Application of UAV in bidirectional wireless communication network and monitoring system

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Abstract. UAV has the advantages of good flexibility, low cost and easy maintenance, and is widely used. In situations where there is an urgent need to build radio networks, drones have advantages that no other means can match. By analyzing the mission route of UAV, this paper establishes the monitoring system based on UAV and the radio communication network assisted by UAV repeater, and then realizes the two-way transmission of radio communication by the optimization of genetic algorithm. Thus, the communication and monitoring effect of emergency rescue departments are guaranteed.

Keywords: UAV, Relay Communication, Nonlinear Programming, Genetic Algorithm, Two-way Radio Communication Network.

1. Introduction

In the face of large-scale sudden disasters such as forest fires, it is often urgent to establish a stable and reliable radio communication network and monitoring system. And, this ensures that the command department can realize timely communication with the on-site rescue forces, so that the command department can grasp the fire situation in time, issue instructions more effectively and command the rescue work of front-line personnel.

At present, the traditional cellular wireless network can provide stable and reliable communication to a certain extent, but this method can't be applied to some urgent communication needs that need fast movement. In addition, the cost of using satellite relay to realize communication is very high and the flexibility is poor. In contrast, UAV relay has many advantages, such as good flexibility, low cost, convenient maintenance and so on. Moreover, the UAV is equipped with high-definition thermal imaging camera to monitor the on-site environment, which can replace the traditional monitoring method of aerial photography by operators by helicopter, reduce human and material resources and improve safety.

Therefore, taking advantage of UAV, considering economy and communication quality, through task path planning and network topology optimization, this paper establishes a radio communication network and detection system assisted by UAV repeater, and provides a fast response scheme for forest fire.

2. Short-range UAV monitoring and radio communication model

2.1 Problem description

SSA drones (drones for surveillance and situational awareness) carries a high-definition thermal imaging camera and telemetry sensor. HD thermal imaging camera can quickly and effectively find and accurately determine the location and scope of fire, and monitor firefighters to ensure their safety. The telemetry sensor can obtain the electromagnetic wave information reflected and radiated by the ground target from a long distance and non-contact, and extract, judge, process and analyze it. Note that the UAV needs to be charged to maintain its working state.

The mission route of the close monitoring force is as follows: At the fire site close to the emergency operations center (EOC), wearable devices worn by ground firefighters (wearable devices can be used

as personal positioning beacons or more complex environmental monitors) and high-definition thermal imaging cameras of SSA drones monitor the fire. Then, the UAV carries the acquired information through the telemetry sensor and flies to EOC to report the situation.

2.2 Establishment of model

(1) Map rasterization

In order to describe the distribution of fire, the forest fire area is meshed into discrete space, and each space has the same length and area. The grid length is 1km (less than the shortest communication distance - 2km), so a new coordinate system - "grid coordinate system" is constructed.

(2) Short-range UAV monitoring and radio communication model

It is known that the position coordinates of EOC are $E=\{e_1,e_2\}, e_k=(e_{xk},e_{yk})$, $k=(1,2)$, the location of the fire are $F=\{f_1,f_2,...,f_M\}$, $f_i=(f_{xi},f_{yi})$, $i=(1,2,...,M)$, UAVs positioning point are $C=\{c_1,c_2,...,c_N\}, c_j=(c_{xj},c_{yj})$, $(j=1,2,...N)$. Since the maximum flight distance of SSA is $30km$, the fire occurrence point close to EOC meets the following requirements:

$$|(f_x,f_y)-(e_x,e_y)|\leqslant 30 \tag{1}$$

Considering the dense distribution of close fire, if an SSA drone is used to monitor each fire point, the economy will be greatly reduced. Therefore, the collection of fire sites shall be handled as follows: d_{ij} indicates the distance between two fire points. If it is satisfied $d_{ij}<a$, the two fire points will be monitored centrally, so several centralized monitoring sets can be obtained. The above process can be realized by system clustering algorithm [1]. Thus, it can be obtained that the distance between the farthest point from EOC and the nearest point in each centralized monitoring set is:

$$d_1=|(a_x,a_y)-(b_x,b_y)| \tag{2}$$

The distance from the point farthest from EOC in each centralized monitoring set to EOC is:

$$d_2=|(b_x,b_y)-(e_x,e_y)| \tag{3}$$

The state vector of the SSA drone is: $\{V,T,S,t\}$, which V represents the flight speed of UAV, T represents the flight time of UAV, S represents the flight kilometers of UAV and t represents the charging time of UAV$(1.75h)$.

Taking into account the purchase cost, the utilization rate of UAV, and the efficiency of disaster information transmission, this paper constructs a nonlinear programming model with the maximum working frequency of UAV in a day as the objective function:

$$\max \sum \frac{24}{\left(T+\frac{d_2}{V}+t\right)\cdot N_2}$$

$$s.t.\begin{cases}\frac{30}{2.5}\leqslant V\leqslant 20\\ d_2\leqslant S\leqslant 180\\ S-d_2\geqslant d_1\\ T=\frac{S}{V}\end{cases} \tag{4}$$

3. Long-range UAV monitoring and bidirectional radio communication model

3.1 Problem description

Firefighters carry handheld two-way radios working in VHF / UHF band. The UAV can carry a repeater that can automatically replay high-power signals and hover far above the ground to expand the range of front-line low-power radios.

The mission route of the remote monitoring force is as follows: At the fire site far away from the emergency operation center (EOC), the ground firefighters monitor the fire, send information through handheld two-way radio, and then expand the signal transmission distance through the UAV equipped with repeater to transmit the information to EOC, so as to realize two-way radio communication between EOC and front-line firefighters.

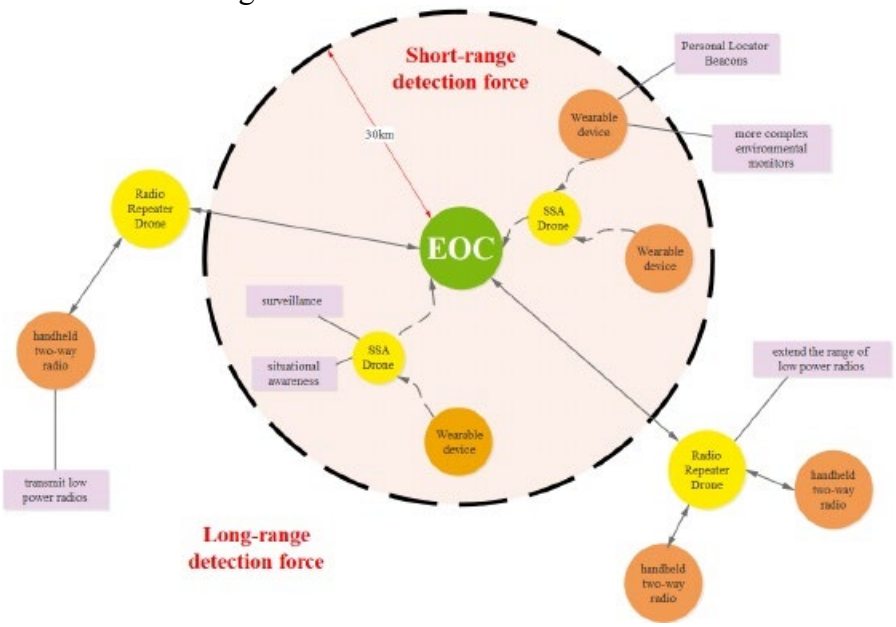


Figure 1. The mission route for UAV to realize monitoring and radio communication functions.

3.2 Establishment of model

(1) The concept of "equivalent height"

Since the transmission distance of radio signal is affected by cities and villages, the concept of "equivalent height" is introduced in this paper, which is defined as follows:

$$h = k \cdot \rho \cdot E \tag{5}$$

In the formula, $k = 0.5$ represents $10\ people/km^2$ and is equivalent to the altitude of $5m$, ρ represents population density, E represents wireless transmission distance of electrical signal. The relationship between the equivalent height and the propagation distance of the radio signal is:

At the highest equivalent height, the barrier effect is the strongest. The transmission distance of the radio repeater UAV is $8km$, and the transmission distance of the handheld radio is $2km$.

At the lowest point of the equivalent height, there are no obstacles. The transmission distance of wireless repeater UAV is $20km$ and that of handheld radio is $5km$.

According to this linear relationship, we can get the transmission distance matrix of handheld radio and the transmission distance matrix of radio repeater UAV.

(2) Constructing signal transmission state matrix

In order to ensure the bidirectional transmission of radio signals, this paper analyzes the signal transmission status between various points:

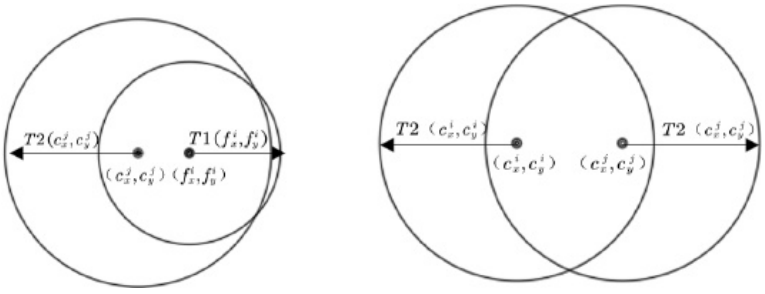


Figure 2. Effective signal transmission between points

As can be seen from the figure, for the signal transmission state of the handheld radio at the fire site:

$$a_{ij}=\begin{cases}1 & |(f_{xi},f_{yi})-(c_{xj},c_{yj})|\leqslant T_1(f_{xi},f_{xj})\\ 0 & else\end{cases} \tag{6}$$

For signal transmission status of radio relay UAV:

$$a_{ij}=\begin{cases}1 & |(c_{xi},c_{yi})-(c_{xj},c_{yj})|\leqslant T_2(c_{xi},c_{xj}) \quad or\\ & |(c_{xi},c_{yi})-(e_{xj},e_{yj})|\leqslant T_2(c_{xi},c_{yi})\\ 0 & else\end{cases} \tag{7}$$

In equations (6) and (7), $a_{ij}=1$ means that the radio signal can be transmitted in both directions.

Thus, the signal transmission state matrix is constructed:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1(M+N+2)} \\ a_{21} & \ddots & & \\ \vdots & & \ddots & \\ a_{(M+N+2)1} & & & a_{(M+N+2)(M+N+2)} \end{bmatrix} \tag{8}$$

Explain the matrix A:

Each row of the matrix A represents the signal transmission results between point i and point j. The front M line represents the signal transmission status of the handheld radio at the fire site, the middle N line represents the signal transmission status of the radio relay UAV, and the last two rows represent the signal transmission status at EOC.

(3) Optimization of network topology based on genetic algorithm [2]

In order to obtain the optimal network topology, this paper uses genetic algorithm to solve the signal transmission state matrix A. The implementation steps of genetic algorithm are as follows:

Step1: Planning project

The elements in the upper triangular matrix of the adjacency matrix A are used as the gene sequence of a single chromosome, that is, the gene sequence of a chromosome is:

$$B\left[b_1,b_2,\ldots,b_{(M+N+3)(M+N+2)/2}\right]$$

Among them, the corresponding relationship between gene b_k and element a_{ij} in the upper triangular matrix is:

$$k=\begin{cases}\dfrac{i(i-1)}{2}+j & i\geqslant j\\ \dfrac{j(j-1)}{2}+i & i<j\end{cases} \tag{9}$$

Step2: population initialization

Random initialization generates Z chromosomes, and each chromosome corresponds to the topology of a radio communication network.

Step3: Fitness function

The fitness function is the objective function. In order to ensure the maximum utilization of each radio relay UAV in the two-way radio communication network, this paper constructs the network cost function:

$$\varphi_1 = \sum_{i \geqslant j} a_{ij} \tag{10}$$

In order to ensure excellent network transmission performance, this paper constructs the network communication efficiency function:

$$\varphi_2 = \frac{\sum_{i \geqslant j} d_{ij}}{(M+N+3)(M+N+2)/2} \tag{11}$$

It reflects the average number of nodes experienced by the signal from one node to another. When the connectivity of the radio communication network is basically not affected or less affected, deleting the number of nodes of the radio relay UAV in the network can further reduce the purchase cost and improve the economy of the solution. Thus, the "degree" function is introduced:

$$\varphi(x) = \sum_{i=x} a_{ij} \tag{12}$$

According to the calculation result of the degree of each node in the wireless communication network, the nodes are arranged in turn. Delete the two nodes with the lowest degree of nodes, and recalculate the network transmission performance until the network transmission performance meets the requirements of this paper. Thus, the last function is introduced:

$$\varphi_3 = \left(\frac{\acute{\varphi}_2 - \varphi_2}{\varphi_2} \right) - 1 \tag{13}$$

The ultimate goal is to use the least radio relay UAV to optimize the transmission performance of the radio communication network. Therefore, the multi-objective is transformed into a single objective, and the fitness function is obtained as follows:

$$\varphi = w_1\varphi_1 + w_2\varphi_2 + w_3\varphi_3$$
$$s.t. \begin{cases} w_1 + w_2 + w_3 = 1 \\ 0 < w_i < 1 \qquad (i = 1, 2, 3) \end{cases} \tag{14}$$

Step4: Chromosome crossover and mutation operation

Through the crossover mutation operation, the permutation and combination of various feasible solutions of the signal transmission state matrix can be obtained.

Step5: Chromosome selection

After calculating the individual fitness, the chromosome with the highest individual fitness is selected from the parent population and the offspring population, and the optimal preservation strategy is adopted to preserve the excellent chromosomes.

Step6: Algorithm termination

When the number of iterations reaches 100000, the algorithm terminates and returns the optimal chromosome gene sequence.

(4) Verify the connectivity of the two-way radio communication network

The element b_k in a chromosome B reflect the probability that the radio signal starts from a node and reaches the EOC after passing through a limited number of nodes. $b_k = 1$ indicates that the signal is successfully transmitted in two adjacent nodes. After the chromosome B is restored to the matrix A, the connectivity from the two nodes to the whole network can be judged by the operation of the matrix A^{n-1}. $A^{n-1} = 1$ indicates that the network is connected, otherwise it indicates that the network is not connected.

4. Conclusion

In this paper, the task route of UAV based monitoring system in large-scale disaster is planned, and the radio communication network based on UAV repeater assistance is built. By solving the signal transmission state matrix with genetic algorithm, the location distribution of UAV repeaters and the optimal topology of two-way radio communication network are obtained. And the emergency operation center can obtain the on-site disaster situation through UAV monitoring system in time to guarantee the emergency rescue work. UAV can be used not only for forest fire monitoring and wireless communication relay, but also for battlefield information network. Battlefield information network is a complex system, which involves many technologies such as physical layer and protocol layer. It is an important research direction of UAV in the future.[3-5]

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