A method for UAV monitoring road conditions in dangerous environment

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Abstract. This paper analyzes the scene of UAV executing path monitoring task in dangerous environment, and puts forward a method for UAV path selection in dangerous environment. In the proposed method, the operator mode and the agent operator mode are provided, and the model checking tool prism is used to model and verify the path selection scene of UAV. In normal environment, the UAV performs the path selection under the operator mode, and counts the number of successful and failed photographing of UAV. When the UAV reaches the harsh environment area and loses contact with the operator, the UAV path in the past is analyzed through the agent operator mode, the judgment of the operator is simulated to enable the UAV to continue to carry out the path monitoring task. The UAV road condition monitoring scene in dangerous environment is analyzed and verified from different scales and different operator characteristics.

1. Introduction
In recent years, unmanned aerial vehicle (UAV) technology has developed rapidly. It is mainly used in military, agricultural, industrial and other fields. It mainly performs surveillance, patrol, target tracking and emergency rescue tasks, and plays an important role in dealing with natural disasters, accident disasters and social safety incidents [1]. 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, Markov decision process model is adopted in literature [8-10], and 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] has 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 carried out good research in path planning and modeling verification, but these studies do not consider the situation that UAV may lose contact with ground control center operators when carrying out path monitoring tasks in mountainous or jungle environment.

In this paper, a method for UAV path selection in dangerous environment is proposed. The scene of UAV performing path monitoring task in mountain or jungle is analyzed. The probabilistic model checking tool for prism is used to build formal model and verify the attributes of the scene for UAV path selection. When UAV loses contact with operator in dangerous environment area such as mountain and jungle, it can't send the picture to the operator and can't choose the next path. In normal environment, the strategy of counting the number of successful and failed photographs taken by UAV is proposed. When the UAV reaches the dangerous environment area and loses contact with the operator, the number of successful and failed taking photos can be obtained, the judgment of the operator is simulated, so that the UAV can continue to execute the operations for selecting path and taking photos. Finally, path environment monitoring scene for UAV to carry out flight mission is analyzed and verified according to different scales and different operator characteristics in dangerous environment.

2. Algorithm description

When the UAV passes through mountains or jungles and other poor signal environment to perform road condition monitoring tasks, it will lose contact with the operator of ground control center. After the interruption, and it will not be able to carry out the follow-up operation. For this reason, this paper simulates the dangerous environment of road condition monitoring scene, we set the monitoring area as n × n grid area, and the critical point is set as (n/2, n/2) of the grid area. In our provided method, the UAV monitors the road condition in the critical point area before reaching the critical point, and the number of successful and failed images taken by the UAV is counted respectively. When the UAV arrives at the critical point, a new mode for operator agent is generated by the number of successful and failed images. Under this mode, the probability of image quality is judged. When the UAV is monitoring the road condition in the N/2 ~ n area, the probability is calculated to continue. The monitoring scene in dangerous environment is mainly divided into three parts to describe.

The first part, road condition monitoring before UAV reaches the critical point of dangerous environment area. Suppose that the UAV starts from the initial position (0, 0), and each step is reached and UAV flights to the next position, then the next position is taken as the current position, UAV takes photos and sends them to the operator. The operator judges quality of images. If the quality is qualified, the operator sends a qualified command, and the successful count is increased by one. After the UAV receives the command, the next path selection is made. If the image quality is not qualified, the operator will sends a command for failure, and the count of the failure is increased by one. The UAV pauses the next selection, takes a picture of the current area again, and sends it to the operator again until the operator judges that the picture is qualified. When reaching the (n/2, N/2) node, the communication between the UAV and the operator is interrupted.

The second part, the agent mode is turned on. Due to the loss of contact between the operator and the UAV, the UAV can not get instructions from the operator and can not make the next step of path selection. Therefore, by calculating the success and failure counts judged by the operator, the judgment probability of the agent operator is generated again. By obtaining the probability of success and failure of the picture, the UAV can run normally, and the next path selection can be carried out in the agent mode.

The last part, when the UAV reaches the terminal pointer (n, n), the flight mission is terminated. Suppose that the UAV must pass through the position(n/2, N/2) when executing tasks, but it will lose contact with the operator after passing through this position, then the agent operator mode will be
turned on after passing through the node \((n/2, N/2)\). The proposed algorithm is mainly composed of two modules, UAV module and operator module.

The UAV model consists of two parts: route selection in operator mode and agent operator mode. In the agent operator mode, it is necessary to obtain the probability of qualified or not qualified image quality judged by the proxy operator. Therefore, the UAV needs to obtain the probability for success and failure of the current node's image quality qualified and unqualified after a period of execution. In view of this, the node \((n/2, n/2)\) is regarded as the node that must be passed through in the scene design, and it is also the critical point for the operator to lose contact with the UAV. Before the UAV reaches the critical point, the path selection in the operator mode is performed. According to the current state, the UAV selects the path in the \((n/2)^*\)(n/2) area. After the UAV passes the critical point, the abscissa of the critical point is changed into the abscissa of the start node, and the path selection of the agent operator is performed. The details of path selection in agent operator mode of UAV module are shown in Figure 1.

The operator agent model consists of an operator and an agent operator. In operator mode, the operator's workload, proficiency and other factors affect the judgment of whether the picture needs to be taken again. When the image quality is qualified, the system will judge whether the UAV has reached the critical point. If the critical point is reached, turn on the agent operator mode, the label for “toAgent” is set to true, if the operator mode is not followed, the agent continues to execute in operator mode. The operator agent model is described in Figure 2.

Error and success respectively calculate the number of qualified and unqualified images taken before UAV reaches the critical point. When reaching the critical point, the qualified rate (abbreviated as \(Pro(suc)\)) and failure rate (abbreviated as \(Pro(error)\)) of the judgment image of the agent operator are calculated. The calculation formula is as follows:

\[
Pro(suc) = \frac{\text{success}}{\text{success} + \text{error}}, \quad Pro(error) = \frac{\text{error}}{\text{success} + \text{error}}
\]

![Figure 1 UAV path selection model](image-url)
Module operator

\[
\begin{align*}
\text{error} &= \text{init} \cdot 0; \quad \text{success} = (0 \cdot 0) \text{ init} \cdot 0; \quad \text{toAgent bool} \text{ init} \cdot false; \\
\text{image} &= \text{stop} \& \to\text{Agent} \& \text{true} \& x = 0 \rightarrow (1-p) \cdot (i=0) \& \text{p} \cdot (i=1) \& (i=2) \& (i=0); \\
\text{image} &= \text{stop} \& \to\text{Agent} \& \text{true} \rightarrow (\text{success} \cdot (\text{success} \cdot \text{error}) \cdot (i=0) \rightarrow (\text{success} \cdot (\text{success} \cdot \text{error}) \cdot (i=1)); \\
\ldots \\
\text{wait} &= \text{stop} \& \to\text{Agent} \& x = 2 \& \text{error} < 50 \rightarrow (i=0) \& (i=0) \& (\text{error} \cdot \text{error} + 1); \\
\text{go} &= \text{stop} \& \to\text{Agent} \& \text{true} \rightarrow (\text{success} < 50 \rightarrow (i=0) \& (i=0) \& (\text{success} \cdot \text{success} + 1); \\
\text{to_agent} &= \text{stop} \& \text{true} \rightarrow (\text{true} \cdot (\text{true} \cdot \text{true} \cdot \text{true} \cdot \text{true}); \\
\text{wait} &= \text{stop} \& \text{true} \rightarrow (x = 0); \\
\text{agent_go} &= \text{stop} \& \text{true} \rightarrow (\text{success} < 50 \rightarrow (i=0) \& (i=0) \& (\text{success} \cdot \text{success} + 1); \\
\rightarrow \text{stop} \& x = 2 \rightarrow (i=0), \\
\text{operator_stop} &= \text{true}.
\end{align*}
\]

The label for “Toagent” is used to mark whether it is in agent operator mode. If “Toagent” is true, select the action in agent mode, where action for [to Agent] is mainly used to determine whether the position of UAV has reached the critical point, the action for [image] is used to perform path selection in agent mode, the action for [wait] is executed to wait for the UAV to send the image again, the action for [image] is used for the UAV to send the image to the operator, and the action for [operator] is used to execute the action for [wait], the action for [operator_stop] indicates that stop is true and the traffic monitoring task is terminated.

3. Experiment analysis and verification
Firstly, the agent operator system model is verified, and whether the UAV has the possibility to complete the task is analyzed. The attribute formula is: \( P > 0 \) \([\text{stop}]\), and the task area with \( n = 12 \) \((n \times n)\) is verified, and the result is shown in Fig. 3. The verification result shows that it is true. Therefore, in the current task area, the probability of completing the road condition monitoring task is \( P > 0 \), so it is possible to complete the task.

![Figure 3 feasibility verification](image)

![Figure 4 the maximum probability for agent operator mode](image)

The maximum probability of completing a task within a certain time \( t \) is verified. The attribute formula of verification is \( P_{\text{max}} = ? [\text{true} U < t \text{ (stop)}] \). The critical point is \((n/2, n/2)\), the verification results under agent mode and operator mode is analyzed, and the grid area \((4 \times 4, 8 \times 8, 10 \times 10, 12 \times 12, 14 \times 14)\) is verified. The results are shown in Fig. 4, the maximum probability of completing the task within the determined time \( t \) in the agent operator mode and the maximum probability of completing the task in the determined time \( t \) in the operator mode are shown in Fig. 5.
Figure 5: maximum probability of completing tasks in time $t$ for operator mode

Through the analysis of Fig. 4 and Fig. 5, it can be concluded that the maximum probability of completing a task in a certain time decreases with the increase of task area in operator and agent operator mode, and the growth trend is the same. Longitudinal analysis from $t = 1000$, the maximum probability of each task area under the agent operator mode in Figure 4 is compared with the same as in Figure 5 for operator mode. It is shown that the maximum probability in Figure 4 is larger than that in Figure 5. This is because in the operator mode, with the increase of time, the operator's workload and fatigue will affect the probability of judging whether the picture is qualified or not. However, in the operator agent operator mode, after reaching the critical point, there will be no effect of the operator characteristics, and the judgment is based on the qualified rate and failure rate of the picture obtained at this time. Therefore, the agent operator model of figure 4 is reasonable, and the maximum probability in Fig. 4 is higher than that in Fig. 5. In view of this, the agent operator mode can ensure the continuous execution of tasks when UAV and operator lose contact in dangerous environment, which has certain research value.

4. Conclusion
In this paper, the UAV monitoring task in dangerous environment is taken as a case study, we put forward a method to deal with the loss of contact between UAV and operators based on probabilistic model checking. The formal model of Markov decision-making process is established by the probabilistic model checking tool prism, and the attributes are described by PCTL. The experimental results show that the probability of UAV completing the task in dangerous environment is higher than that in the operator mode within a certain time $T$. However, when the critical point is closer to the target point, the maximum probability of the two modes gradually approaches, and the gap becomes smaller and smaller. Therefore, according to the time of approaching the critical point, the mode from operator to agent operator has certain research value in dealing with UAV flight dangerous environment.

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