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Prediction and Evaluation Method of Vehicle Mobility Performance

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Abstract: Predicting and evaluating vehicle maneuverability is an important method to improve vehicle parameters and improve vehicle maneuverability at the beginning of production design; it is also an important reference for users to fully understand vehicle performance and operate rationally according to its performance. This paper firstly introduces the meaning of vehicle maneuverability prediction and evaluation; secondly, by reading a large number of relevant literatures on current maneuverability prediction and evaluation techniques and methods, it expounds its development status, and summarizes and introduces the widely used vehicle maneuverability prediction and evaluation methods, and compared and analyzed the advantages, disadvantages and limitations of each method. Finally, it puts forward some thoughts on the selection direction of wheeled vehicle maneuverability prediction and evaluation methods, which provides a useful reference for the subsequent quantitative research on the prediction and evaluation of the overall maneuverability of wheeled vehicles.

1. Introduction

The research on vehicle maneuverability began in the 1950s, and the military needs of various countries during the Cold War prompted people to gradually increase their attention to issues related to vehicle maneuverability. In recent years, with the vigorous development of military intelligence, mechanization of production and life, and the exploration of space and deep-sea unmanned vehicles, the need for vehicle mobility prediction and evaluation is more urgent.

2. Prediction and Evaluation of Vehicle Mobility Performance

Vehicle mobility can be systematically divided into terrain mobility and ground mobility. Terrain mobility refers to the vehicle's passing ability under terrain conditions such as trenches, slopes, craters, and mud; The maximum speed that can be achieved according to the driver's ability to drive under road conditions such as roads, gravel roads and slag roads, etc. Before leaving the factory, each car will also be accompanied by relevant technical parameters at the beginning of the product design, such as its engine power, maximum vehicle speed, maximum steering angle, fuel consumption per 100 kilometers, maximum travel and acceleration per 100 kilometers, etc. These indicators taken together, it is called the overall maneuverability of the vehicle. The values of these mobility performance indicators are based on tests on ordinary roads, but in practical applications, the vehicle may be driven in various situations, such as country potholes, roads full of dregs, gravel roads and so on. Compared with ordinary roads, the vehicle driving under these road conditions is very different, and the speed and acceleration that can be achieved will be affected to varying degrees. If the vehicle's maneuverability under such road conditions is predicted and evaluated at the beginning of the design, and various parameters such as the vehicle body, suspension, tires, and engine are reasonably designed, the vehicle can exert its maximum efficiency under various working conditions.

The prediction and evaluation of maneuverability refers to the prediction of various road conditions that the product may face in the future during the product design and production stage, through theoretical formula derivation, mathematical modeling analysis or simulation using virtual simulation analysis software, so as to obtain a specific working condition. The concept of maneuvering performance parameters such as maximum speed, minimum turning radius and maximum climbing degree under conditions.

3. Prediction and Evaluation Method of Vehicle Mobility Performance

3.1. Numerical Calculation Method

3.1.1. Maneuverability Prediction and Evaluation Method Based on Cone Index

In the mid-1960s, the U.S. Department of Armament planned to predict the maneuverability of military off-road vehicles. Formulas related to passing capacity and driving resistance under soil conditions and the relationship between hitch traction coefficient and slip rate at a given soil strength condition. Although this method has been widely used, it simplifies the role of tires and road soil when the vehicle is driving on the road, and has great limitations.

3.1.2. Maneuverability Prediction and Evaluation Method Based on the Principle of Ground Mechanics

In order to better express the force relationship between the vehicle and the ground, the instrument developed by Professor Baker from the University of Michigan can measure the relationship between pressure-sinking amount and the shear force-displacement.

The device can measure the resistance of the vehicle, the maximum speed of the vehicle and the traction of the vehicle. However, this method must measure soil properties on-site, which is too dependent, difficult to implement, and cumbersome to operate. Moreover, the ground mechanics principle method does not consider the situation that the vehicle rolls when driving on a three-dimensional road, resulting in inconsistent forces on both sides of the vehicle body. Therefore, the importance of establishing a vehicle-ground space model is self-evident.

3.2. Simulation Analysis Method

In order to more accurately reflect the vehicle-ground interaction, researchers have begun to use simulation technology to predict and evaluate vehicle maneuverability. This method needs to establish two simulation models of vehicle and road respectively, and simulate the driving of the vehicle through the joint simulation of the two.

3.2.1. Establishment of Vehicle Multibody Dynamics Model

Create a vehicle model, including the following two methods:

3.2.1.1 Virtual simulation analysis software

Adams integrates a variety of technologies, and can build a simple linkage model, vehicle subsystem model and simple vehicle assembly model and simulate its motion process.

Figure 1 below shows a simple independent suspension model built using the command browser in the toolbar in Adams/view, including tires and a spring damping system.

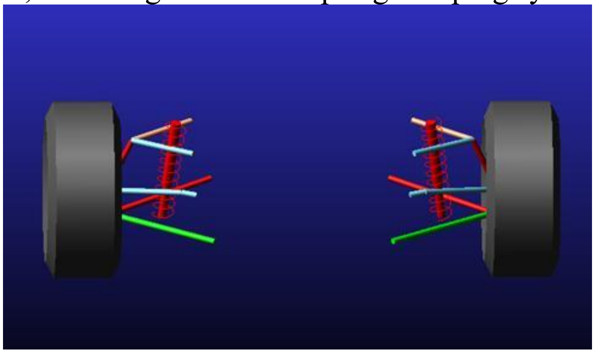

Figure 1: Double wishbone independent suspension constructed by Adams

3.2.1.2 3D drawing software

Software such as AutoCAD, CATIA and Solid Works. The vehicle model established by solid works software is shown in Figure 2 below:

Figure 2: Solid works wheeled vehicle model

Cheng Hongjie et al. [1] established a refined vehicle dynamics model including braking system, suspension system, steering system, etc. through the Adams/car module. The thinking of braking optimization problem of special vehicles is expanded and explored. Shang Xiwen et al. [2] used Adams to establish a simplified vehicle model, and carried out driving simulation on the B-level road surface, which provided a model for subsequent researchers to collect vibration signals of driving vehicles. Li Jiang et al. [3] established the suspension model through Adams, and obtained the optimal design scheme of the suspension hard point coordinates through the design variable method. Li Jiasheng et al. [4] established a multi-body dynamics model of a wheeled vehicle chassis, and combined with the roadblock impact test to verify the accuracy of the model. The results show that the model has high reliability.

3.2.2. Modeling and Simulation of Random Pavement Model

The construction of the pavement model is a key part of realizing the mobility simulation, and it is very important for the prediction and evaluation results of the final mobility. Three-dimensional random road roughness generation includes the following methods: harmonic superposition method and input method based on white noise.

The harmonic superposition method uses the cosine function to fit the road roughness, and the road power spectral density formula is:

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-w} \quad (1)$$

The above formula: n_0——reference spatial frequency, take 0.1m-1;$G_q(n_0)$ is the power spectral density of the road surface under the condition of reference spatial frequency;w——frequency index, usually = 2;n——effective spatial frequency, bandwidth range $[n_1, n_2]$. The variance of road roughness within the bandwidth is:

$$\sigma_q^2 = \int_{n_1}^{n_2} G_q(n)dn \quad (2)$$

Discretize the integral, dividing $[n_1, n_2]$ into small intervals,$\Delta n_i \ \ i = 1,2, \cdots m$.

$$\sigma_q^2 \approx \sum_{i=1}^{m} G_q(n_{mid,i}) \cdot \Delta n_i \quad (3)$$

The above formula:$n_{mid,i}$- the center frequency. The relationship between the longitudinal displacement of the pavement and the random displacement of the pavement elevation obtained by the superposition of sine waves in the small interval is as follows:

$$q(x) = \sum_{i=1}^{m} \sqrt{2G_q(n_{mid,i})\Delta n_i} \sin(2\pi n_{mid,i} x + \theta_i) \quad (4)$$

The above formula:x-the longitudinal displacement of the road surface;θ_i-a random variable on $[0, 2\pi]$.

The above formula establishes a two-dimensional random road surface. In order to obtain a three-dimensional random road surface, the formula is extended:

$$q(x, y) = \sum_{i=1}^{m} \sqrt{2G_q(n_{mid,i})\Delta n_i} \sin(2\pi n_{mid,i}\sqrt{x^2 + y^2} + \theta_i(y)) \quad (5)$$

In the above formula: y represents the random lateral displacement of the road surface, and $\theta_i(y)$ represents the random number $[0, 2\pi]$ corresponding to a row of y.

The national standard GB7031-87 road grade standard divides the road into eight grades, as shown in Table 1:

Table 1: Classification of national standard pavement grades

Road Grade	$G_q(n_0)$ Geometric mean of road roughness	Rms value σ_q Root mean square value of road unevenness
A	16	3.81
B	64	7.61
C	256	15.23
D	1024	30.45
E	4096	60.90
F	16384	121.80
G	65536	243.61
H	262144	487.22

The numerical value and distribution of three-dimensional random pavement vertical elevation with longitudinal extension and lateral variation are obtained through Matlab programming. Figure 3 below shows the Matlab three-dimensional random pavement unevenness distribution.

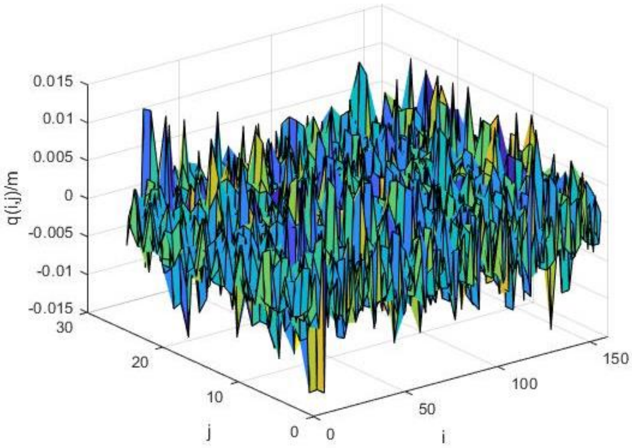

Figure 3: Random roughness distribution of grade B three-dimensional road surface

Import the data into the Adams pavement file to generate a visual 3D random pavement of the corresponding grade. As shown in Figure 4, it's a random road surface of class B.

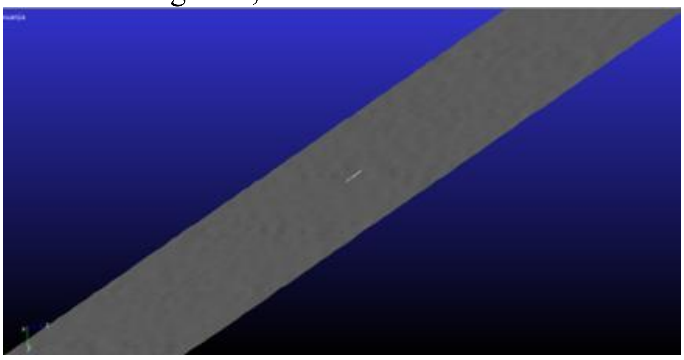

Figure 4: B-level random pavement generated after importing Adams

Nie Yanxin et al. [5] used the AR model method to verify the correctness of the harmonic superposition method. Huang Zhiqiang et al. [6] extended the two-dimensional random road surface to generate a three-dimensional random road surface and visualized it, which proved the effectiveness of the road surface. Although this method can generate an effective three-dimensional random road surface, it has high requirements for space division in the application process. If it is too small, the result error will be large, and it is difficult to obtain accurate road roughness; if it is too large, the running time of the program will be greatly prolonged.

3.2.3. Modeling and Simulation of Granular Soil Model

The establishment of random road surface does not consider the interaction between vehicle tires and ground soil particles. It can only judge the driving and passing conditions of vehicles on a certain level of road surface. Based on this, finite element analysis and discrete element analysis are used to establish a soil model. - Soil co-simulation can more accurately judge the passing performance of vehicles.

3.2.3.1 Soil model based on finite element analysis

Finite element analysis decomposes a body system into multiple, finite number of interacting points, hence the name finite element. Using finite analysis of soil structure, it is approximated as a continuum, which can simulate the resistance and passing capacity of simulated vehicles when driving on soil. [7] Finite element analysis software such as ANSYS LSDYNA, ABAQUS, PAM-CRASH, etc. can be used to simulate the interaction between vehicle tires and soil pavement. Ragheb et al. [8] used PAM-CRASH to simulate the relationship between tires and soft soil. Shoop etal. [9,10] used finite element analysis to establish a model of the interaction between the tire and the soil, and explained the deformation of the soil when the two interacted. However, this method is still difficult to effectively represent the separation, flow and attachment of soil. Based on this, Wright etal.[11] carried out a study on the interaction between tires and non-cohesive soil, and successfully simulated the interaction between the two using the LSDYNA analysis software, but there are also certain limitations, which cannot explain the friction force of the solid boundary. Effect. This is one of the key research directions in the future.

3.2.3.2 Soil model based on particle model

Although the above methods can simulate soil deformation, the soil is a structure composed of many fine particles, and there is a certain interaction between the particles, which affects the passing ability of vehicles. Based on this, the researchers developed a granular soil model. Figure 5 below shows the force model between soil particles. [12]

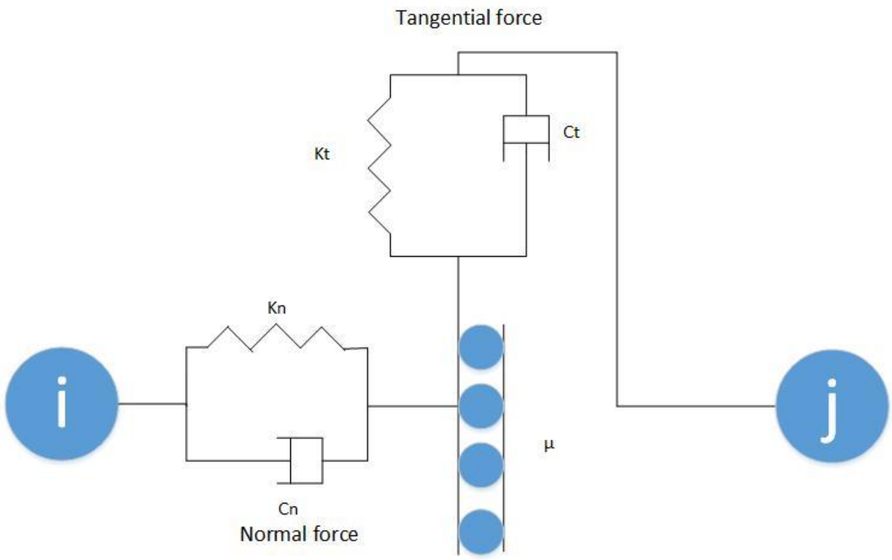

Figure 5: Model of soil particle interaction

The granular soil model has been developed to simulate vehicle-ground interaction, and has included many methods: discrete element method, smooth particle hydrodynamics method and material point method.

The discrete element method is another platform for decomposing and solving the system after the finite element method, establishing a particle structure model, and analyzing the interaction between particles. The contact force, friction force and elastic force of soil particles should be considered in the discrete element analysis of soil. Smith et al. [13] established the interaction model of rigid wheel and cohesive soil by discrete element method. Wasfy et al. [14-16] proposed a discrete element model that can represent the internal force of the soil, and successfully simulated the driving process of the vehicle on a softer road surface.

In smooth particle hydrodynamics, soil is regarded as interacting particles, and each particle is regarded as an entity with physical quantities such as mass and velocity. By solving the motion trajectory and dynamic equation of these particles, the hydrodynamic characteristics of the soil system can be obtained. The effect of particles in this method is smaller as the distance increases. This concept is called "smooth kernel", and the maximum distance that can act is "smooth kernel radius". Lescoe et al. [17] used PAM-CRASH to simulate the interaction between flexible tires and SPH soil. The SPH soil model can better simulate the flow and deformation of the soil, but the model not only needs to calculate the force between two adjacent particles, but also the interaction between the particles within the radius of the smooth core needs to be calculated, resulting in the calculation speed is slower.

The material point method is a numerical method jointly proposed by Sulsky and Chen in 1994. It uses particle discrete matter, and the particle has mass. It uses the background grid to calculate the spatial derivative and momentum equation, and combines the advantages of Euler and Lagrangian methods. It is suitable for solving materials and systems with large deformation and fracture, and it is suitable for simulating soil terrain with large deformation.

Through the comparison of soil modeling analysis before and after this section, the soil model based on particle modeling is better than the finite element analysis soil modeling based on grid, its calculation accuracy is higher, the calculation cost is relatively low, but the calculation speed is slow.

3.3. Machine Learning Methods

The method based on numerical simulation relies too much on the high-fidelity vehicle model and road surface model. As the vehicle mechanism becomes more complex, there are too many soil particles, and the random road surface is longer and larger, which greatly increases the time cost of modeling and simulation calculation. The model will take a week or a few weeks. In recent years, with the vigorous development of the field of artificial intelligence, researchers have proposed the use of machine learning methods for vehicle maneuverability prediction evaluation to improve the efficiency of vehicle maneuverability prediction evaluation.

Machine learning is one of the most important developments in the field of artificial intelligence in recent years. The idea is to make machines learn to handle things on their own, allowing them to learn to handle complex and heavy tasks from previous experience or data. The most commonly used method for training machine learning is the neural network algorithm.

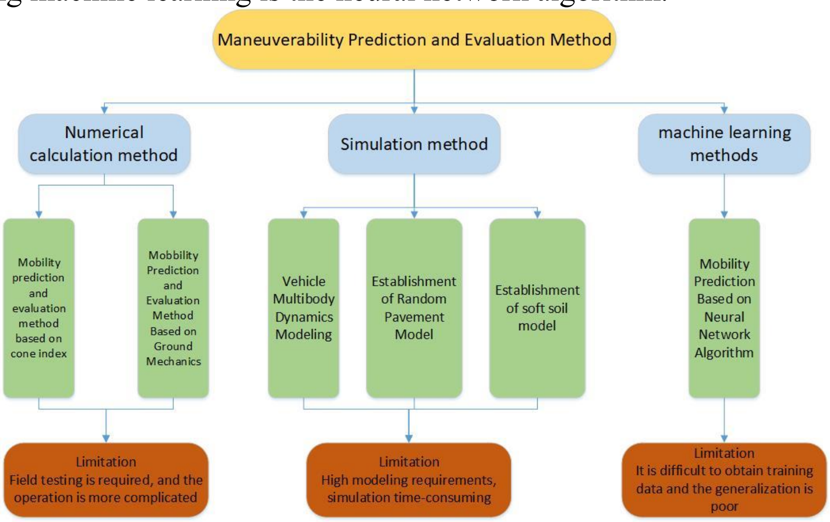

Figure 6: General idea

Mechergui [18] obtained the speed distribution of the vehicle in a mountainous area by using the neural network algorithm combined with the simulation analysis method. However, this method cannot obtain speed data in real time, and can only predict and evaluate the maximum speed of the vehicle. Chen et al. [19] established a hierarchical multi-scale off-road vehicle maneuverability prediction and evaluation model. By inputting terrain factors at the previous moment, the neural network outputs the ground-vehicle interaction at the next moment, which greatly shortens the simulation time. However, it is necessary to establish a mobility prediction and evaluation model in the simulation software in advance to simulate the interaction between the ground and the vehicle when the vehicle is traveling in various states. It is difficult to obtain data before using the neural network algorithm.

This section mainly summarizes the maneuverability prediction methods and the advantages and disadvantages of each method, and expounds the application prospects of related methods. The general idea is shown in Figure 6 below.

4. Conclusions

To sum up, the previous studies on the prediction and evaluation of vehicle maneuvering performance have considered relatively single maneuvering performance indicators. For example, the cone index method only predicts the passing ability of the vehicle; the ground mechanics only predicts the speed, traction and slip rate, etc.; the simulation method only considers the maximum speed of the vehicle, and the passing ability is not enough to indicate the overall mobility of the vehicle; machine learning. The method is based on the simulation analysis method, and the result is only whether the regional velocity is passable or not. The maneuverability of a single vehicle should include the minimum turning radius, maximum travel, maximum speed, maximum average speed, acceleration, trench width, etc. In the future, quantitative evaluation research on the above maneuver performance indicators can be carried out to make the evaluation results more intuitive.

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