UAV hill fire prevention system based on machine learning

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Abstract: Wildfires have displaced many residents and animals. If wildfires occur again in the future and are not prevented and controlled quickly and effectively, the consequences will not only be economic losses, but also the reduction of biodiversity and the destruction of ecological balance, which will be an irreparable loss for all mankind. The Victorian National Fire Service dispatched frontline firefighters, SSA drones and radio relay drones to complete monitoring and fire fighting tasks, so our team of consultants was hired to plan the combination of the two drones in the face of following situations. To solve the problem of the optimal number and combination of SSA UAVs and radio relay UAVs, we first divide the missions into two types: observation and communication. For the existing UAV types, we design a UAV resource scheduling plan based on different types of tasks in a specific region, and provide UAV scheduling schemes for two different types of missions under the constraints of satisfying observational and communications mission needs, capability and safety, mission area geographic conditions, and maximizing economy.

1. Introduction

The 2019-2020 fire season saw the most serious wildfire in Victoria, Australia, which were made more difficult to extinguish by the continuous drought and windy weather. The Victorian National Fire Service dispatched frontline firefighters, SSA drones and radio relay drones to complete monitoring and fire fighting tasks, so our team of consultants was hired to plan the combination of the two drones in the face of following situations. The specific issues are as follows: Determine the optimal numbers and mix of SSA drones and Radio Repeater drones based on Australia's topography, observational and communications mission needs, and the size and frequency of fires, balancing economy with safety.

In this paper, we put forward the following assumptions:

- Ignore large-scale uncontrollable phenomena caused by wars, meteorites and other factors.
- Assume that all drones are launched from a preset EOC.
- Assume that drones consume the same amount of power per unit time whether flying or hovering.
- Assume there are enough charging piles in the EOC.
- The cost of replacing the auxiliary battery for radios or video & telemetry is negligible.
- Assume that when the relay drone is charging at the EOC, the remaining power of the auxiliary battery can keep the repeater working properly, and if the auxiliary battery is dead, the staff will replace it with a new one at the first time, and when the drone is fully charged and relaunched, the auxiliary battery is sufficient to complete the next observation or relay mission.

2. Determine the Best Number and Combination

To solve the problem of the optimal number and combination of SSA UAVs and radio relay UAVs, we first divide the missions into two types: observation and communication. For the existing UAV types, we design a UAV resource scheduling plan based on different types of tasks in a specific region, and provide UAV scheduling schemes for two different types of missions under the constraints of satisfying observational and communications mission needs, capability and safety, mission area geographic conditions, and maximizing economy.

The UAV scheduling problem in an observation or relay mission can be represented by the 5-tuple {E, R_1, R_2, M, C}, where E is the geographic environment of the scheduling problem, as terrain, climate and other factors; R is the set of UAS remote sensing systems, R_{ssa} = {R_1, R_2, R_3, ... R_{Cssa}}, C_{ssa} is the number of SSA UAV resources, R_{radio} = {R_1, R_2, R_3, ... R_{Cradio}}, and C_{radio} is the number of relay UAV resources. M is the set of tasks = {M_1, M_2, M_3, ... M_b}, b is the number of tasks. C is the set of constraints in the optimal scheduling problem.

The longest communication distance S_{fmax} of single UAV, the range of SSA and repeater range is similar to 20km, and only one SSA is used to communicate directly with EOC during the observation mission, at which time the flight distance of SSA is 20km and the longest communication distance S_{fmax} is 40km.

Subject to the maximum distance limit with the control center remote control UAV, the maximum distance of a single SSA UAV observation is calculated to be 40km, taking into account that the limit communication distance is not enough to meet the security requirements. Define the communication range between UAV and EOC, frontline troops and UAV, and multi-UAV system need to cross at least 1km distance.

3. Single drone observation mission model

First, let's discuss the SSA single drone observation mission. In the case of a small fire, taking into account the safety of front-line troops, and from the perspective of weighing the economy, the SSA single drone can be used to monitor and report data on the wearable devices of front-line personnel. m is the task type flag variable. If the drone resource R_{ssaj} performs the observation mission M_i when the fire is small, $m_{i,j}$ = 0, and the task level is upgraded to a relay task when the fire is large, and the communication distance is expanded.

Task triggering is based on conditions such as fire alarm calls. When the frontline troops learn about the fire and head to the scene, they will launch drones, while ensuring that the drones arrive at the scene before the frontline troops arrive. If the mission is not completed, but the UAV's battery is about to run out, considering the return time and conservative flight time, the conservative flight time should be used as the time to return to EOC, and at the same time, it is necessary to ensure that the UAV will continue to execute before leaving. The mission drone has arrived.

4. Build a drone shuttle model

Define the minimum time T_{fmin} required for the UAV to fly the conservative distance L_{fn}, that is, the minimum time required to fly at the fastest speed to reach the mission location or return to the EOC from the mission location. The maximum flying speed of the UAV is V_{fmax}, $T_{fmin} = \frac{L_{fn}}{V_{fmax}}$. The new drone needs to be launched in advance and arrive before the old drone starts to return. Define the time $T_{freturn} = T_{fn} - T_{fmin}$ when the old UAV should return to the EOC, excluding the round trip time, the hovering working time of the old UAV is $T_{fwork} = T_{freturn} - T_{fmin}$. If the new drone wants to arrive just before the old drone returns, the relative departure time is $T_{fgo} = T_{fwork}$. It is calculated that under the default operating parameters, T_{fmin} is about 0.4028 hours. In this way, even if the old drone has to return for recharging, the new drone can continue to complete the task, and set off in advance before the old drone returns. When the old drone starts to return, the new drone just arrives at the designated position, forming a seamless connection of range.

Since the normal working time of the SSA UAV is about 1.5244 hours, the T_{fwork} is less than 1.75 hours for the built-in battery charging time, and the T_{fwork} is less than 1.75 hours. Therefore, if there are only two SSA drones working alternately, during the charging process of the old drone, if the fire is smaller and the priority of the emergency is lower, you can wait for the old drone to be fully charged before setting off, although the tasks cannot be seamlessly connected, there may be a short period of loss in the middle, but the execution risk of the task is low, and the risk is within an acceptable range and there is greater economic benefit. If the priority of fire urgency is higher, the mission execution risk is high, and the risk of communication loss cannot be accepted (not to be ignored), more SSA drones should be added to meet the needs of seamless connection.

5. Relay task model

When the fire is large, the priority of the fire emergency degree reaches the threshold, and the communication range of the SSA single drone can no longer meet the actual fire monitoring needs, the SSA and radio relay multi-drone communication system are introduced. The farthest communication distance of a multi-UAV system is improved compared with that of a single UAV. Define the farthest communication distance S_{fsmax} of SSA and radio relay multi-UAV system. Based on the longest distance of SSA movement, add a radio relay UAV to SSA to extend the maximum communication distance $S_{fsmax} = S_{femax} + L_{fmax}$. It can be seen that the longest communication distance of the system composed of SSA and relay UAV is about 50km. Considering the stability of signal quality, define the normal communication distance of multi-UAV system $S_{fsn} = S_{femax} + L_{fn}$, which is about 49km.
The round-trip replacement of the multi-UAV communication system is the same as that of a single drone. Each drone calculates the individual relative time according to their departure time to satisfy the return and replacement and ensure the stability of the signal.

As the SSA drone cannot play a relay role when charging, it is assumed that there are enough charging piles in the EOC to support multiple drones charging at the same time, because the cost of the auxiliary battery is negligible, and the staff operates normally when replacing the battery ensuring that the auxiliary battery is sufficient to complete the next task after the drone is fully charged. During the process of charging the built-in battery, if there is a radio relay drone charging in the EOC, it can be regarded as a small base station with a range of 20km. The working time of the EOC relay drone is equal to the charging time of this drone. At this time, using the repeater of the radio-relaying drone that is charging can reach the longest communication distance under normal conditions without taking off. You can use this reasonable planning to achieve performance and safety that is the highest communication experience with the least number of drones.

Because the frontline troops carry handheld two-way radios that work in the VHF/UHF band. The unobstructed ground range is 5km, the urban area drops to 2km, and it is expected to reach 4km in the forest environment. It can communicate with SSA to maintain communication quality and cross 1km with SSA signal. The movable range is 3km, then the actual communication distance of multi-UAV system S_{fsmax} is increased to 52km.

6. The optimal number model of drones that weighs safety and economy

In the initial state, according to the actual location of the fire point and the size of the fire in recent months, according to the normal communication distance S_{fn} of a single drone, the EOC should be set up in a safe location around several areas with higher fire frequency. The location of the EOC should be avoided in large areas where the center of the fire-burning forest area and city (urban environment will interfere with signal transmission), you should choose a relatively open and relatively safe field area to establish EOC. If there is a fire that is difficult to extinguish and spreads quickly, the EOC should be moved to a safer place away from the fire while the forwards retreat.

We mapped and diorama the terrain of Australia in order to better analyze the terrain and plan the right mix of UAVs according to the type of mission.

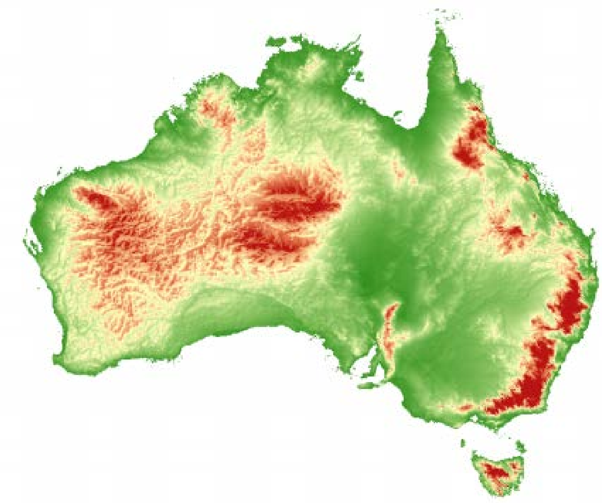

Figure 1 Diorama of Australian terrain

We used Google Earth to measure the range of wildfires in Victoria, Australia, and found that from 2019 to 2020, the area of wildfires near the southeastern coast of Australia reached 25610.48 square kilometers. Among them, the area of wildfires in Victoria is 11547.22 square kilometers, which accounts for about 45 percent of the total area, the main fire location was a large part of the forest area in southeastern Victoria.

With reference to NASA's fire satellite data, Australia's wildfires lasted around October 2019 until February 13,2020 before being extinguished one after another. Based on the existing satellite judgment data, we removed the fire data with poor confidence, draw a map of wildfire locations. We use parameters such as S_{fn} and S_{fsn}, and use the Active Fire data of NASA's VIIRS 375 m satellite to define parameters such as fire size F_{size} and fire frequency $F_{frequency}$, and based on the fire data in recent months when the Australian wildfire occurs, around the fire point Under the premise of ensuring the monitoring field of vision and communication range, the simulation establishes the most suitable EOC to meet the requirements of drone detection and repeater coverage.

We used the fire information for resource management system to measure the average distance between the borders of the largest wildfires in Australia, and found that the existing solutions can provide good coverage of the locations where wildfires occurred on an economic basis, it can be seen that this kind of drone can play a very good role in daily fires and extreme mountain fires.

Using 2019 Victorian hill fire data, we selected a subset of fire sites and automatically planned the location and number of EOCs.

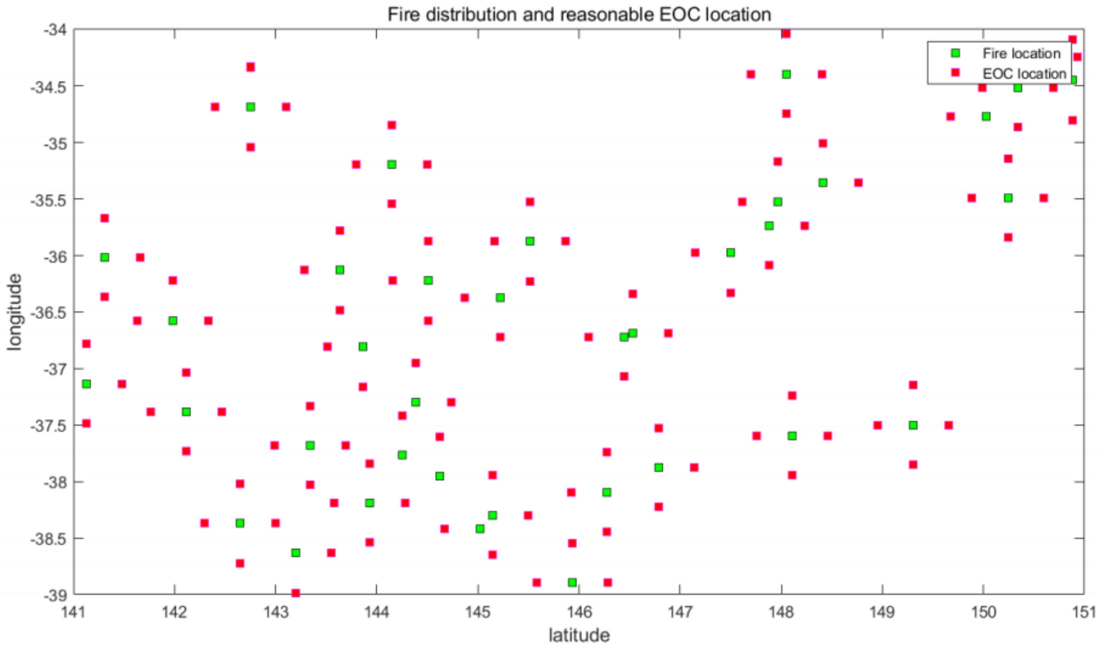

Figure 2. Establish EOCs for drone communication scenarios based on satellite maps of fires in selected areas in 2019

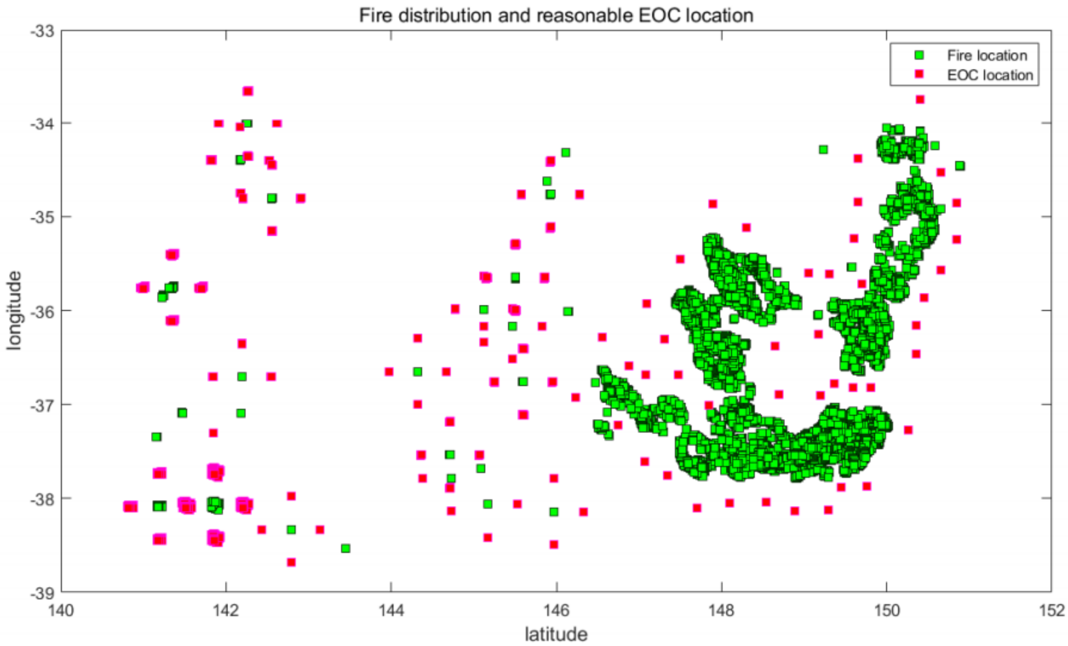

Figure 3 EOC creation for UAV communication scenarios based on satellite maps of the January 2020 fire

7. Stepped adjustment of maximum speed

The maximum speed V_{max} of the basic particle swarm algorithm is a fixed value, which cannot take into account the convergence speed and search accuracy at the same time. Therefore, we can change the maximum velocity in the elementary particle swarm from a fixed value to a step value. The maximum speed in the early stage is large, although the search accuracy is low, but the search range of the particles can be expanded; the maximum speed in the mid-term is appropriately adjusted to take into account the convergence speed and accuracy; the maximum speed is reduced again in the later stage to improve the search accuracy of the particles for easy More detailed search. The maximum speed formula of the stepped type is:

$$v_{\max} = \{ \begin{matrix} v_1, & 0 < t < 0.3T \\ v_2, & 0.3T < t < 0.6T \\ v_3, & 0.6T < t < T \end{matrix}$$

In the above formula, $v_1 > v_2 > v_3$, after such step adjustment, the algorithm can take into account the requirements of comprehensive search and precise search in different iteration stages. In the early stage, the global search ability is emphasized, in the middle stage, he global search ability and search accuracy are balanced, and in the late stage, the search accuracy is emphasized, so as to strengthen the universality of PSO.

Learning from the optimal position replacement strategy of genetic algorithm can greatly enhance the global search capability of particle warm algorithm. This optimal position replacement strategy can be understood as when a certain iteration is completed, the fitness of each particle is calculated separately, and the ranking is based on the value of the fitness. The value of fitness is low, indicating that the particle has poor fitness, that is, the distance between the particle and the optimal solution is far, and the reference value is not high, so the particles with low fitness need to be eliminated. However, if we completely replace the particles with poor performance, it is very likely to increase the possibility of falling into local optima and search stagnation. Therefore, we make a small shift in the position and speed of the replacement, that is, the replacement formula is:

$$x_{\text{bad}} = x_{\text{good}} + 2\rho_1(r - 0.5)$$
$$v_{\text{bad}} = v_{\text{bad}} + 2\rho_2(r - 0.5)$$

In the above formula, x_{bad} and v_{bad} are the positions and velocities of the particles with poor fitness, x_{good} and v_{good} are the positions and velocities of the particles with poor fitness, ρ1 is the position deviation radius, and ρ2 is the velocity deviation radius.

8. Conclusion

To solve the problem of the optimal number and combination of SSA UAVs and radio relay UAVs, we first divide the missions into two types: observation and communication. For the existing UAV types, we design a UAV resource scheduling plan based on different types of tasks in a specific region, and provide UAV scheduling schemes for two different types of missions under the constraints of satisfying observational and communications mission needs, capability and safety, mission area geographic conditions, and maximizing economy.

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