TRAJECTORY PLANNING FOR SEARCH-AND-RESCUE UAVs USING A GREEDY ALGORITHM

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Abstract

This article presents a trajectory-planning program for research-and-rescue UAVs based on the use of a local optimization greedy algorithm. Trajectories are generated over a search domain characterized by a probabilistic score map. For multiple-UAV systems, the program can assign each device to a search mission based on the probabilistic property or the geometry of the search domain. Some parameters such as the maximum travelled distance and trajectory resolution could be input into the program. In this study, the program was tested to run for a two-UAV system over a given probabilistic score map. The input trajectory paremerters were selected based on the properties of each UAV and the requirement of a search-and-rescue mission. The program may be seamlessly integrated with UAV flight control software, enabling a direct translation of the obtained trajectories into autonomous mission execution.

Keywords: *UAV; search and rescue; greedy algorithm; trajectory planning.*

1. Introduction

Unmanned aerial vehicles (UAVs) have been developed and widely used in many fields of life, society, and national security. The current types of UAVs are diverse in terms of characteristics, such as fixed-wing UAVs with the ability to operate over a wide range and at high speeds; multirotor UAVs with the advantage of hovering, observation, and target tracking capabilities; and hybrid VTOL (vertical take-off and landing) UAVs that can combine the advantages of fixed-wing and multirotor UAVs. One of the practical and essential applications of UAVs is to support search-and-rescue (SAR) operations and to mitigate the impact of accidents, natural disasters, and incidents. For this type of mission, flight trajectory-planning for UAVs must ensure the coverage of sufficiently wide airspace while maximizing the probability of detecting the target in the shortest possible time. Research on UAV trajectory optimization has been of interest for recent years, in parallel with the application and development of algorithms such as Particle Swarm Optimization (PSO) [1], graph search algorithms like Dijkstra, A*, Theta* [2, 3], genetic algorithms [4], and potential field methods [5].

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However, these algorithms mainly focus on finding the globally optimal trajectory when the destination is known. For SAR UAVs, trajectories are complex due to the uncertainty of final destinations. Hence, locally optimal algorithms like the greedy algorithm are often used and combined with other techniques to enhance the applicability [6].

Researchers have studied the use of UAVs for SAR missions. In the study by Chen *et al.* [7], the importance of incorporating environmental information into the path-planning process for UAV was emphasized. The authors proposed an online approach that leverages the spatial correlation among target locations. Another piece of research introduced an integrated assessment and search planning framework tailored explicitly to 3D environments [8]. Additionally, some work has considered the optimization of data transmission and surveillance path planning for UAVs [9]. More recently, Wan *et al.* focused on the tradeoff between flight path length and terrain threat, presenting an accurate 3D path planning method based on a multi-objective swarm intelligence algorithm [10]. Collectively, these contributions highlight the significance of factors such as environmental awareness, data communication, and comprehensive path optimization in enhancing the effectiveness of UAV-based SAR operations.

For domestic UAV research, scientists have been focusing more on integrating hardware systems and application technologies for UAVs rather than delving into algorithm and software development [11, 12]. Optimal trajectory/path planning algorithms are usually applied to robots [13, 14] rather than UAVs. One reason is that UAVs and other aerospace objects are still relatively new. Some authors have studied global UAV trajectory optimization algorithms under different flight conditions based on graph search methods [15]. However, these algorithms do not apply to SAR UAVs, which require comprehensive search coverage in a wide spatial area.

In this study, a program platform is presented for SAR UAVs based on an improved greedy algorithm. The algorithm can be applied simultaneously to a system with multiple UAVs deployed in parallel based on the search area's characteristics and each UAV’s capabilities.

2. Methodology

2.1. Probabilistic score map and search domain

The rectangular search domain is modelled as a probability distribution of detecting the missing object. In this study, the search domain is discretized into a Cartesian grid, and the probability of detecting the missing object at grid node (i, j) ($i^{\text{-th}}$ along the x-axis and $j^{\text{-th}}$ along the y-axis) is assumed to follow the Gaussian distribution:

$$p_{ij} = \sum_{k=1}^{N_s} w_k \frac{e^{\frac{-\left|\mathbf{r}_k^s - \mathbf{r}_{ij}\right|^2}{2\sigma_k^2}}}{2\pi\sigma_k^2} \quad (1)$$

where N_s is the number of probability distribution sources within the search domain; $\mathbf{r}_{ij}$ and $\mathbf{r}_k^s$ are the position vectors at grid node (i, j) and the $k^{\text{-th}}$ source, respectively; σ_k and w_k are the standard deviation of the probability distribution and the weight of the *k-th* source. These weights represent the degree of influence of each source and are normalized to ensure that the total probability over all grid nodes in the search domain is 1.

Figure 1 illustrates the probabilistic score map in the search domain with five hypothetical sources. Here, the position vector, the magnitude and the weight of each source are given; and the probabilistic score on each node is calculated by Eq. (1).

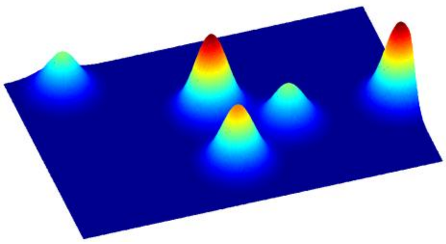

Fig. 1. Score map showing the probability distribution of detecting the missing object.

2.2. The greedy algorithm and trajectory-planning program

This study uses the greedy algorithm [6] to determine an appropriate trajectory of the UAV to maximize the accumulative probability of detecting objects. Compared to other globally optimal path-planning methods [1-5], this approach is more efficient in generating wide-coverage trajectories. Instead of considering the whole map, the greedy algorithm focuses on only neighboring nodes, and attempt to move the node of the highest probability. Figure 2 shows the current node and its neighboring nodes, to which the UAV can move in the next step. The visited node is then marked on the map and is prevented from revisiting, except for special cases. To generate a suitable trajectory, some improvements to the algorithm are introduced. Specifically, when all neighboring grid nodes have been marked, the UAV is trapped; it is then guided to the unmarked grid node with the highest probability within the whole search domain. The program is terminated when the UAV has visited all the grid nodes in the search area or the total flight distance (including the travelled distance and that expected to return to the starting position) exceeds the allowed value. The details of the algorithm are show in Fig. 3.

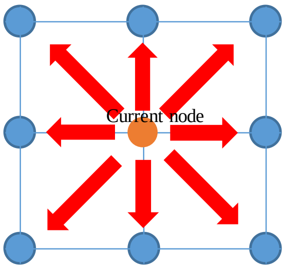

Fig. 2. Current and neighboring grid nodes.

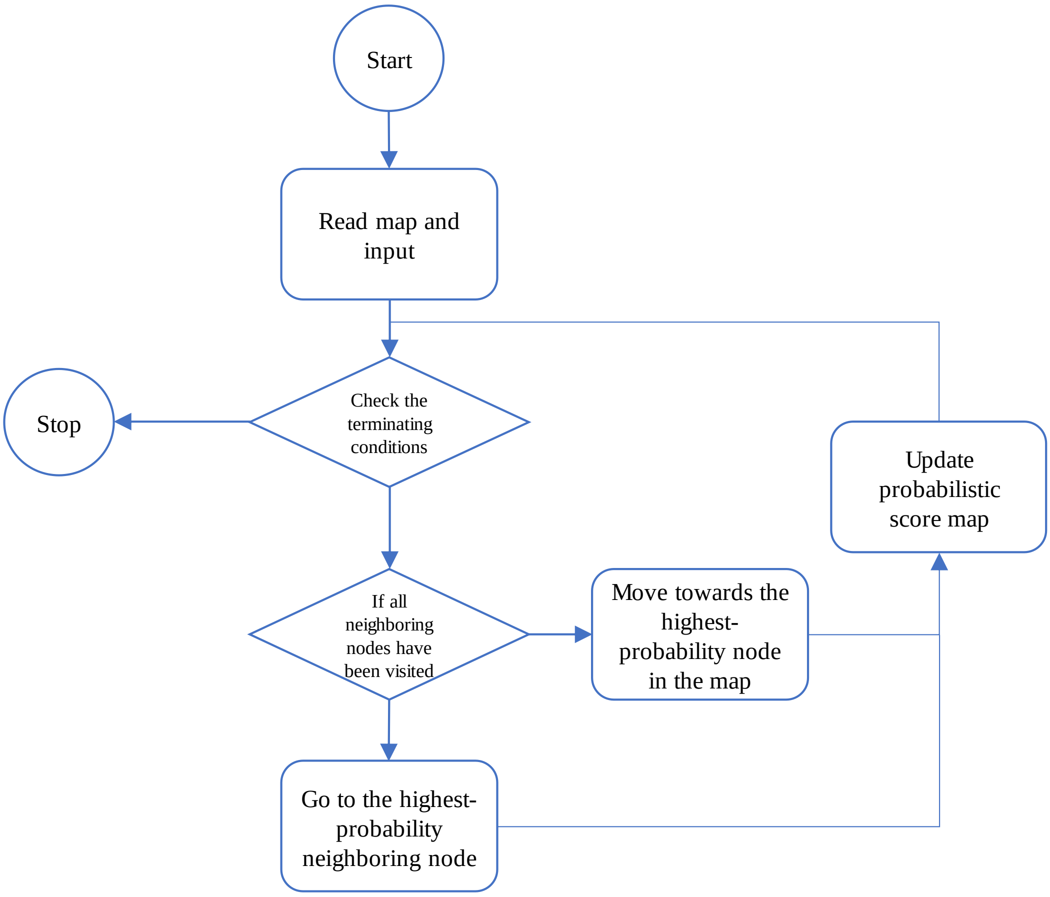

Fig. 3. Current and neighboring grid nodes.

The search area of each UAV may be defined either based on the geometry or the probabilistic property. The algorithm can be applied to a system of UAVs, in which, each UAV is responsible for a searching mission within a predefined probability range or a given area.

The trajectory-planning program was developed to run in the MATLAB environment with the source code written in FORTRAN. The program uses the graphics of MATLAB to draw maps and flight paths.

3. Simulation results and discussion

The algorithm was tested by running simulations to search within a 3×4.5 km rectangular domain. Figure 4 illustrates the probability distribution of detecting the mission object in this domain.

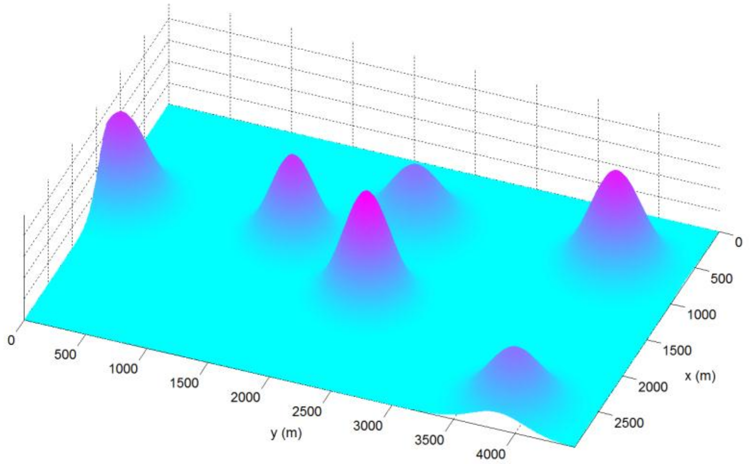

Fig. 4. Probability distribution of detecting the mission object.

The algorithm was applied to a system of two UAVs. For the first case, a search mission was assigned to each UAV based on the probabilistic property. UAV1 was set to search areas covering 60% highest probability while UAV2 was assigned to the search mission over the remaining areas. The resolutions in the search map for UAV1 and UAV2 are 50 m and 200 m, respectively. The resulting trajectories of the two UAVs are shown in Fig. 5. The flight distance travelled by UAV1 and UAV2 are 37 km and 119 km, respectively. It is noted that the trajectory resolution of each UAV could be selected based on the properties of on-board devices such as cameras used for the search mission. Moreover, constrains in the flight maneuver of each UAV also needs considering while setting the input parameters of the program. For fixed-wing aircraft, due to the constraint on the minimum flight-path radius, lower map-resolution may be applied. The grid size cannot be smaller than the allowed minimum radius. For quadrotors, this type of constraint may be released.

Figure 6 shows the variation of normalized probability score of each UAV during the search mission. It is obviously observed that UAV1 is in charge of high-probablity regions (over 0.4), while UAV2 operates in the below 0.4 probability score regions.

While searching based on geometry, we can obtain the trajectories as shown in Fig. 7. In these cases, two UAVs are assumed to have the same trajectory resolution.

The searching area division method could be defined by the user. Figure 7 presents the trajectory results while applying the vertical and horizontal division methods. Figure 8 shows the expected trajectory of a SAR UAV after exporting to flight control software. Here, the flight control software can upload the generated trajectory to any kind of UAV platform including multicopters, fixed-wing and VTOL aircraft. However, it should be noted that each type of UAV has its own maneuver and kinematic constraint that should be considered while inputting parameters.

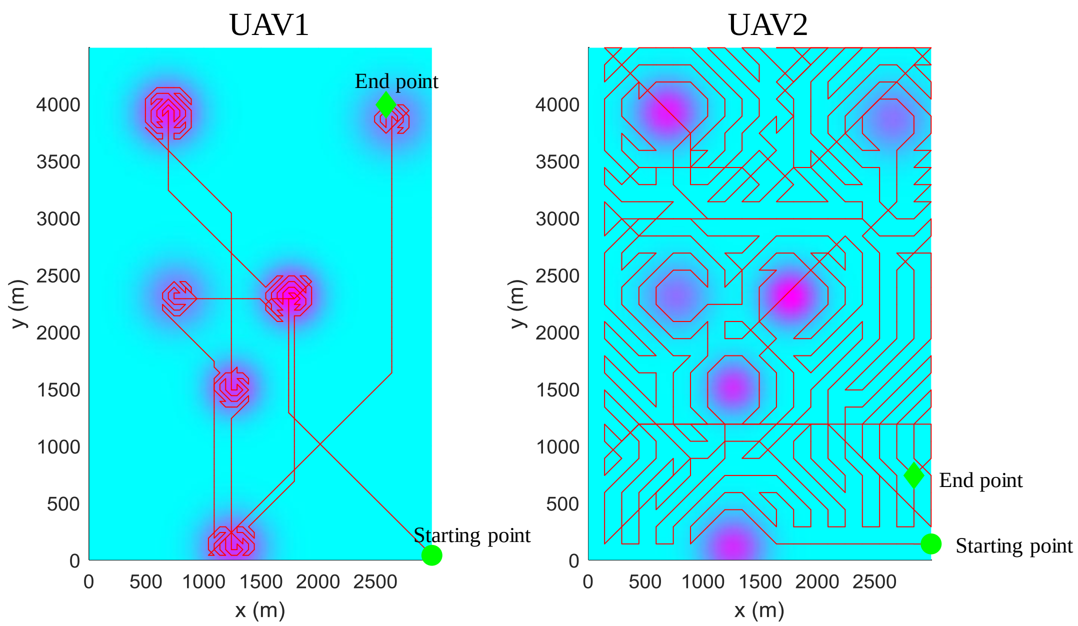

Fig. 5. Trajectories of UAV1 and UAV2 for probability-based search missions.

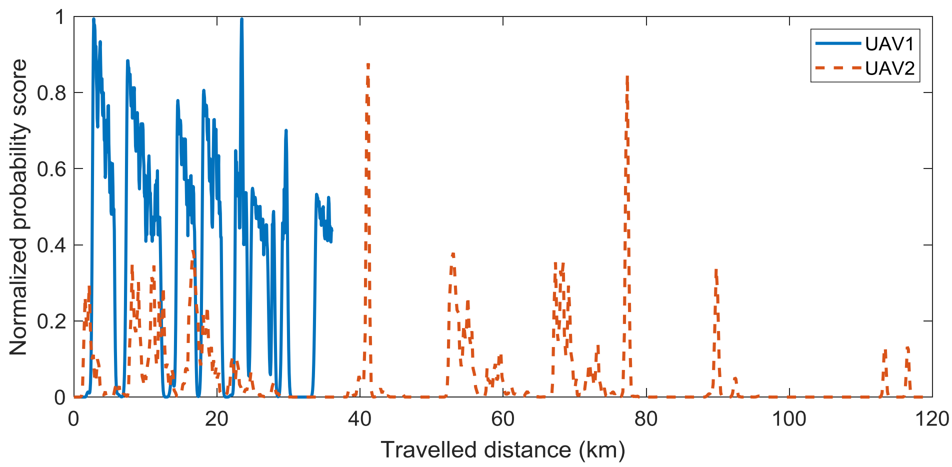

Fig. 6. Normalized probability score against the travelled distance of each UAV.

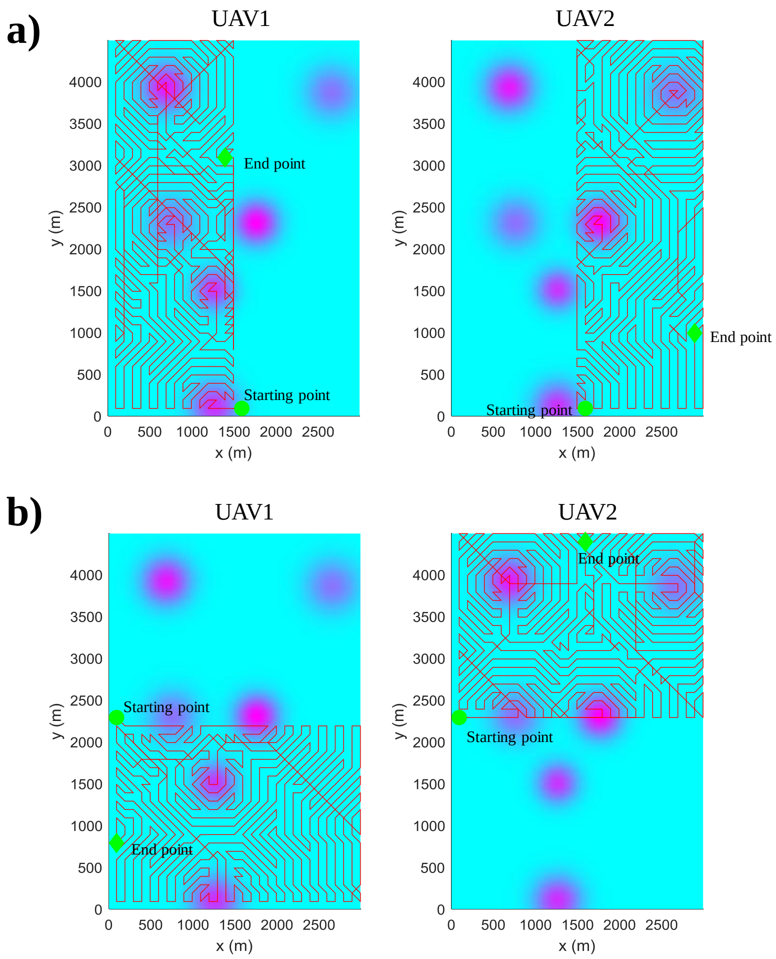

Fig. 7. Trajectories of UAV1 and UAV2 for geometry-based search missions.

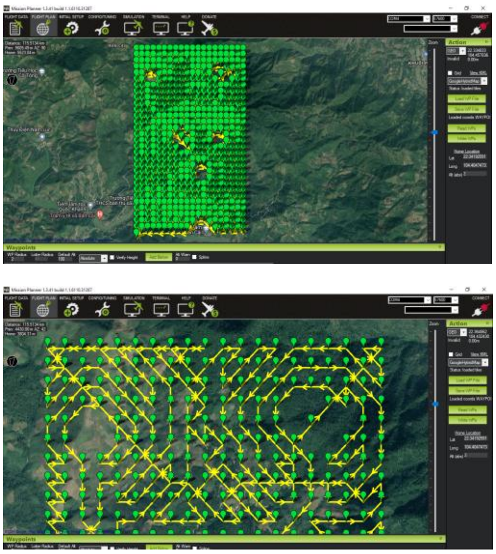

Fig. 8. SAR UAV trajectory in flight-control software.

4. Conclusion

The article has presented a computer program for optimizing UAV trajectories in search and rescue operations using a greedy algorithm. The program is also incorporated with flight control software that can be used for real flight of UAVs. In the future, the program can be improved by considering flight energy [16] and more accurate kinematic constraints [17]. The influence of terrains and other environmental factors may also be incorporated in the program to generate more realistic and practical search patterns for real-world flight. Moreover, more advanced modelling techniques can be applied while generating probabilistic score maps, which may enhance the quality of SAR missions.

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HOẠCH ĐỊNH QUỸ ĐẠO CHO UAV TÌM KIẾM CỨU NẠN SỬ DỤNG THUẬT TOÁN THAM LAM

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Tóm tắt: Bài báo trình bày chương trình hoạch định quỹ đạo cho UAV tìm kiếm cứu nạn dựa trên việc sử dụng thuật toán tham lam tối ưu cục bộ. Quỹ đạo được tạo ra trên miền tìm kiếm đặc trưng bởi bản đồ phân bố xác suất. Đối với hệ thống nhiều UAV, chương trình có thể phân chia và gán mỗi thiết bị với một nhiệm vụ tìm kiếm dựa trên tính chất xác suất hoặc hình học của miền tìm kiếm. Một số tham số như quãng đường di chuyển lớn nhất và độ phân giải quỹ đạo có thể được nhập vào chương trình. Trong nghiên cứu này, chương trình được thử nghiệm chạy cho hệ thống hai UAV trên bản đồ phân bố xác suất cho trước. Các tham số quỹ đạo đầu vào được lựa chọn dựa trên tính chất của từng UAV và yêu cầu của nhiệm vụ tìm kiếm. Chương trình có thể dễ dàng kết nối với phần mềm điều khiển bay UAV, từ đó cho phép chuyển quỹ đạo thu được vào quá trình thực thi nhiệm vụ bay tự động.

Từ khóa: *UAV; tìm kiếm cứu hộ, cứu nạn; thuật toán tham lam; hoạch định quỹ đạo.*

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