A path optimization algorithm based on multi-objective monitoring scenario analysis for UAV

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Abstract. The path planning of UAV monitoring task was used to a case study, a path optimization algorithm based on multi-objective monitoring scenario analysis for UAV was proposed. In the proposed algorithm, the UAV multi-objective task monitoring scenario was analyzed and modeled, Markov decision-making process model was established by model checking tool prism, two different sub-algorithms for MPOA_LRTP and MPOA_RR were provided to verify and analyze the model of UAV multi-objective task monitoring scenario. Compared MPOA_LRTP and MPOA_RR, the results of formal verification show that MPOA_LRTP with eight direction selecting was an effective way to complete the monitoring task for UAV, it spent shorter time and had higher efficiency, and the probability of completing the task in a certain time was greater. Besides, the smaller the workload and the less fatigue of the operator, the better the system performance and the higher the efficiency of completing the task.

1. Introduction

With the rapid development of computer technology, unmanned aerial vehicle (UAV) technology has been widely used in military, agricultural, industrial and other aspects. It mainly performs tasks such as monitoring, patrol, target tracking and emergency rescue, and plays an important role in dealing with natural disasters, accident disasters and some safety events. However, the tasks faced by UAV system are becoming more and more complex, which usually requires the system to complete the given task under the circumstances of assistant decision-making of console operator and unknown flight environment. In complex task scenarios, different path selection and operator's different characteristics for workload and fatigue will have a significant impact on the efficiency and probability of completing the task. Therefore, the path selection of UAV model and quantitative analysis of operator characteristics are of great significance to improve the efficiency of completing UAV flight mission.

On the related path planning analysis and research, part of the observable Markov decision process model is proposed in literature[2]. Through the analysis of simulation experiments, the model can better plan the path and achieve the effective tracking of the monitoring target. In reference[3], a 3D environment modeling method with high dimensionality reduction is proposed. Through simulation
and analysis, it is concluded that the method can improve the processing efficiency of path planning. In reference [4], how to avoid obstacle of robot is analyzed by method for probability model checking. Through formal verification, it is concluded that the reasonable path planning can make the robot avoid obstacles successfully. Reference [5-6] proposed a monitoring scenario model of interaction between operator and UAV, and analyzed the impact of operator characteristics on UAV mission completion quantitatively by formal model of prism [7]. The above research results have made good research in path planning and modeling verification, but can not fully meet the safety requirements of the system due to the limited test vector, or the expansibility of the model is not strong, so it is difficult to make better path planning for regions of different scales, and do not consider the probability of UAV completing tasks in a certain time and the characteristics of operators influence.

In view of this, this paper proposes a UAV path optimization algorithm based on multi-objective monitoring scenario analysis, which can model the monitoring tasks in any n × n matrix area, and proposes a multi-objective path optimization algorithm based on location relationship of target points (hereinafter using abbreviation MPOA_LRTP) and multi-objective path optimization algorithm based on random roaming (hereinafter using abbreviation MPOA_RR) to compare and verify the task scenarios of multiple target nodes that need to be monitored, and established the fault model and analyzed the obstacle that need to be avoided. The experimental results show that 8-direction MPOA_LRTP algorithm needs less time to complete the task, and has higher efficiency and better effect of successful completion of the task in a certain time. Compared with the existing research results, the proposed algorithm can better analyze and verify the path planning of UAV monitoring task, further improve the safety of the system, and provide better theoretical guidance and technical support for the application of UAV technology.

2. Algorithm description

In this paper, we adopt probability model checking tool for prism and Markov decision process model (hereinafter using abbreviation MDP) [8-9], and propose algorithms MPOA_LRTP and MPOA_RR, which is used to analyze the multi-target monitoring scenario, and verify the attribute of the system through PCTL formula [10]. The specific description and analysis for MPOA_LRTP and MPOA_RR are as follows.

Step 1: UAV takes photos at the current node and sends them to the operator. Step 2: image quality is judged according to the workload and fatigue of the operator. Step 3: if the image quality is not distinct, return to step 1; if the image quality is qualified, judge whether UAV has completed the multi-objective monitoring task. Step 4: if UAV has completed the multi-target monitoring task, the mission will be terminated and the flight will be stopped; otherwise, it will be judged whether there is a selected unsupervised target point (x_m, y_m). Step 5: if there is no selected target point, execute the selection algorithm of the target point to be monitored, and then return to step 4; otherwise, judge whether next flight of UAV will reach the dangerous area. Step 6: if next step selection will reach the dangerous area, the obstacle avoidance algorithm will be executed and return to step 5; otherwise, the UAV path selection algorithm will be executed, and the next unknown node will be flown to return to step 1.

In step 4, the selection algorithm of the target point to be monitored is analyzed, and the algorithm is shown in Figure 1. By using the word selected to mark whether there are selected target points, selected = 0 represents no selected target point, selected = 1 represents existing selected target point, and [select-target] means to select one of the non monitored target points as the current target point.
In step 6, the path selection algorithm is analyzed, and the algorithm is shown in Figure 2, where q represents the current location node of UAV, go indicates the start of UAV path selection, and D represents the four direction selection of up, down, left and right. When the UAV is in the middle region, there are four directions to choose; when the UAV is in the four non vertex regions, there are three direction choices, when the UAV is in the four vertex positions, there are two direction choices.

In multi-target node task monitoring scenario of the MPOA_RR algorithm, UAV needs to monitor multiple target points. It randomly selects the optional location of the current node when selecting path. The visited location node and target point may be repeatedly accessed until the task is completed. The specific description of MPOA_RR algorithm is shown in Figure 3. The variable z_k indicates whether the optional location is the target point, k ∈ {1, 2, ..., l}.

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initialization: q=(i,1), go=true, sent=true, a=false, step=false
while true do
    { If (sent=true) //UAV sends photos to operator
        If ((q1||q2||q3))
            /// All target points are not accessed
            carry out [go] // Execute the action go
            { execute path selection }...
        If (q_k)
            /// A target point z_k has been accessed
            a = true.
            // Mark the target point z_k for access
            carry out [go] // Execute the action go
            { selecting the path }...}
```

Figure 3. Pseudo code for MPOA_RR
Same obstacle avoidance strategy is used in MPOA_LRTP algorithm and MPOA_RR algorithm, so MPOA_RR algorithm is used to analyze obstacle avoidance in multi-target monitoring scene. In the complex monitoring environment, the flight height of UAV is limited, the UAV needs to adopt certain strategies to avoid obstacles in the mountain area. In this paper, we assume that the dangerous area is \( ROZ = (i=1 & j=n-2) \& (i=n-2 & j=n-2) \), the proposed obstacle avoidance strategies is as follows.

Step 1: judge whether the next step selection of current UAV coordinate position will reach the dangerous area. That is to judge location relationship between \( ((i+1,j) \& (i,j+1) \& (i-1,j) \& (i,j-1)) \) and Roz dangerous area.

Step 2: if the next location will reach the dangerous area, then avoid the dangerous path.

Step 3: if the next location does not reach the dangerous area, continue with the next step of path selection.

3. Experimental Analysis

In this paper, the multi-target monitoring scenario of UAV assisted by operator is modeled, two different algorithms for MPOA_LRTP and MPOA_RR are proposed, which can verify the spent time and maximum probability for UAV to complete a task. The model of four selected directions and eight selected directions are compared and analyzed.

(1) Under the influence of different factors, the time spent by UAV to complete the task is analyzed. In MPOA_RR algorithm, the verified attribute formula is \( R\{\text{time}\}\min = \{F(z_1 \& z_2 \& z_3)\} \) in MPOA_LRTP algorithm, the verified attribute formula is \( R\{\text{time}\}\min = \{F(z_1 \& z_2 \& z_3 \& \text{select=0})\} \), and the results of proposed algorithms are compared and analyzed.

In different grid areas, the time spent by UAV to complete the task is verified and analyzed. Firstly, we make UAV start from the initial node position \((1,1)\), four direction selection and eight direction selection for MPOA_LRTP and MPOA_RR are verified by their respective attribute formula. The verification results are shown in Figure 4 and Figure 5. The experimental results show that the 8-direction path selection algorithm takes less time to complete the task, and MPOA_LRTP can takes less time to complete the task and has made higher efficiency.

Different fatigue threshold \(C_T\) and discount factor \(f\) are used to analyze the effect for UAV to complete a multi-objective monitoring task. We assume that the value of \(n\) is 8, in 8-direction selection algorithm for MPOA_RR and MPOA_LRTP, and verify the minimum time required for UAV to finish the task. Verification results for MPOA_RR and MPOA_LRTP are shown in Fig.6 and Fig.7. Verification results show that with the increase of discount factor, the time taken by UAV to complete...
the task gradually decreases under different fatigue thresholds. In Figure 6, when \( C_T = 50 \), it shows that the change of discount factor \( f \) has obvious influence on the time spent by UAV to complete multi-objective tasks, and the value of \( C_T \) is bigger. In Figure 7, when \( C_T = 50 \), it shows that the change of discount factor \( f \) has little effect on the time spent by UAV to complete multi-objective tasks. So MPOA_RR algorithm is better than MPOA_LRTP algorithm, it takes less time and is more efficient.

![Figure 6. The Effect of Different C_T and F on UAV mission completion by MPOA_RR](image)

![Figure 7. The Effect of Different C_T and F on UAV mission completion by MPOA_LRTP](image)

(2) Within the determined time \( t \), the success rate of UAV to complete the multi-objective monitoring task is analyzed. In MPOA_RR algorithm, the verified attribute formula is \( P_{\text{max}} = \{ \text{true} \ U \leq T (z_1 \& z_2 \& z_3) \} \). In MPOA_LRTP algorithm, the verified attribute formula is \( P_{\text{max}} = \{ \text{true} \ U \leq T (z_1 \& z_2 \& z_3 \&(\text{select}=0)) \} \). The verification results for the algorithm MPOA_RR show that the maximum probability of UAV completing the task is 0.810469 when the fixed time is \( t = 10000 \) and \( N = 12 \). The results of for the algorithm MPOA_LRTP show that the maximum probability is 1 when \( t = 300 \) and \( N = 12 \). Through the comparative analysis of two algorithms, we can get MPOA_LRTP algorithm has higher success rate and shorter time.

(3) Obstacle avoidance of multi-target monitoring scene is analyzed in MPOA_RR algorithm. When UAV flies at a certain altitude, it may encounter obstacles higher than the flight altitude. When an obstacle is detected, it is necessary to reselect the path to avoid the obstacle. The corresponding attribute verification formula is \( P > 0 \{ \text{roz} \ & \ (F \ z_1 \ & \ z_2 \ & \ z_3 \&(\text{select}=0)) \} \), which is used to verify whether the probability of encountering the dangerous area is greater than 0. The verified result shows that UAV will visit dangerous area before obstacle is avoided. When the safety model is established according to obstacle avoidance strategy, UAV can successfully avoid obstacles in the process of performing tasks.

4. Conclusion

In this paper, UAV multi-objective task monitoring scenario is use to a case study, a MDP model for the interaction between the operator and UAV is established, two different algorithm for MPOA_RR and MPOA_LRTP is provided, experimental results show that in the process of path selection of UAV, the path optimization with eight directions select is better than four directions, the efficiency of MPOA_LRTP algorithm is higher than MPOA_RR, and the probability of completing the task in a certain time is bigger, and the time spent is less, so MPOA_LRTP with eight directions select algorithm is better.
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