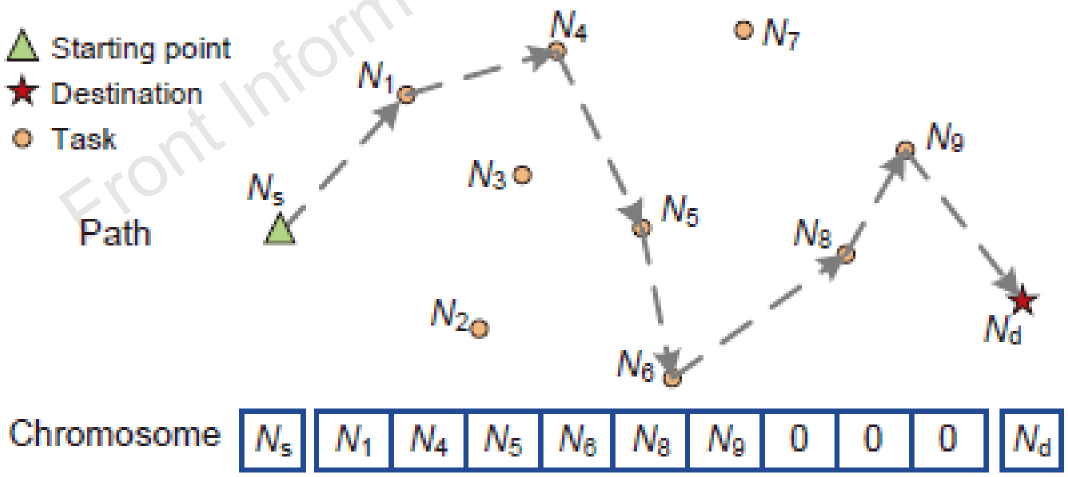
2. Taking the ocean complexity into consideration, we model the stochastic local path cost as the superposition of normal and Poisson distributions, which is based on the fact that the randomness of the path cost comes mainly from the path cost estimation error and the maneuvers caused by dynamic obstacles.

3. The route cost is obtained by sampling from the probability density functions (PDFs) of the local paths. The sampling-based route-cost estimator is integrated into the route planner to evaluate the fitness of each feasible route by sampling local paths in the optimization.

Method

1. Greedy strategy based genetic algorithm (GGA): solver for the orienteering problem

Based on the improved operators of the genetic algorithm (GA), a rebirth operator is proposed and thus a new route-planning method is generated, namely the greedy strategy based genetic algorithm (GGA).



Method (Cont'd)

The operators include selection, crossover, mutation, and rebirth.

The operator aims at minimizing the profit loss when some tasks have to be abandoned to satisfy the total cost restriction.

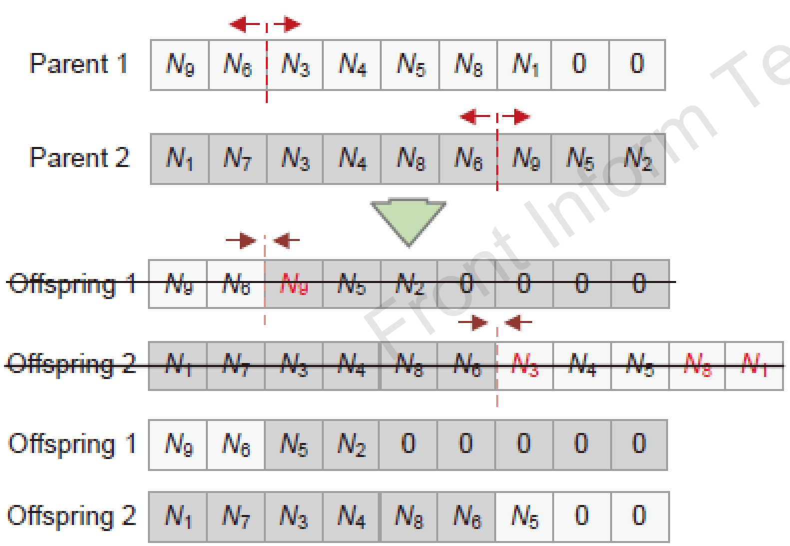


Fig. 4 An example of the crossover operation

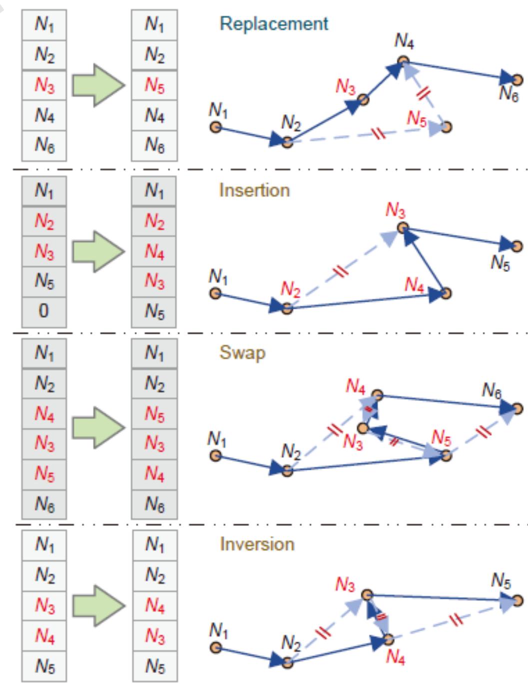


Fig. 5 Optional suboperators in the mutation operation (the dotted and solid lines represent the routes before and after being operated on, respectively)

Method (Cont’d)

2. Global route planning with stochastic local path cost

Based on the deterministic local path cost, the stochastic local path cost is considered as a random variable influenced by the moving uncertainty and undiscovered dynamic obstacles. The evaluation of each possible route is executed by sampling from the PDFs of the local path cost, and the sampling-based route-cost estimator is embedded in the route planner.

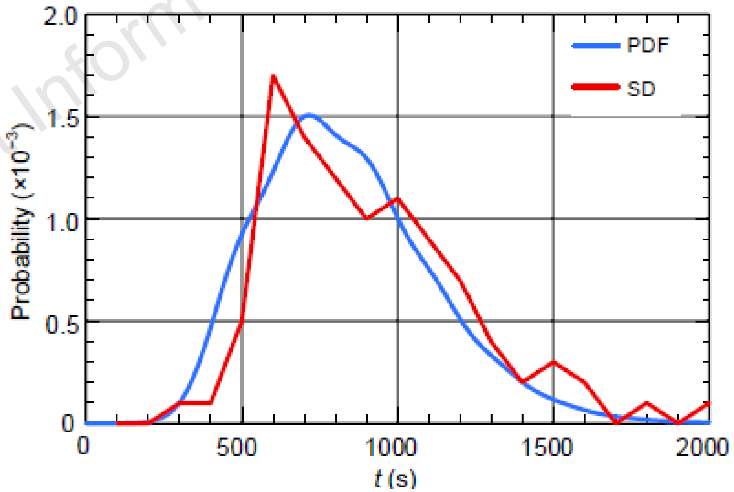


Fig. 7 Probability density function (PDF) and sample distribution (SD) of the local path $P_{i,j}$

Major results

Performance of GGA

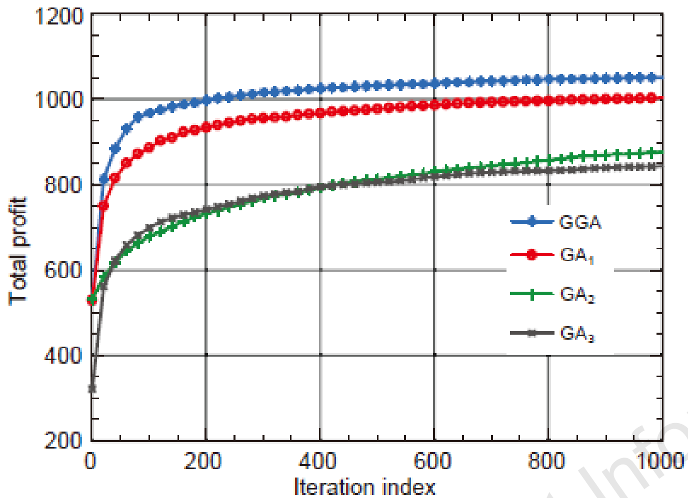


Fig. 9 Variation of the total profit in 1000 iterations (average of 60 Monte Carlo simulations)

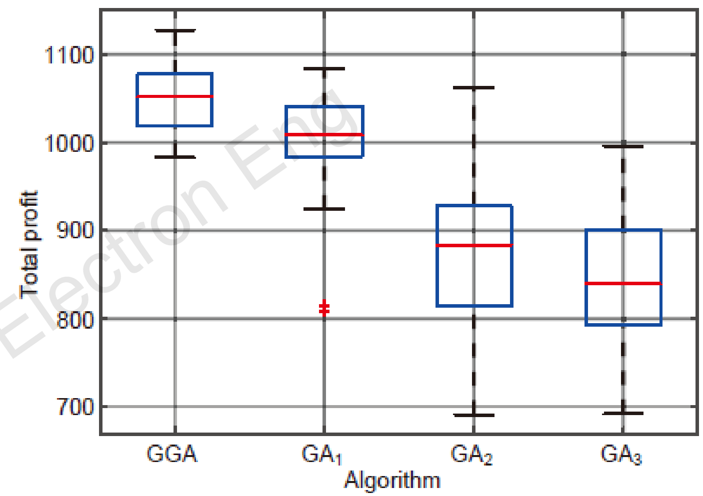


Fig. 10 Comparison of the stability of GGA, GA$_1$, GA$_2$, and GA$_3$ (the central mark, bottom and top edge marks on each box indicate the 50th, 25th, and 75th percentiles, respectively, and the whiskers extend to the most extreme data points that do not consider outliers, while outliers are noted individually by "+")

Table 2 Results of 60 Monte Carlo simulations

Algorithm	Available time (s)	Residual time (s)	Total profit	Minimum profit	Maximum profit	CPU time (s)
GGA	10 800	29.3	1051.2	984	1128	12.94
GA$_1$	10 800	41.8	1004.0	809	1074	19.54
GA$_2$	10 800	39.8	876.5	691	1062	9.84
GA$_3$	10 800	71.8	843.4	692	996	7.60

Major results (Cont'd)

Performance of the sampling-based GGA route planner (S-GGARP)

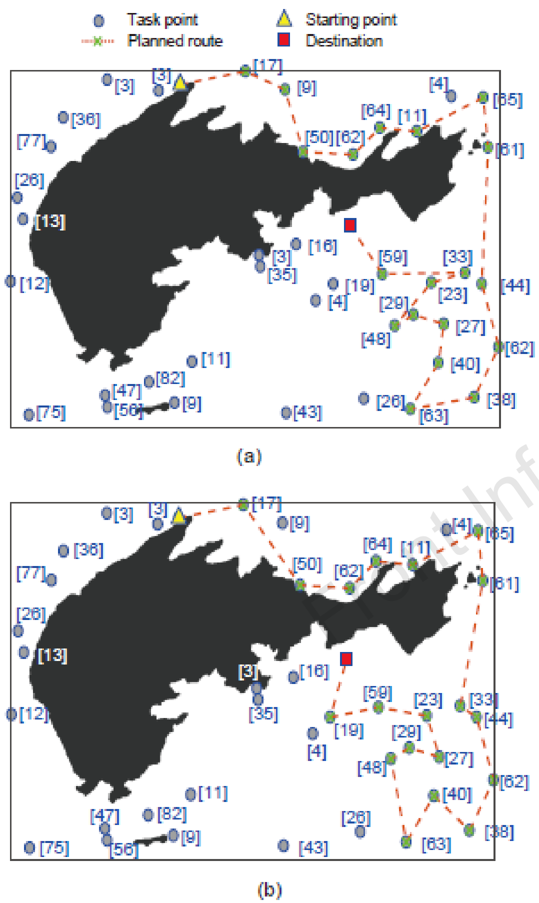


Fig. 11 Routes given by GGARP (a) and S-GGARP (b)

Table 3 Performance of GGARP and S-GGARP when the path cost is stochastic

Route planner	Average profit (expected)	Average profit (tested)	Standard deviation	CPU time (s)
GGARP	798	747.15	64.92	10.72
S-GGARP	790	788.45	16.17	40.40

Table 4 Expected and tested profits of route planners when the path cost is stochastic

Route planner	Total profit (expected)	Total profit (tested)
GA_1RP	749	700.20
GA_2RP	674	606.55
GA_3RP	663	599.80
GGARP	789	746.85
S-GGARP	791.5	790.15

Conclusions

- A GA-based AUV route planner is proposed using the novel rebirth operator and the sampling-based route evaluator.
- Traditional evolutionary operators are improved to enhance the algorithm's capability for the AUV route-planning problem, and the greedy strategy based rebirth operator is integrated into the evolution process.
- The evaluation of each possible route is executed by sampling from the PDFs of the local path cost, and the sampling-based route-cost estimator is embedded in the route planner.
- The proposed GGA outperforms its counterparts by 4.7%–24.6%, and the S-GGARP improves the average profit by 5.5%.

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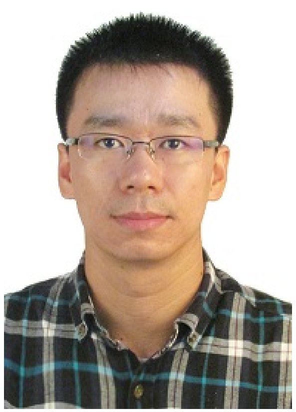

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