Area Surveillance with Obstacles by Multi-UAVs with Energy Support from a UGV

Hanqi Li, *Kyoto University*, Kyoto, Japan, herculelhq@gmail.com
Fumitoshi Matsuno, *Kyoto University*, Kyoto, Japan
Evgeni Magid, *Kazan Federal University*, Kazan, Russia
Jackrit Suthakorn, *Mahidol University*, Bangkok, Thailand
Mikhail Svinin, *Ritsumeikan University*, Kyoto, Japan

***Abstract*—We consider planning the path of multi-UAVs to complete the area surveillance, and planning a path of a UGV to provide energy support for multiple UAVs. We implement a genetic algorithm(GA) to accomplish this goal.**

***Index Terms*—multi-UAVs, area surveillance, UGV, path planning, GA**

I. Introduction

In the scenario of urban search and rescue (USAR), we consider the problem of regional surveillance using UAVs. UAVs need to fly to cover the area for information collection. However, the battery power of a UAV can usually support a flight of about 30 minutes to an hour. This flight time is not enough to support the area surveillance mission for a large area. Yu [1], [2] proposed a pattern of using UGV to charge a UAV to support the UAV for area coverage. They applied an algorithm to plan the path of single UAV and single UGV simultaneously to accomplish the area coverage task. We will consider using multiple UAVs for area coverage and using one UGV to provide energy support for them, and there are obstacles in our target area, so we need to consider avoiding obstacles while planning the paths of multiple agents.

II. Problem Setting

A. Assumption

For a target area with known obstacle locations and shapes, we aim to use multi-UAVs equipped with cameras or other types of sensors to fly over the target area to collect information of the whole area. Because the area is large and requires the UAV to fly for a long time to complete the monitoring task, and the UAV's own energy is considered unsustainable, we use a UGV with a battery exchange service to provide energy support for multi-UAVs. The target area we consider is where obstacles exist. The UGV cannot pass through these obstacles. The flight altitude of the multi-UAV is considered to be higher than the maximum height of the obstacles in the area, so the obstacles do not obstruct the flight of the multi-UAVs. For the goal of information gathering over the entire area, we develop a method to plan the paths of multiple UAVs and the UGV as well as the timing and location of battery exchange services.

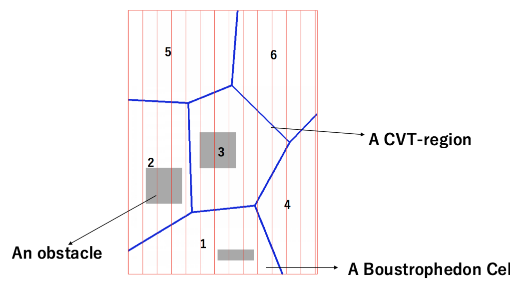

Fig. 1. Decomposed area

B. Area Decomposition

Since we use multiple UAVs to accomplish area coverage tasks, collisions may occur when multiple UAVs fly simultaneously over the entire area. In order to avoid a collision, we divide the whole area into several sub-areas, and specify that one UAV only performs the coverage monitoring task in one sub-area. We use the CVT-method [3] to partition the whole region (as shown by the blue line in the Fig. 1) and obtain multiple polygonal CVT-regions with similar size. In Fig. 1 a grey box is a obstacle. Since the flight altitude of the multi-UAV is determined, the sensing range of the sensors equipped on the UAV is also determined. Here we use the Boustrophedon Cell Decomposition (BCD) algorithm [4] to further segment each CVT-region (as shown by the red dashed line in Fig. 1). The width of the Boustrophedon Cell is equal to the diameter of the sensing range of the sensors equipped on the UAV. Therefore, as long as the UAV flies along the midline of a Boustrophedon Cell from end to end, all the information in this cell will be collected. We specify that the UAV must enter a cell from one end, and must fly from the end to the other. If the UAV covers all the cells in a CVT-region, then the UAV is considered to have completed the information acquisition task for that CVT-region.

C. Target

In the decomposed target area, we assume the coordinates of each Boustrophedon cell and the shape and location of the obstacles are known. Each UAV covers the area of each corresponding CVT-region, and the UGV can reach either of the two ends of a Boustrophedon Cell and wait for the UAV to land and provide battery exchange service before the UAV's battery runs out, and the UGV's trajectory should avoid the obstacles in the area. We should consider an algorithm to optimize the path of multiple UAVs and the UGV and the time and location of the battery exchange service to achieve the task and minimize the time cost for the whole area coverage.

III. Method

Our problem is a discrete optimization problem with many parameters to be considered. The problem has a possible huge solution space. Considering simplicity of implementation, a genetic algorithm is applied to solve this problem.

A. Encoding

In the encoding process, we need to encode the path of multiple UAVs, the path of UGV, and the time and location of the battery exchange service in the same chromosome.

- The path of a UAV, is represented by the order of the UAV's access to the cells in the corresponding CVT-area. We encode the paths of multiple UAVs and splice them together in a defined order while recording the stitched positions on the chromosome for later operations.
- For the time and location of the battery exchange service, we define a behavior pattern for the UAV to follow. When a UAV enter a cell, it decides whether it chooses to land on the UGV and exchange the battery, and whether carry out it at the entrance or the exit of the cell, depending on its battery power state. Thus, we can obtain the time and location of each UAV's battery exchange behavior based on the paths of multiple UAVs recorded on the chromosome.
- For the path of the UGV, since the location and time of the battery change service can be obtained, the UGV visits these locations sequentially in time order. The A* algorithm is applied to plan the path of UGV to avoid the obstacles in the area.

B. Selection

For a given chromosome, the paths of multiple UAVs can be obtained, then we can calculate the time required to complete the whole area coverage based on the speed of UAVs. In addition, we also consider two constraints. First, different UAVs cannot perform battery exchange at the same time. The second is that the UGV must arrive at the scheduled battery exchange location before a UAV arrives at the location. We select the best chromosome to complete the subsequent crossover and mutation operations based on the time cost and whether these two constraints are satisfied.

C. Crossover and Mutation

Based on the previously recorded splice positions on the chromosome, we will cut a chromosome into multiple segments representing different UAV paths based on these splice positions in this step. Two segments from different chromosomes representing the same UAV's path generate a new segment by the crossover operator. For a single segment representing a UAV's path, we perform the mutation operation.

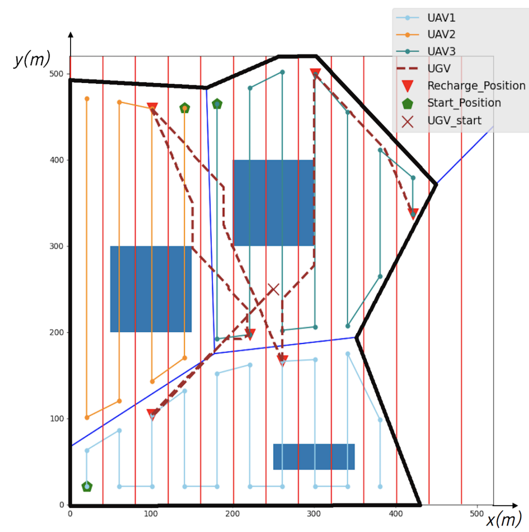

Fig. 2. Simulation result

IV. Simulation

- UAVs cover CVT-regions with 3 obstacles marked as 1, 2, 3 and one UGV supplies UAVs' energy.
- UAV' speed is $1.0m/s$ and UGV's speed is $2.7m/s$.
- The diameter of field-of-view for the camera equipped on UAVs is $40m$.
- UGV's initial coordinates is $x = 250m$, $y = 250m$ shown as "X" in Fig. 2.
- Time for a UAV to land on UGV, exchange its battery, and take off is set as $60s$.

In Fig. 2 we can find 3 UAVs' paths cover 3 CVT-regions. The UGV moves around to offer battery exchange service to UAVs meanwhile avoiding collision with obstacles in the environment.

V. Conclusion

We propose a new path planning problem of using multiple UAVs to cover the area with obstacles and using a UGV to provide energy support. We utilize the CVT and BCD algorithms to perform the region decomposition. We then implement a GA to solve this problem. Our proposed coding approach has a good performance in solving this complex problem.

References

[1] Yu K, Budhiraja K, Tokekar P (2018). Algorithms for routing of unmanned aerial vehicles with mobile recharging stations. In: 2018 IEEE International Conference on Robotics and Automation, pp. 5720-5725

[2] Yu K, O'Kane M, Tokekar P (2019). Coverage of an environment using energy-constrained unmanned aerial vehicles. In: 2019 international conference on robotics and automation, pp. 3259-3265

[3] Du Q, Emelianenko M, Ju L. (2006). Convergence of the Lloyd algorithm for computing centroidal Voronoi tessellations. SIAM journal on numerical analysis 44(1): 102-119

[4] Choset H (2000). Coverage of known spaces: The boustrophedon cellular decomposition. Autonomous Robots 9(3): 247-253.