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Local Approach Planning Method of Underground Unmanned Vehicle in Mining Area Under Global Constraints

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Abstract:

Due to the particularity of underground operation in mining area, there are high requirements for production safety. With the rapid development of unmanned driving technology, the related technology of using unmanned vehicles to complete underground transportation tasks in mining area has been widely concerned. The transportation approach is usually a predefined global approach. However, scenes in mining area change dynamically and new obstacles will appear, so unmanned vehicles need to plan local approaches in real time. According to the characteristics of underground work in mining area, this paper proposed a local approach planning method under global constraints. On the one hand, the approach obtained by the approach planning should satisfy the constraint of the global approach to ensure moving according to the predefined approach; on the other hand, it should satisfy the constraint of the local approach, avoid obstacles and make the most efficient use of the acceleration of the vehicle to keep the speed. To verify the proposed method, an experiment was carried out in the actual underground scene of mining area, and the experimental results proved the effectiveness of this method.

***Keywords**: Approach planning; Unmanned driving; Global constraints; Local obstacle avoidance*

I. INTRODUCTION

Social demands such as alleviating traffic congestion, improving driving safety and protecting the environment have promoted the rapid development of unmanned driving technology. At the same time, the development of intelligent unmanned platform technology, such as autonomous driving, has also provided new solutions for industries with high requirements for safe production, such as mineral mining and geological exploration [1, 2]. Realizing unmanned transportation in mining areas is one of the important applications of autonomous driving technology to improve safe and efficient production.

In unmanned driving technology, approach planning is an important part of the system. The task of approach planning is to generate a feasible approach from the starting position to the destination position without collision according to optimization criteria, such as time constraint, approach length constraint, approach smoothness constraint and vehicle parameter constraint. approach planning is generally divided into two categories, namely global approach planning [3, 4] and local approach planning [5, 6].

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In certain application scenes such as underground mining areas, new constraints related to carrying tasks are introduced to the goal of approach planning. For example, the global approach is usually known, and the approach planning needs to solve the problem of local approach planning that conforms to the global approach constraint. That is, the local approach planning cannot deviate from the global planning goal. Based on this practical application problem, the author proposed a local approach planning method under global approach constraints.

II. DYNAMIC WINDOW LOCAL APPROACH PLANNING

Dynamic Window Approach, (DWA), a classical local approach planning method, is widely used in approach planning tasks of mobile robots, unmanned aerial vehicles, unmanned aerial vehicles and other systems [7-10]. Its principle is to sample the speed and angular velocity of the mobile platform according to the motion parameters of the carrier at time T, and predict the possible motion trajectory of the mobile platform in time T according to the sampled motion parameters. The basic principle is shown in Figure 1.

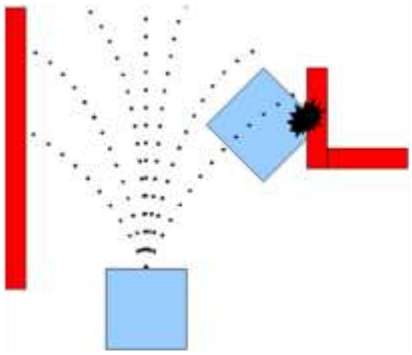

Figure 1 Schematic diagram of DWA principle

Assuming that the current vehicle speed is v and the angular velocity is ω, the kinematics model of the vehicle body can be established as follows:

$$\begin{cases} x' = x + v(\sin(\theta + \omega\Delta t) - \sin\theta) \\ y' = y + v(\cos\theta - \cos(\theta + \omega\Delta t)) \\ \theta' = \theta + \omega\Delta t \end{cases} \tag{1}$$

Wherein, (x, y, θ) and (x', y', θ') are the two-dimensional coordinates and heading angle of the current time and the next time, respectively, and Δt is the time interval between the two times.

Because the motor torque of an automobile is limited, its maximum and minimum speed and acceleration are limited. There will be a dynamic window in a cycle, and the speed in this window is the speed that the car body can actually reach after the cycle is over.

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After speed sampling, DWA algorithm deduces different trajectories according to the sampling speed, and evaluates the trajectories, so as to select the best speed and angular velocity. Through the constructed evaluation function, the predicted trajectory is scored, and the trajectory with the highest evaluation score is usually selected as the output of local approach planning.

III. LOCAL APPROACH PLANNING METHOD UNDER GLOBAL CONSTRAINTS

In the underground transportation task of mining area, the global approach is usually determined because of the specific transportation approach. Therefore, when planning the local approach, it is necessary to fully consider the constraint of the global approach on the local approach. When selecting the candidate solution of local approach, the end point of the trajectory should be as close as possible to the target point of the global approach, so that the vehicle can drive along it as much as possible. Secondly, the end point of the local approach should be as far as possible outside the full-speed driving range of the vehicle, so as to ensure the full-speed driving of the vehicle.

Based on the above considerations, the $i-th$ approach is set, and the cost function of approach planning established in this paper is

$$cost_i = \alpha_1 \cdot \phi_1(r_i) + \alpha_2 \cdot \phi_2(r_i) \tag{2}$$

Wherein, $\phi_1(\cdot)$ represents the degree of twists and turns of the approach, $\phi_2(\cdot)$ represents the distance between the approach and obstacles, and α_1, α_2 represents the weights of two evaluation functions. The specific expressions of $\phi_1(\cdot)$ and $\phi_2(\cdot)$ are:

$$\begin{cases} \phi_1(r_i) = \max\limits_{1 \le i \le N}(distance(P_i, \overrightarrow{P_1 P_N})) \\ \phi_2(r_i) = \max\limits_{1 \le i \le N}(distance(P_i, obstacle)) \end{cases} \tag{3}$$

Through the evaluation function, we can calculate the minimum distance between an approach and the wall and the degree of twists and turns of the approach, score each approach, select a relatively flat approach which is far away from obstacles among a plurality of candidate approaches, and then select the best candidate approach for subsequent generation of local approaches.

After the candidate approaches are determined, they are sorted according to the evaluation scores, and then different endpoint selection strategies are formulated according to the following three situations to meet the requirements of global constraints. The specific principle is shown in Figure 2. Assuming that the point where the vehicle is located is P, and the point closest to the point P on the global approach is P':

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(1) When the center P of the vehicle is far from the global approach, that is, the distance being greater than D_1, the vehicle should be able to return to the global approach as soon as possible. So, the endpoint selected is k_1 m behind the point P' on the global approach;

(2) If the center P of the vehicle is closer to the global approach, that is, the distance being less than D_1, a circle is made with the farthest distance that the vehicle can advance in the forward forecast time as the radius and P as the center. The point on the global approach k_2 m ahead of the intersection point of the circle and the global approach is the selected endpoint;

(3) If the distance between the vehicle center P and the end point of the global approach is less than a specific threshold D_2, the endpoint of the global approach can be directly regarded as the endpoint of the local approach. Such a determined end point can make the selected trajectory not only close to the global approach, but also reach the endpoint quickly.

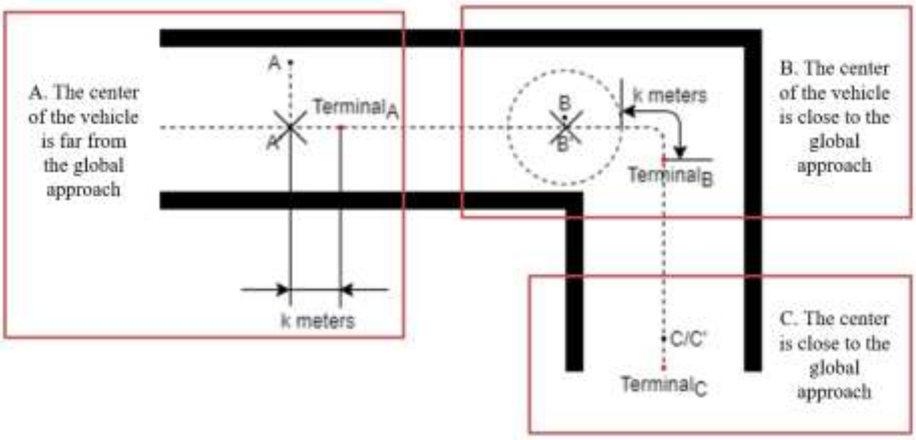

Figure 2 Three strategies for selecting the endpoint

IV. EXPERIMENT

The flow chart of the algorithm used in this paper is shown in Figure 3. After sampling in the speed space, the approach closest to the end point after the FORWARD_DT time is taken as the best approach. If there are some obstacles on the approach, the approach will be discarded directly, and the system will calculate downwards according to laser-point cloud update frequency to obtain a local approach.

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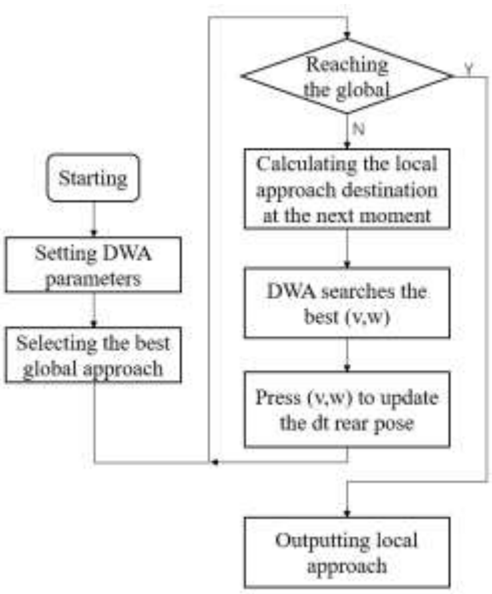

Figure 3 Flow chart of local planning approach generation

The meaning of each parameter in the algorithm is shown in TABLE I.

TABLE I. DWA parameters

DWA parameters	Meaning
V_MAX	Top speed
V_RESOLUTION	Velocity resolution
V_ACC	Linear acceleration
W_MAX	Maximum angular velocity
W_RESOLUTION	Angular velocity resolution
W_ACC	Angular acceleration
FORWARD_DT	Forward prediction time

By adjusting the parameters for different scenes, a better local approach can be obtained.

This method runs on Ubuntu 18.04 with 32-line lidar, and the test results are shown in Figure 4. The local approaches generated in three different scenes, namely straight line, roundabout turn and fork intersection turn, are displayed respectively. In the figure, the red part is the obstacle extracted from the point cloud. The white line is the predefined global approach, and the green line is the calculated local approach. The generated approach is based on the global approach and can meet the driving conditions of the vehicle.

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(a) Straight approach (b) Approaches with turns (c) Bifurcation intersection

Fig. 4 Approach planning results in real scene underground of mining area

V. CONCLUSION

Aiming at the demand of unmanned underground transportation in mining area, this paper proposed a local approach planning method under global constraints, adding global approach constraints to the traditional dynamic window approach method. Firstly, an approach evaluation function was constructed, and any sampling approach was graded according to its distance from obstacles and vehicle driving parameters. Then, the sampling approaches sorted according to the evaluation function were selected by using the constraints of global approaches, so that the finally generated approach planning approach was consistent with the global approach.

To verify the effectiveness of the method proposed in this paper, the author set up a test platform, and carried out experiments in real scene underground of mining areas. The experimental results show that the method proposed has a good effect on straight approaches, intersections, approaches with turns and other scenes.

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