Research on Motion Control of Tracked vehicle in Virtual Reality

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Abstract. Based on the preview-following theory, the control method of following the polygonal trajectory is designed in combination with the manipulating rules and driving experience of drivers after establishing sliding model and analysing moving characteristics of the tracked vehicle. And with the combination of Creator and Vega Prime, the autonomous movement of tracked vehicle is realized to meet the immersion and real-time requirements in the virtual environment. The experimental results show that the tracked vehicle can effectively avoid the obstacles to reach the expected target position, which proves the effectiveness of this control method. And this also provides a reference for the realization of the motion control of tracked vehicles and the driver's driving training.

1. Introduction

Virtual reality, which is saw as an emerging technology has developed rapidly and matured in recent years, has been extensively studied and applied in three-dimensional environment modeling[1], weapon application simulation[2-3], vehicle simulation driving[4] and many other field. Especially, some features including its good real-time, immersion and interaction are suitable for the application of vehicle simulation driving. Many experts and scholars have carried out related research. Luo Yuan[5]achieved motion simulation of intelligent vehicle under different traffic conditions in the urban roads, focusing on virtual reality traffic flow simulation. Wang Wenfeng[6] and Luo Zhuhui[7]designed the vehicle simulation driving system in the consideration of vehicle dynamics, which better rendered the 3D virtual scene, realized realistic and accurate driving motion simulation, and met the requirements of interaction and real-time requirements. Ji Jie[8]established the model with regarding the vehicle's vertical and horizontal motion tracking error as the variable and verified the path tracking ability of the vehicle following system in use of the simulation test platform. The response characteristics show that the simulation test platform has high reliability. In addition, the simulated driving systems have also been developed for drivers’ training to simulate actual driving maneuvers[9-10]. What's more, A.M.Shara[11] also developed a similar vehicle-based simulation driving system, which integrated the driver's operational actions and proved the robustness and fidelity of the simulated driver under typical conditions. X.Yan[12]made use of virtual reality technology to reproduce the traffic environment at an intersection in Orange County, and explored the impact of the visualization of traffic environment in virtual reality on the simulation fidelity and effectiveness of driving simulator driving behavior.

The current research on simulated driving is mostly for civilian vehicles. In contrast, there are few tracked vehicles in the position of attention and most of them are research on independent motor-driven track vehicles. There is relatively little research on the motion control of tracked vehicles with two-stage planetary steering gear. In this paper, the supporting software and simulation structure of the virtual simulation system are briefly described. Then, a tracked vehicle is taken as the research object with...
establishing the sliding motion model of it. Combined with the driving control law and the preview-following theory, the motion control methods are designed to achieve the vehicle to follow the fold line trajectory. In the three-dimensional virtual simulation experiment, the driver's control operating rod and the speed of the sprocket at both sides of the track are taken as input, and the speed and angular velocity of the vehicle body are regarded as the output, both of which realize motion control of the tracked vehicle under direct and steering conditions.

2. Structure of the virtual simulation system
Creator/Vega Prime is a professional software developed by MultiGen Paradigm. It has the excellent ability to realize 3D solid modeling and visual simulation and has become one of the widest tools for virtual reality technology. Creator, which integrates powerful and convenient vector editing, interactive modeling and assembling, and geomorphologic generation to provide a “what you see is what you get” visual simulation environment, is designed for visual simulation[13]. Vega Prime based on VSG has outstanding object-oriented capabilities, functional modules, flexible program settings and real-time programming adjustments with Visual Studio 2003. Motion control simulation of the tracked vehicle is realized with integrating advantages of softwares. The structure of it is shown in figure 1.

Fig.1 The motion control simulation structure of tracked vehicle

2.1. 3D solid modeling based on Creator
Creator has a powerful database for managing 3D model data, which makes operation processing such as input, structuring, modification, creation of prototypes and optimization models simple. Tracked vehicles belong to externally operated entities. So the model built first needs to obtain the external feature size and related texture data of the vehicle. At the same time, LOD technology is applied in the process. The accuracy of LOD models and the degree of detail at different distances are different. Terrain modeling uses the plug-in module provided by Creator to dispose the elevation data files. The first is to convert them into usable DED files, and the second is to set the terrain LOD to build and optimize the 3D terrain database, and the last is to form the terrain road and obstacle model in flt files. The model of the vehicle and terrain is shown in Figure 2. In addition, the relationship between the physical ground and the mesh plane when importing the model should be paid attention to. The modeling should be carried out according to the principle of minimizing the number of faces, and the whole virtual scene should be arranged reasonably according to the actual reference environment.
2.2. Visual simulation driver based on Vega Prime

After completing the 3D solid modeling, the Vega Prime is used to simulate the visual simulation. With the API interface of the model, the user can programmatically read, write and build the flt file, and set up the characteristics of the vehicle model and the terrain model. The workflow of running the program is: initializing the vp module; defining the configuration file; configuring the resources to be used; frame loop; closing the vp module. The initialization and shutdown methods are all defined in vp::namespace. Definitions, configuration, frame loops, and other runtime control methods are defined in the vpKernel class[14]. In addition to building an application process directly with vpKernel, the vpApp class was also used to achieve it. vpApp encapsulates the above five methods that are all inline virtual functions. Deriving application types from vpApp and adding extensions are not a difficult thing. In order to enhance the immersion of the vehicle motion, the rendering effects such as sound effects and ruts are added in the process of movement, and the collision detections between the solid models are designed.

3. The tracked vehicle’s motion control modeling

3.1. Sliding model

The steering mechanism of the tracked vehicles differs from that of the wheeled vehicles, because it is a differential steering based on the difference in speed between the two tracks. This section analyzes the steering motion of tracked vehicle from the perspective of plane motion. It is considered that the vehicle is geometrically symmetric about its transverse longitudinal plane, and the center of the mass coincides with the geometric center of the vehicle body; the vehicle carries on uniformly steady-state steering on the horizontal ground; The centrifugal force is small enough to be ignored when turning. As is shown in figure 3, the inertial coordinate system and the vehicle sliding steering description in the vehicle coordinate system are established. C is the center of mass of the tracked vehicle:O/O’ is the actual/ideal steering center; \( R_c/R'_c \) represents respectively the actual/ideal turning radius; \( v_q/v'_q \) represents respectively the advanced speed and the circular velocity of two sides of the track, where 1—represents the inner track and 2—represents the outer track. The following is the same. \( \omega_c \) and \( \omega'_c \) represent the speed of vehicle body and angular velocity respectively. The vehicle's centroid coordinates are described as \((X, Y, \theta)\) and \(\theta\) is the vehicle's heading angle. Change of the pose of the vehicle is described as Eq.(1):

\[
\begin{bmatrix}
X \\
Y \\
\theta
\end{bmatrix} =
\begin{bmatrix}
cos \theta & 0 & 0 \\
sin \theta & 0 & 0 \\
0 & 1 & \omega_c
\end{bmatrix}
\begin{bmatrix}
v_c \\
0 \\
\omega_c
\end{bmatrix}
\]

The driving force of the sprocket at the track on both sides of the tracked vehicle is different, so the circular velocity is different. This is the reason why the sliding speed \( \Delta v \) of the track on both sides is also different. It is considered that angular velocity of the sprocket at the inner and outer crawler tracks is \( \omega_1, \omega_2 \), and pitch radius of the sprocket is written as \( r \). The track slip/skid rate on both sides of the vehicle can be expressed as Eq.(2):
\[ i = \frac{|v_j - \omega_j r_j^2|}{v_j}, \quad j = 1, 2 \] \tag{2}

Considering the effect of track slip/skid on both sides of the vehicle, the actual turning radius of the vehicle is obtained by Eq.(3):

\[ R_c = \frac{B (\omega_2 + \rho \omega_1)}{2 (\omega_2 - \rho \omega_1)} \tag{3} \]

Where \( \rho \) is the constant related with the track slip/skid, and \( \rho > 1 \).

It can be known from equation (3) that \( R_c > R_c' \). Tracks on both sides of the vehicle are subjected to sliding, so the actual turning radius is increased compared with the ideal turning radius. That is a disturbance to motion control of the vehicle, which must be considered when controlling steering motion.

3.2. Motion control model of the tracked vehicle

A tracked vehicle adopts a two-stage planetary steering machine to realize differential steering. Under low-speed motion conditions, the first and second position of the steering gear is adopted, which is determined by the internal mechanical transmission structure, and the sprocket's speed on both sides of the track is output to a fixed ratio; Under high-speed motion conditions, internal components of the steering gear are slippery and the sprocket's speed on both sides of the track has great uncertainty; the front position represents the straight-line motion of the vehicle with the speed of the sprocket on both sides consistent. The position distribution of operating rod is shown in Figure 4.

![Diagram of position distribution of operating rod](image)

**Fig.4 Schematic diagram of the position distribution of operating rod**

Due to the limitations of the performance of the internal mechanical transmission, only partial stepwise steering can be achieved. Thus the motion control of the vehicle cannot follow the smooth curve trajectory with continuous changes of curvature. Combined with the operating law and driving experience of such tracked vehicles, it can be seen that the movement of such tracked vehicles mainly relies on the coordination of local heading adjustment and straight-line driving, and finally forms a trajectory of discontinuous connection between straight-line and arc-line, especially this feature is more apparent under low-speed conditions. Based on the preview-following theory, a new motion control method for following polygonal trajectory under low-speed conditions is proposed. The selection of
preview points is an important part. Selecting the turning point in the polygonal trajectory as preview points in combination with the motion characteristics of the vehicle is designed instead of applying the conventional way of traversing path points. Turning points’ coordinates are set to \((X_d, Y_d, \theta_d)\). As is shown in figure 5, the tracked vehicle follows the desired polygonal trajectory; A, B, and C are three selected preview points; and \(\beta\) is defined as angle of deflection between the real-time heading of the vehicle and connection between the real-time position and the next preview point. The circles with different radius near the turning point represent the turning radius of the first and second positions of the steering gear. \(d\) is the braking distance before the tracked vehicle reaches the preview point, and irregular shapes represent the area of obstacles.

The circle where the turning radius is located is tangent to the desired polygonal trajectory. \(d\) can be expressed by Eq.(4)

\[
d = \frac{R_c}{\tan \frac{\alpha}{2}}
\]

The pose tracking error \(E\) is given by Eq.(5) below

\[
E = \begin{bmatrix} X_e \\ Y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} X_d \\ Y_d \\ \theta_d \end{bmatrix} - \begin{bmatrix} \cos \theta & 0 \\ \sin \theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} r_z \left( \frac{\omega_2}{2} \frac{1 + i_2}{1 - i_1} \right) \\ r_z \left( \frac{\omega_2}{B} \frac{1 + i_2}{1 - i_1} \right) \end{bmatrix}
\]

Where \(\alpha\) is the angle of turning point corner, \(B\) is the distance of between the centers of the track on both sides.

The key problem of the motion control of following the desired trajectory can be described as the reasonable selection of when to start to brake and how long to sustain the brake at a certain rotated speed of sprockets. So the vehicle's trajectory is fitted with the desired trajectory, and the pose error \(E\) is continuously decreasing until it converges near the preview point. Combined with the vehicle's operating law and driving experience, the cosine of the angle of deflection is selected as the objective function. This is expressed by Eq.(6)

\[
f(\beta) = \frac{\ddot{u} \cdot \dot{w}}{\|\ddot{u}\|\|\dot{w}\|}
\]

The switching condition of the vehicle’s steering and the direct driving is expressed by Eq.(7):

\[
limit_{\beta=\beta_0} f(\beta) \to k
\]

Where \(\ddot{u}, \dot{w}\) represent relatively heading vector and the vector formed by the real-time position and the next preview point. \(i_t\) is the switching time of any mode in the vehicle motion. \(k\) is the neighbor value of 1. And the closer \(k\) is to 1, the smaller the pose error \(E\) is.
4. Motion control simulation example
In order to prove the effectiveness of the control method of the tracked vehicle proposed above, the polygonal trajectory is designed to realize the motion of the tracked vehicle following trajectory. When the tracked vehicle is turning at a certain speed, the slip/slip rate is usually assumed to be a certain value [15]. The final results of trajectory tracking simulation are shown in Figure 6. The left figure is the diagram of trajectory tracking, in which the polygonal trajectory is desired. And the right figure shows lateral position error. It is obvious that the large lateral position error appears near preview points, especially the error of it is up to 4.5 m when the corner of preview points is the acute angle. And the error of transition phase between preview points within 1.5 meters is quite smaller. The appearance of lateral position error of 4.5 m does not mean that this control method is invalid. This is because the fixed turning radius is limited by the physical structure of the vehicle itself, so some trajectory cannot be tracked accurately at all. Therefore, the requirement is proposed that acute angle in the polygonal trajectory should be as little as possible to make actual trajectory smooth. Perhaps, a sufficient distance between the turning point and the obstacle should be set to ensure that the vehicle can smoothly avoid obstacles, which is fully in line with the driver's driving experience.

The simulation experiment of the tracked vehicle is carried out in the virtual scene through setting obstacle poles with the shape of "工" and applying this kind of motion control method. In the visual scene, it is seen that the tracked vehicle can successfully avoid obstacle poles and reach the expected target position. Adjustment in the position of obstacle poles can provide a reference for the improvement of the driver's driving training method. Autonomous movement of the vehicle is shown in Figure 7.

5. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:
(1) It is shown that sliding mathematical model of the tracked vehicle and 3D solid model of the vehicle and terrain are established, thus the actual turning radius is increased to lay the foundation for the next simulation experiment a certain extent.

(2) Combined with the driver's operating law and driving experience, a new control method of polygonal trajectory tracking based on the preview-following theory is proposed with the sliding parameter to be used as the control input.

(3) Virtual simulation result shows that the tracked vehicle succeed to avoid obstacles and to reach the expected target position within reasonable errors, and the sound, ruts and other rendering effects are added to the virtual scene to meet the immersion and real-time requirements of the virtual simulation system.

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