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Abstract

As the development of unmanned aerial vehicle (UAV), it has been widely used in the field of the security surveillance. Given the practical situation, plans are optimized according to shape of target region and density of population. In this paper, specifically aiming at Yangpu District, we propose solutions to the following three problems:

Firstly, use as few UAVs as possible to monitor the entire Yangpu District to ensure all point of the region remain observed in at least 15minutes. We divide the whole region using the basic blocks, which is the scope of a static UAV. Then we conclude that the optimized solution is to find the combination of perfect routine and minimize the overlap. We use circle routine to use circle routine for the external edge. Then with the shrinking of uncovered areas, apply small blocks to fill the internal hole. The result is that we need 19 UAVs to accomplish the goal;

Secondly, it is required that the observation interval in high density region is 5 minutes and interval in low density region is 20 minutes. We treat the two areas as special, separate cases from the normal region. We think we need 23 UAVs to achieve the requirement.

Thirdly, provide the surveillance coverage when 30% UAVs are unusable. We build a model to find out the maximum area. Moreover we judge whether the routine can reach the ideal maximum area. If can, find out the best routine. Otherwise we should find out the actual maximum area. The maximum area in our paper is $54.6km^2$.

Key words：Unmanned Aerial Vehicles (UAVs), Routine scheme

Routine Scheme for UAVs Surveillance

1. Introduction

1.1 Background

With the development of aerospace Industry, much attention have been put on the unmanned aerial vehicles (UAVs), in order to accomplish the tasks which can't be achieved by manned aircrafts. Countries all over the world have invested much manpower and material resources into inventing UAVs.

The UAV aerial remote sensing technology in a small area has achieved remarkable performance in practice. And the micro aerial remote sensing technology, which used the UAVS as aerial remote sensing platforms, can satisfy the needs of country's economic and cultural construction and development, and provide an effective means of remote sensing technology services for small and medium cities, especially for the city, town, county, township, etc. Aerial remote sensing technologies play an important role in promoting Chinese economic development.

The images of UAV aerial are high-definition, large-scale, small area and high potential, which is suitable for obtaining aerial images of banded region (roads, railways, rivers, reservoirs, coastlines, etc.). And unmanned aircraft for aerial photography provides a remote sensing platforms that is convenient to operate and easy to turn the field. Takeoff and landing are less restricted by the space. It can take off and land in the playground, road or other open space. It becomes so popular due to its stability, security and easy transition.

The current UAVs are relatively robust to complicated external environment, can fly up to 4 hours without need to refuel, and require no human being to monitor each of them – instead, a sophisticated computerized controller can be programmed to follow any patrol strategy of your choice.

1.2 Our work

As the development of UAV, it has been used in the field of the security. Now the government decides to design a surveillance plan for the entire borough of Yangpu District by the UAVs.

Problem 1: Choose as few UAVs as possible to monitor the entire Yangpu District, and make sure that all geographic point of Yangpu District should remain observed from the air for at least 15 minutes in a row.

Problem 2: Some parts of the district are more important, e.g. the neighborhood of Fudan University and the Wanda Plaza. Such areas should be observed at least once in each 5 minutes interval. On the other hand, some roads have lower density of people, and there is no need to observe it more than once in 20 minutes. Choose serval UAVs to provide the requested variable level of coverage.

Problem 3: count out the surveillance coverage our plan provide, when some UAVs are not reliable and 30% of them become unusable.

2. Assumption

1. The photo that UAV shoots in the midair is clear.
2. The routines of UAVs are not influenced by environment circumstance.
3. The UAVs won't collide by each other in the midair.
4. The distance between UAVs and base station is not far so that photo can be send back to ground.

3. Terms, Definitions and Symbols

Symbol	*Interpretation*
h	Flight height of the UAVs.
α	Depression angle of UAVs
r	Radius of monitoring scope
v	Speed of UAVs
l	Flight Distance of UAVs in t min
t	Longest time a place under no surveillance
p	Number of UAVs
s	Area of one UAV's monitoring scope

4. Normal Routine Scheme

4.1 Analysis

According to the objective situation, some data of UAVs are as Table 1 shows.

Table 1: Parameters about UAVs

Specification	*data*
Height	0.6 km
Viewing angle	70^{o}
Speed	20km/h

The UAVs used for surveillance always fly up to 0.6km high from the ground. Either too high or too low is not suitable for surveillance. The photo will obscure when the UAVs fly too high, while the UAVs may run into tall buildings when fly too low.

The angle α is 35^{o}, half of the viewing angle. So the radius of its monitoring scope can be calculated by $r = h \cdot \tan\alpha$, and the value of its radius is about 0.42km.

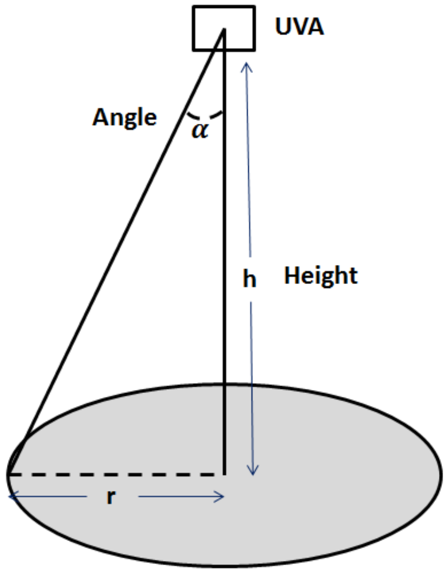

Figure 1 Simulated diagram of UAV

The speed of UAVs is about 20km/h. That means the UAVs can fly though 5km in 15 minutes. Although the monitoring scope is a circle, the scope UAVs swept is approximately a square when flying. We can easily calculate the area of square is about 0.7km ^{2}.

The area of Yangpu District is 60.61 square kilometer and the map is as figure 2 shows.

Figure 2 Map of Yangpu District

Assuming that UAV is static in the midair, we try to use UAVs to cover the district, just as Figure 3 show. In this figure, one green grid represents a monitoring scope area of a static UAV. And the area is 0.7 km ^{2}as we mention above. The number of UAVs to cover the district is 107.

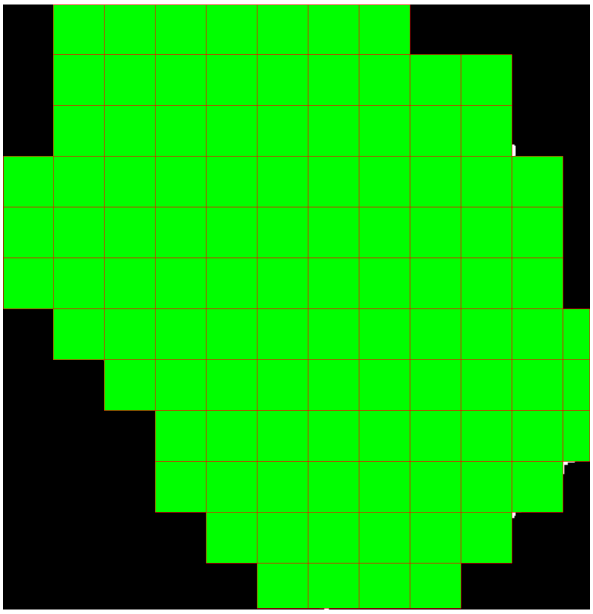

Figure 3 Grid picture of Yangpu district

In practice, the UAV can fly to anywhere when it carries out a task. As a result we should confirm the number of UAVs we use. Moreover, for each UAV we should determine a routine.

The speed of UAV is 20km/h and the distance it flies though is 5km in 15min. that means it can fly though 6 grids in figure 3. While all geographic point of Yangpu District should remain observed from the air for at least 15 minutes in a row. The UAV should return back to its start point, or there should be another UAV at its start point in 15min.

4.2 The Foundation of Model

In order to solve the problem, we establish model to choose p UAVs and make sure that the overlaps between should as few as possible.

$$\min O = s_x - s_{all}$$

$$s.t. \begin{cases} \sum_t x_t = s_{all} \\ \sum_i x_i = p \\ t \le 15 \end{cases}$$

In formulate above, s_x means the total UAVs monitoring scope, and s_{all} means the area of Yangpu District. x means the situation about the grids.

$$x = \begin{cases} 1 & when\ the\ grid\ contain\ UAV \\ 0 & when\ the\ grid\ does\ not\ contain\ UAV \end{cases}$$

The objective function means that the difference between total UAVs monitoring scope and the area of Yangpu District should be minimum value.

The meaning of constraint condition as follows:

1. The all area of Yangpu District should be under surveillance in t minutes.
2. The number of UAVs in the Yangpu District is p.
3. The longest time that one grid is not under surveillance should be less than 15min.

4.3 The Results of Model

If UAV gets back to its starts points in 15min and does not overlap any grids at all. We can call it perfect routine. There are two situations about perfect routine.

1. One UAV or serval UAVs can make up the routine as a block.

If there is only one UAV in a block, it can only fly though 6 grids in 15min as we mention above. One of the shapes of the block is as figure 4 shows.

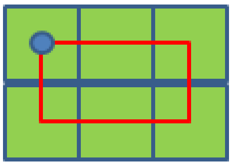

Figure 4 Block for one UAV

If there are serval UAVs in a block, they can fly though more than 6 grids in 15min, and the shapes can be more varied. But there should be another UAV at its start point when one UAV set out. One of the shapes of the block is as figure 4 shows.

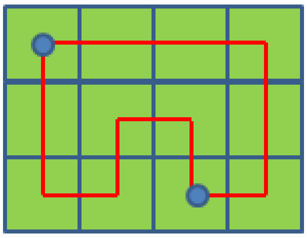

Figure 5 Block for two UAVs

We can infer that if the length or wide of the block is an even number, and the number of the grids is integral multiples of 6, the block can be flied though by serval UAVs.

2. Serval UAVs can make up the routine as a circle.

Serval UAVs can make up not only a block, but also a circle, just as figure 6 shows. The green grids mean the area under surveillance, while the gray grids mean the area under no surveillance.

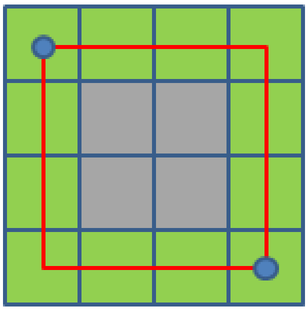

Figure 6 Circle for two UAVs

We can infer that in the perfect routine, the number of the grids should be integral multiples of 6.

The algorithm we use to solve the problem is as follows:

Step I: We can use circle to match the margin of Yangpu District from the exterior grids into the interior grids.

Step II: When the interior grids are not suitable for circle, we can use blocks to fill the interior grids.

In all the steps, we should make sure that overlaps should be as few as possible. The flight scheme of the UAVs can be showed as figure 7. There are four routines in this figure. The yellow one and the pink one are circles, while the black one and the brown one are blocks.

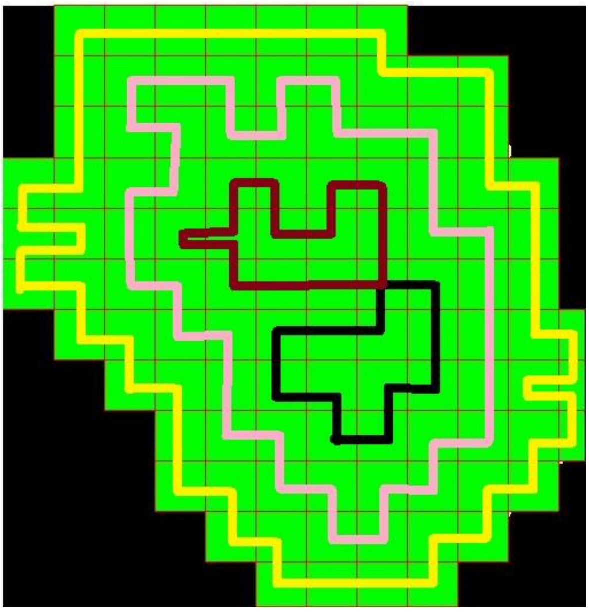

Figure 7 Perfect scheme

More details about the four routines can be found in table 2. We can make a conclusion that **19** UAVs needed for surveillance the at least. The minimal overlap is **5** grids.

Table 2 Details of routines

Routine	Type	Number of grids	Number of UAVs	Overlap
Yellow	Circle	46	8	2
Pink	Circle	24	6	0
Black	Block	12	2	0
Brown	Block	15	3	3

5. Weighted Routine Scheme

5.1 Analysis

This question requires us to build a model aimed at different area of Yangpu district with different density of people. In general, there is a more huge flow of people in the area near schools, malls, hospitals and stations. On the contrary, there will be less people around some small flow area. As a result, we should pay different weights on different areas.

After investigating the flow of people in most of the areas of Yangpu district, Shanghai， the Huge flow areas and small flow areas are as table 3 shows.

Table 3 huge and small flow areas

Huge flow areas	*Small flow areas*
Fudan University	Gongqing Forest Park
Wujiao Square	Industrial park
Yangpu Station	Machine tool plant
University of Science and Technology	

We found that the density of people of the area near Fudan University and Wujiao Square is the highest. Also, there is a huge flow of people in the area with the Yangpu Station and University of Shanghai for Science and Technology nearby. So we choose both of them as the important area of Yangpu district for building our model, as showed in the figure 8, represented by the two regions within the red line.

However, the flow of people is always small in the area near the Gongqing Forest Park and industrial park, without any schools, malls, hospitals or other important states around. Therefore, we choose it as the unimportant area for building model, as showed in the figure 8, represented by the region within the blue line.

Figure 8 Huge and small flow areas in Yangpu District

According to what we did in first the problem, we use combination of the basic blocks, which stand the observation scope of a static UAV, to describe each area. In the following picture, we use green to denote the normal area, yellow for high-density area, and blue for low-density area.

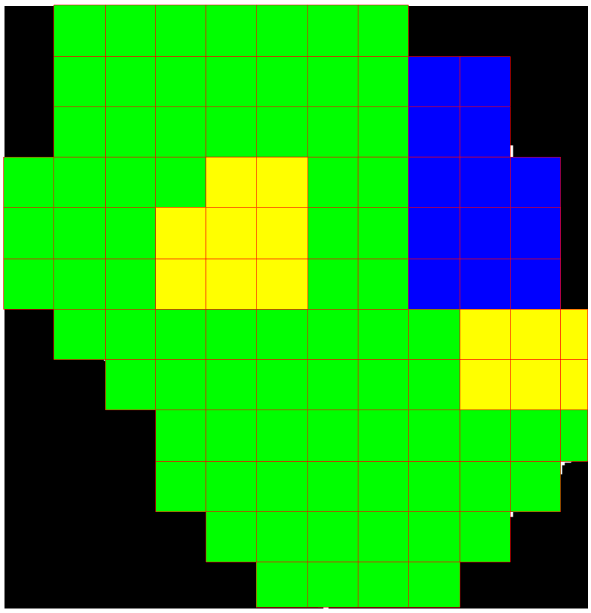

Figure 9 Grid picture of Yangpu district

Different weights should be paid on different areas. As an extension of the first problem, we treat the area of low density and high density as two special cases, just as table 4 shows.

Table 4 Different types in area

Type	Interval time	Routine grid
low-density area	20min	8
normal area	15min	6
high-density area	5min	2

We divide the whole area into three parts: normal area, where the interval of observation is 15minutes; high-density area, where the interval of observation is 5mintures; low-density area, where the interval of observation is 20 minutes. Each area is a separated system, that is, we compute the routine of UAV separately in three areas and the UAVs for different areas can't be shared.

For the high-density area, it is required that the observation interval is less than 5minutes. During that time the UAV can get through 2 grids. In the same way, in the low-density area, the interval between two UAVs is 8 grids. As with the variation of the interval between UAVs, we should arrange the routine properly to maximize the efficiency.

5.2 The Foundation of Model

In order to solve the problem, we establish model to choose *p* UAVs and make sure that the overlaps between should as few as possible.

$$\min O = O_l + O_n + O_h$$

In formulate above, O_l means the overlaps in low-density area, the difference between the UAVs monitoring scope and the low-density area. O_n means the overlaps in normal area. O_h means the overlaps in high-density area.

The objective function means that the total difference in the area of Yangpu District should be minimum value. When getting the number of overlaps in different areas, we can use the method mentioned in chapter four.

5.3 The Results of Model

First we excluded the two special areas. For these parts we use block to design the routine separately. Then for the rest of blocks we still follow the strategy: use circle routine for the external edge.

Then with the shrinking of uncovered areas, apply small blocks to fill the internal hole. This process involves partial empirical analysis and flexible adjustment.

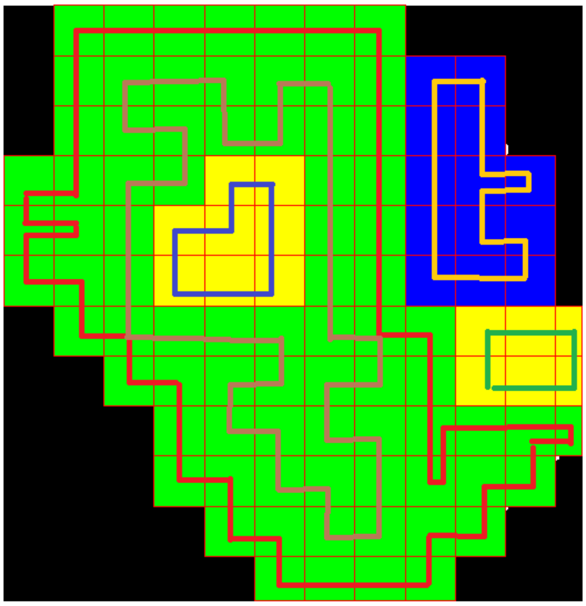

Figure 10 Perfect scheme

The following table shows the details of our solution.

Table 5 Details of routines

Routine	Type	Number of grids	Number of UAVs	Overlap
Red	Circle	45	8	3
Pink	Circle	34	6	2
Blue	Block	8	4	0
Green	Block	6	3	0
Yellow	Block	14	2	1

In order to accomplish the task, the total number of UAVs we need is **23**. There are 14 UAVs in normal area; 14 UAVs in high-density area and 2 UAVs in low-density area. The total overlap in the three areas is **6** grids.

From the number of UAVs in each area, we can make a conclusion that more attention should be put into high-density area.

6. Maximum Monitoring Area

6.1 Analysis

This problem requires us to build a model to predict that how much the area do the left UAVs can observe when 30 percent of the UAVs malfunctioned.

According to solutions to the first problem, when 30 percent of the UAVs are unusable, there is 13 UAVs left. And it is clear that if the 13 UAVs can get back to its starting points in 15min without overlapping any grids at all, that is 78 grids. We call this maximum area is ideal or best area, just as showed in the following formula:

$$\text{The ideal area } = \left\| 19 - 19 \times 0.3 \right\| \times 6 = 78\,(\text{grids})$$

So what we should do in this problem is to find whether the routine can reach the ideal or best maximum area. If can, find out the best routine. Otherwise we should find out the actual maximum area.

6.2 The Foundation of Model

In order to solve the problem, we establish model to choose p UAVs and make sure that the total UAVs monitoring scope as large as possible.

$$\min S = \sum_{i=1} s_i$$

$$s.t. \begin{cases} \sum_i x_i = p \\ t \le 15 \end{cases}$$

In formulate above, s_i means the unit UAVs monitoring scope. x means the situation about the grids.

$$x = \begin{cases} 1 & when\ the\ grid\ contain\ UAV \\ 0 & when\ the\ grid\ does\ not\ contain\ UAV \end{cases}$$

The meaning of constraint condition as follows:

1. The number of UAVs in the Yangpu District is p.

2. The longest time that one grid is not under surveillance should be less than 15min.

6.3 The Results of Model

There are many routines for the model, just as show in figure 11 and figure 12. In figure 11, we just use an entire circle to cover the maximum area. While in figure 12, we use serval blocks to cover the maximum area.

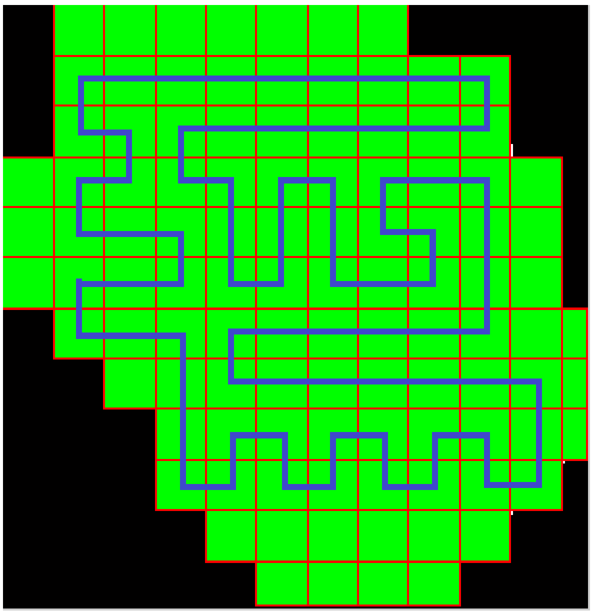

Figure 11 Perfect scheme of circle

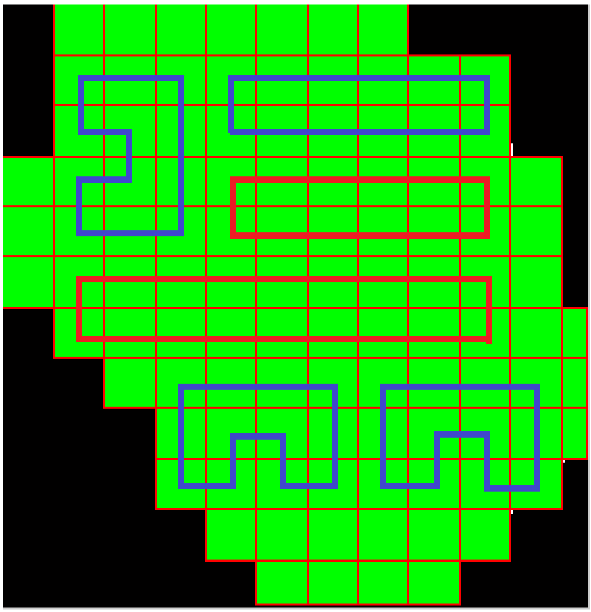

Figure 12 Perfect scheme of block

To explain our model, we choose one of them to analyze, as showed in figure 13. It contains both circles and blocks.

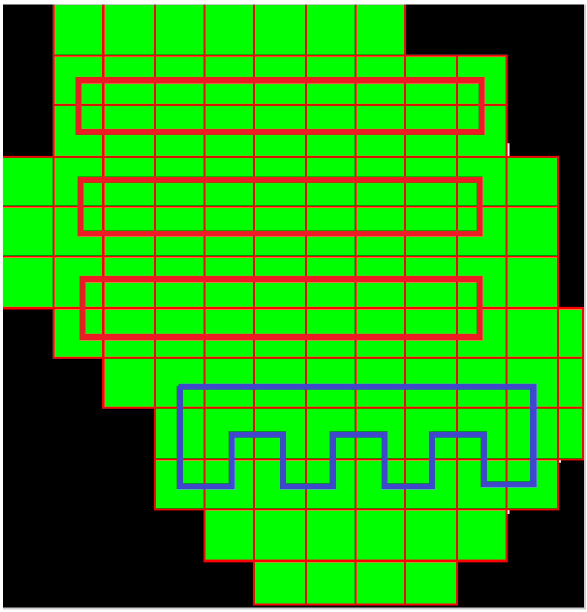

Figure 13 Perfect scheme of circle and block

From the map of Yangpu district, we can see that there are more than 60 grids in the middle of the figure 9, 54 of them make up a rectangle and there are more than 30 grids in the bottom of the figure1, 24 of them constituted a rectangle, too.

Therefore, firstly, we can finished the routine by two large parts, as showed in figure 1, the red part and the blue part, while the red part constituted of three same parts, and each of them can be made up from three blocks, which make up the routine as a circle .While the blue part can be made up of four blocks.

More details about the four routines can be found in table 6. We can make a conclusion that we can provide surveillance coverage with 78 grids when 30 percent of the UAVs were unusable.

The real area in the Yangpu District is $78 \times 0.7 = 54.6km^2$.

Table 6 Details of routines

Routine	Type	Number of grids	Number of UAVs	Overlap
Red	circle	18	3	0
Red	circle	18	3	0
Red	circle	18	3	0
Blue	blocks	24	4	0

7. Conclusion

7.1 Strengths

1. In our paper, we have established a model to find the optimal routine for UVAs. It can make sure that the overlap in the area is the minimum.
2. We have put forward two different perfect routines: circle and block, and can find out the appropriate maximum area in any circumstance.

7.2 Weakness

1. The routine we put forward in our paper is only straight line, we haven't taken curve or other shapes routine into consideration.
2. In the second problem, one of our flaws is that the three areas are not connected. That means spare observation in some area cannot be shared with others.

7.3 Improvement

All the routine scheme is based on the basis that the actual map can be described using grids approximately and we limit the orientation of routine is the orientation of chosen axis x and axis y. Actually, to ensure that our routine can cover the whole area, the grid-map contains all blocks that overlap actual map. This lead to the phenomena that in fringe blocks, the ratio of actual map area and block area is ranges can be as low as 10%. That means we practically enlarge the real area we need to observe. Projecting to proper coordinate system or change the arrangement of blocks can reduce unnecessary enlargement.

As we mentioned before, in the second problem one of our flaws is that the three areas are not connected. That means spare observation in some area cannot be shared with others. For example, in the blue area above we arrange 2 UAVs for supervision, whereas the region only includes 14 grids. Theoretically, taken no account of the shape of the aiming area, 2 UAVs can cover at most 16 grids, which is beyond the 14 grids in our solution.

Another problem is how to minimize the total overlap of arranged routine. Currently we compute our routine manually. This brings about a serious problem:

handcrafted routines lack the ability to generalize. Given a much larger area, let's say the area of the whole Shanghai, 6340.5 km^2, which would be more than 9000 grids. It's hard to imagine the workload of this computation. Given more time, using the method of induction or theoretical derivation, maybe we can conclude a general way to scheme routine using combination of perfect routine.

8. Reference

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