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Maritime Unmanned Vehicle Cruise Path Planning for Maritime Information Collection ⋆

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AbstractMaritime Unmanned Vehicle (MUV) as Unmanned Surface Vehicle is introduced as a novel traffic device for continuous maritime traffic information collection and complementing existing methods for Electronic Patrol System (EPS). MUV cruise path planning is studied regarding maximum sailing time, which is aiming at completing MUVs cruise task on a certain number of the areas with relatively high risk needed surveillance. With detailed description of MUV cruise path planning problem, it is abstracted as travel salesman problem solved by ant colony algorithm in this paper. The approach used to select cruise objects is proposed, especially the cloud model applied to choose cruise navigation segments. The factors including total cruise distance and standard deviation of cruise time, and K-means clustering method are used to evaluate and handle the scenario with MUV navigation constraint. On the basis of above operations, the special scenario is finally converted into several ones without constraint. At last, the cases of Fuzhou Maritime Safety Administration areas are demonstrated. The results indicate that the method proposed for MUV cruise path planning is feasible and effective.

Keywords: Maritime Unmanned Vehicle, maritime traffic information collection, Electronic Patrol System (EPS), cruise path planning, cloud model.

1. INTRODUCTION

Maritime traffic information is not only the foundation of the marine traffic management and control for Maritime Safety Administration (MSA), but also the key part for achieving intelligent supervision. Intelligent supervision has been rapidly developed recently, which in turn facilitates the promotion of the concept and application of Electronic Patrol System (EPS). The application of EPS for the dynamic supervision of ships can reduce maritime accidents, and can improve the efficiency of maritime organization services. However, the deficiency that EPS can not entirely obtain the maritime traffic information only with detectors located in fixed places, becomes more and more apparent during applying EPS to marine traffic management. Due to the flexible manipulation, mobility, wide area view and low cost of intelligent vehicles, they are widely used in military activities and civilian life, such as surveillance, reconnaissance, road traffic information collection, etc. (Bishop (2000)). As one kind of intelligent vehicles, Maritime Unmanned Vehicle (MUV) can conduct maritime traffic information collection task to overcome the drawback of EPS. By equipping with different customized sensors, for instance, optical camera, infrared imaging device and synthetic aperture radar, MUVs are able to obtain clear images of monitored targets for the whole day, even in the extreme conditions of i.e., rainy, cloudy and foggy days. After receiving the information from MUVs in real time, MSA can make real-time judgment and regulatory on maritime traffic management through combining information from EPS and MUVs.

To achieve the application of MUV to EPS, several technologies including extraction, fusing and analysis of maritime information, and MUV cruise path planning are urgently needed. Moreover, the MUV cruise path planning is the main and first task required to be carried out. In this paper, the aim of MUV cruise path planning is that MUVs can safely complete their cruise task on a certain number of cruise objects which refer to the areas with relatively high risk needed surveillance. The study of MUV cruise path planning is a branch of the research about cruise ob-

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jects allocation and MUV surveillance deployment which contains kinds of issues listed as follows.

(1) Cruise objects deployment, namely cruise path planning, ensures that every target can be detected by MUV at least one time with the optimization object of the shortest total cruise distance.
(2) Global path planning (Zhu et al. (2014b)) between two neighboring cruise objects while the optimization goals such as the least total cost, the shortest path and the lowest energy consumption are taken into consideration.
(3) Local path planning for MUV sailing in the navigation environment with dynamic obstacles.
(4) Collision avoidance between MUV and conventional vessels while Convention on the International Regulations for Preventing Collisions at Sea (COLREGS) is accounted.

In the past decades, some efforts had been laid on solving the UAV route planning problem in road traffic field, but the studies about MUV cruise path planning of marine area is rare. Ryan et al. (1998) abstracted the UAV route planning problem as a multiple travel salesman problem and applied a Reactive Tabu Search method to solve it and succeed in maximizing expected target coverage. Hutchison (2002) divided the monitored area into several different subareas and assumed every subarea having one Unmanned Aerial Vehicle(UAV) so that the route planning of one UAV for one subarea could be formulated as travel salesman problem which was solved by simulated annealing algorithm to find the shortest UAV cruise route. Tian et al. (2006) studied on applying multiple UAVs to detect monitor with time window, formulated it as a optimization problem with minimizing UAV cruise cost, finally used the genetic algorithm to search lower UAV cost route. Liu et al. (2012) considered using limited number of UAVs to monitor road segments for traffic information collection, proposed multi-objective model, and chose non-dominated sorting genetic algorithm for planning UAV routes. Additionally, for special area such as sparse road network, Liu et al. (2013) presented a UAV allocation method with/without UAV continuous flight distance constraint, used K-means clustering algorithm to divide the whole cruise zone into several sub-zones and employed simulated annealing algorithm to search the shortest route for each UAV in every sub-zone. Niu et al. (2015) introduced UAVs as a special type of mobile sensors for daily traffic information collected for highway sensor network, calculated the link importance degree index according to existing traffic data to select very important links with frequent traffic events, and solved the UAV's route planning problem.

In this paper, the MUV cruise path planning is studied. Additionally, related method for solving this problem is proposed while the above researches about UAV route planning problem are completely considered. The maximum sailing time of MUV will be taken into consideration when describing and modeling the MUV cruise path planning problem. Cloud model will be used to select cruise segments.

In the rest of this paper, the description of MUV cruise path planning and modeling are illustrated in section 2. In section 3, the intelligent algorithm for optimizing MUV cruise path planning is confirmed. The methods for cruise objects selection and division under MUV maximum sailing constraint are defined in section 4. The section 5 shows the scenarios with and without MUV maximum sailing time constraint as cases study. The conclusion is summarized in section 6.

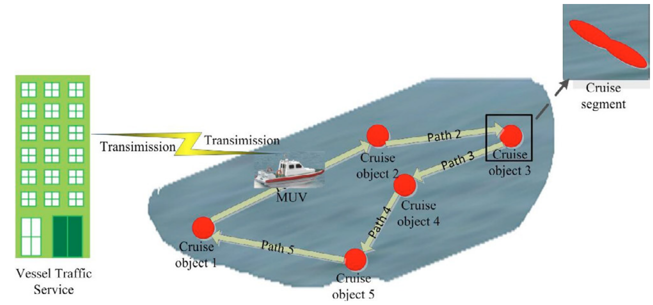

Figure 1. Schematic diagram of MUV cruise for maritime information collection

2. PROBLEM DESCRIPTION

The schematic diagram about MUV for maritime information collection for EPS is shown in Fig.1. If MUV cruise paths had been planned, the cruise path of every MUV could be shown in the geographic map of MUV control platform, here namely the Vessel Traffic Service (VTS). Then each MUV navigates to its cruise objects automatically for collecting maritime traffic information using sensors such as high-definition camera, meanwhile, the collected information were transmitted back to VTS in real time so that the VTS can make further orders to ensure the safety of maritime traffic according to combined information between the extracted information from MUV by both manual observation and image recognition method, and information of EPS. The MUV cruise path planning problem is much similar to the travel salesman problem (TSP) which has been widely studied. Given that a certain number of cruise objects were confirmed, using the minimum number of MUVs to monitor all objects with the cruise cost as low as possible was expected. Hence, it is pretty essential to plan MUV cruise path effectively.

MUV cruise path planning can be defined as follows. MUV starts from specified position to the neighboring position. For each target, MUV can only arrive at or depart from only once with the objective of minimizing the total cruise distance. In order to well build the model of MUV cruise path planning, the cruise segment is modified as a cruise point. Then, assume that there are N cruise objects. The model of MUV cruise path planning is processing as follows.

$$\min \mathrm{Z} = \sum_{\mathrm{i}=1}^{\mathrm{N}} \sum_{\mathrm{j}=1,\mathrm{i}\neq\mathrm{j}}^{\mathrm{N}} \mathrm{C_{ij}X_{ij}} \quad (1)$$

$$s.t.: \sum_{i=1,i\neq j}^{N} X_{ij} = 1 \qquad (i = 1, 2, \cdots, N) \quad (2)$$

$$\sum_{j=1,i\neq j}^{N} X_{ij} = 1 \qquad (j = 1, 2, \cdots, N) \quad (3)$$