IDENTIFICATION AND VERIFICATION OF VEHICLE DRIVE AND STEERING PERFORMANCE

Baoquan Zhu\textsuperscript{1,a}, Ying Lin\textsuperscript{2,b}, Qiang Zhao\textsuperscript{3,c}, Ying Du\textsuperscript{4,d}, Lele Yu\textsuperscript{5,e}

\textsuperscript{1}Traffic Institute, Northeast Forestry University, Harbin, China
\textsuperscript{2}Traffic Institute, Northeast Forestry University, Harbin, China
\textsuperscript{3}Traffic Institute, Northeast Forestry University, Harbin, China
\textsuperscript{4}Technical Automotive Centerline, Dongfeng Group, Wuhan, China
\textsuperscript{5}Technical Automotive Centerline, Dongfeng Group, Wuhan, China

\textsuperscript{a}zbq@nefu.edu.cn, \textsuperscript{b}18846928717@163.com, \textsuperscript{c}ddu0066@163.com, \textsuperscript{d}1194607606@qq.com, \textsuperscript{e}yulele96@163.com

Abstract. Through the analysis of vehicle driving characteristics and steering dynamics, the system identification of vehicle driving performance and steering performance and the identification of driver types are obtained. Using MATLAB software, by analyzing the relationship between speed and engine speed, the specific gear selected by the driver at a certain time is determined, and the throttle percentage and speed amplitude-frequency characteristic curve of the gear are estimated by TTESTIMATE. The driving characteristics of each gear of the experimental vehicle are obtained. According to the values of steering wheel angle, vehicle lateral acceleration and real-time speed, the corresponding law of vehicle lateral acceleration changes and steering wheel angle changes under different speed is obtained by using transfer function identification.

1. Introduction

In recent years, vehicle modeling research has been the focus of traffic safety research at home and abroad. The 2-DOF model and the 3-DOF model are the most typical models\textsuperscript{[1]}. With the further study of dynamic modeling, the model is extended from linear to nonlinear while increasing the degree of freedom of the model. The mentioned vehicle modeling belongs to theoretical modeling. The simplified theoretical model often needs to simplify and adjust the parameters, which is laborious and ineffective. As a more accurate forward modeling method, multi-body dynamic model is widely used, but there are many parameters of mechanical and mechanical characteristics of components needed for modeling. Identification modeling methods can help engineers and researchers to obtain concise mathematical models at lower cost from test data, which can be used for model-based control system design, system performance prediction analysis and improvement guidance\textsuperscript{[2-5]}. In the traditional modeling and simulation research, the vehicle is only used as an independent individual to study its dynamic characteristics, and the driver's style is not considered.

2. Identification of Vehicle Driving Performance Based on Operation Data Acquisition

In order to identify the vehicle driving performance, it is necessary to obtain the vehicle dynamics model analysis and the force analysis of the driving force, as well as the driving performance under different
gears. When it is in different driving condition, vehicle driving resistance analysis is different. In addition, because of the nonlinear relationship between speed and transmission / braking torque, the system model is very complex. Therefore, the dynamic response characteristics of vehicles are studied from the point of view of "operator behavior-vehicle-response" by using the method of system identification. Because of the short duration of braking process and the low sampling frequency, it is impossible to eliminate the constant speed of brake pedal in the working process, so the acceleration performance is mainly analyzed.

2.1. Data Acquisition and Processing of Driver Performance

This experiment mainly uses the OBD interface equipment to collect the vehicle operation data parameter; the test section is the Harbin city road section; the vehicle is Yutong ZK6127H19 bus; the vehicle driving data is obtained by the management platform. The basic performance of the vehicle and the driver's behavior can be obtained by analyzing the vehicle driving data. Table 1 is a partial data used in the experiment. The altitude in the table is the vertical height beyond sea level; the speed is the running speed of the vehicle at this time. When the clutch state is TRUE, the clutch is separated and the FALSE is the joint state; when the brake state is TRUE, the brake pedal operates.

![Table 1: Vehicle Driving Data](image)

The obtained longitudinal vehicle operation data are screened out the input / output variables of the longitudinal dynamic identification system. The longitudinal dynamic model is analyzed as follows: the throttle percentage is selected as the input variable and the speed is selected as the output variable when the throttle pedal is pressed. The relationship between the initial input and the final output is analyzed to obtain the transfer function. By obtaining the ratio of speed to engine speed, the image of the transmission ratio can be obtained by MATLAB. Therefore, we also need to consider the variable speed in the acceleration process. To sum up, throttle percentage, speed and rotation rate should be screened in the analysis of acceleration performance. In this experiment, the analysis of gear needs to do approximate analysis of speed and speed ratio, and eliminate the corresponding term of zero speed. Some tables after removing and replacing singular items in the data are as follows:

![Table 2: Selected tables after removal and replacement of singular items in data](image)
In order to reduce the interference of noise to the experiment and improve the smoothness of the image of amplitude-frequency response, smooth function is used to smooth the data. Concrete smoothing method selects the effect of sgolay, Savitzky-Golay smoothing filter. The smooth function is called in the MATLAB software for smoothing, and the calling command is:

\[ Z = \text{smooth}(Y, \text{span}, \text{method}) \]  

Where \( Z \) refers to the smooth data, \( Y \) to the smooth data, the \( \text{span} \) is the number of smooth points, \( \text{method} \) is the smoothing method.

2.2. Vehicle Driving Performance Identification

In analyzing the driving performance of the vehicle, the transmission loss of the vehicle should be considered. The result of the final speed can be reflected by the vehicle operation parameters, and then the system identification can be made according to the analysis of the initial throttle percentage, which can make the mathematical model more accurate.

From the point of view of force motion, because the quality factor is related to the working gear, the output input variables under each gear can be screened, the mathematical model of driving performance under each gear can be obtained, and the driving performance under each gear can be analyzed [6].

By using the ratio of speed to rotation rate, the transmission ratio image is obtained by using MATLAB image drawing, and then the specific gear selected by the driver at a certain time is determined. Apply the smooth function to remove the noise of the original data when drawing the image. The longitudinal axis is an approximate value, and the gear ratio is drawn as the image 1 approximately.

![Figure.1 approximate drawing of gear ratio](image)

From the gear ratio approximate drawing image analysis, we can see that from the bottom up, the dense area data is corresponding to 1st to 6th gear of data. But in the actual process, the 6th gear can’t be actually reflected. Figure 2 shows the corresponding area of the gear data.

![Figure.2 Regional map for each gear](image)

The fluctuation degree of selected data is 20%, We can screen out the corresponding data by MATLAB:

The 1st gear selection data: \(0.006*(1-0.2) \leq x_1 \leq 0.006*(1+0.2)\)
The 2nd gear selection data: $0.01*(1-0.2) \leq x_2 \leq 0.01*(1+0.2)$
The 3rd gear selection data: $0.016*(1-0.2) \leq x_3 \leq 0.016*(1+0.2)$
The 4th gear selection data: $0.026*(1-0.2) \leq x_4 \leq 0.026*(1+0.2)$
The 5th gear selection data: $0.04*(1-0.2) \leq x_5 \leq 0.04*(1+0.2)$
The 6th gear selection data: $0.06*(1-0.2) \leq x_6 \leq 0.06*(1+0.2)$

Table 3 shows the data of speed and throttle at some gears.

| First gear | Speed (km/h) | Throttle Percentage (%) | Second gear | Speed (km/h) | Throttle Percentage (%) | Third gear | Speed (km/h) | Throttle Percentage (%) | Fourth gear | Speed (km/h) | Throttle Percentage (%) | Fifth gear | Speed (km/h) | Throttle Percentage (%) |
|------------|--------------|-------------------------|-------------|--------------|-------------------------|------------|--------------|-------------------------|------------|--------------|-------------------------|------------|--------------|------------------------|
| 6          | 4            | 9                       | 16          | 17           | 16                      | 26         | 70           | 50                      | 70         | 50           | 40                      | 50         | 63           | 34                      |
| 7          | 10           | 10                      | 8           | 21           | 52                      | 31         | 39           | 58                      | 60         | 60           | 12                      | 28         | 52           | 22                      |
| 8          | 8            | 30                      | 9           | 25           | 54                      | 32         | 41           | 61                      | 63         | 63           | 20                      | 32         | 54           | 19                      |
| 9          | 50           | 10                      | 26          | 26           | 57                      | 32         | 31           | 61                      | 52         | 52           | 12                      | 28         | 44           | 22                      |
| 5          | 34           | 12                      | 28          | 23           | 44                      | 32         | 40           | 62                      | 59         | 59           | 12                      | 28         | 59           | 12                      |
| 8          | 39           | 13                      | 19          | 24           | 43                      | 33         | 41           | 61                      | 40         | 40           | 13                      | 19         | 40           | 13                      |
| 5          | 4            | 13                      | 4           | 26           | 44                      | 33         | 36           | 59                      | 50         | 50           | 13                      | 19         | 50           | 13                      |
| 8          | 47           | 13                      | 9           | 26           | 36                      | 33         | 32           | 59                      | 70         | 70           | 13                      | 36         | 32           | 13                      |
| 9          | 43           | 13                      | 40          | 27           | 50                      | 33         | 10           | 60                      | 44         | 44           | 13                      | 40         | 44           | 13                      |

The amplitude-versus-frequency curve of throttle percentage and speed are estimated by TFESTIMATE. The amplitude-versus-frequency curves of each gear are as follows:

Figure 3 Amplitude-versus-frequency curve of the 1st gear

Figure 4 Amplitude-versus-frequency curve of the 2nd gear
The transfer function model of throttle opening and speed can be obtained. The transfer functions of one to five are as follows:

The 1st gear transfer function is: \( G_1 = \frac{0.6149}{90.63 + s} \)

The 2nd gear transfer function is: \( G_2 = \frac{13.97 + s}{0.8701} \)

The 3rd gear transfer function is: \( G_3 = \frac{8.715 + s}{1.1290} \)

The 4th gear transfer function is: \( G_4 = \frac{4.8145 + s}{17.5} \)

The 5th gear transfer function is: \( G_5 = \frac{0.8387 + s}{1} \)

Through the transfer function of each gear can make the bode diagram to analyze its amplitude-frequency characteristics, the bode diagram is as follows:
Drive performance analysis can be done by bode diagram:

(1) As the gear increases, the speed response gain to the accelerator pedal position increases. The speed gain of low speed gear has little change from one gear to the second gear, and the speed gain is obvious when it is at high speed gear.

(2) With the increase of gear, the delay of each gear is increasing, when it is the 5th gear, the delay is more obvious. The experimental data are operating vehicle operation data, the acquisition frequency is 3, when the sampling frequency is different, the value of delay factor will be different, but the trend is the same.

3. Vehicle Steering Performance Identification Based on Operation Data Acquisition

The steering input of the vehicle has angle input and force input. In this experiment, angle input is mainly selected. The reason why the lateral acceleration is used as the output variable is that the lateral acceleration and the yaw velocity are the most important physical quantities to describe the lateral motion of the vehicle, and the lateral acceleration can also represent the yaw velocity [7-11].

3.1. Acquisition and processing of lateral dynamic data

This experiment is analyzed by the real car experiment. The experimental section is the urban road section in Harbin. The experimental equipment is installed on the Olande 2019. The specific steering wheel angle data are obtained by experimental equipment ID, and a visual platform can be obtained by using Visual Basic software to develop the upper computer program.

The sampling frequency is 20-100Hz. Because the data are taken as the vehicle operation data, the speed section is limited because of the driver's safety considerations. The data collected are as follows:

| Velocity (km/h) | Steering wheel angle (°) | X axis angle (°) | Y axis angle (°) | Z axis angle (°) | X axis acceleration (m/s²) | Y axis acceleration (m/s²) | Z axis acceleration (m/s²) |
|----------------|--------------------------|-----------------|-----------------|-----------------|---------------------------|---------------------------|---------------------------|
| 15             | -18.5                    | -0.313          | 1.472           | 0               | -0.03                     | -0.01                     | 1.06                      |
| 13             | -18.1                    | -0.313          | 1.472           | 0               | -0.03                     | -0.01                     | 1.06                      |
| 14             | -21.5                    | -2.373          | -1.132          | 0               | 0.02                      | -0.05                     | -0.02                     |
| 15             | -27.5                    | -2.373          | -1.132          | 0               | 0.02                      | -0.05                     | -0.02                     |
| 16             | -26.7                    | -2.373          | -1.132          | 0               | 0.02                      | -0.05                     | -0.02                     |
| 17             | -25.6                    | -3.554          | -0.049          | 0               | 0.03                      | -0.06                     | 0                         |
| 18             | -24.6                    | -3.554          | -0.049          | 0               | 0.03                      | -0.06                     | 0                         |
The steering wheel rotation angle is chosen as the input data and the lateral acceleration is used as the output data for the system identification of steering performance analysis. Because the speed has an effect on the lateral acceleration, the speed is also selected as the intermediate variable to analyze the steering performance of the vehicle. When the speed is 0-10 km/h, it can be regarded as moving car in parking lot, stopping in and out of storage, etc. When the speed is 10-60 km/h, it can be regarded as a vehicle driving in the city and turning at a road change or intersection. The data sections for the combination of driving safety and actual road driving selection are 10-20 km/h, 20-30 km/h and 30-40 km/h. The speed, steering wheel angle and lateral acceleration data are shown in Table 5:

| Speed (km/h) | Steering wheel corner (°) | Lateral acceleration (m/s²) |
|--------------|----------------------------|----------------------------|
| 10-20        | -603.0                     | 0.0340                     |
| 10-20        | -598.8                     | 0.0230                     |
| 20-30        | 424.0                      | 0.0650                     |
| 20-30        | 420.1                      | 0.0620                     |
| 30-40        | 378.9                      | 0.0248                     |
| 30-40        | 380.1                      | 0.2390                     |

### 3.2. Vehicle steering performance identification

In the analysis of vehicle steering performance, the analysis method of driving performance, that is, frequency domain response method, is also considered. For safety reasons, the driving speed should not be too high, so the maximum driving speed should not reach 50 km/h.

The collected data are divided into 10-20 km/h, 20-30 km/h and 30-40 km/h according to different speed. When analyzing the steering performance of the vehicle, the relationship between steering wheel angle input and lateral acceleration output is considered. The amplitude-frequency response of different speed segments is as follows:

![Figure 9 Lateral amplitude-frequency response of 10-20m/s](image)
The approximate transfer function is obtained by the amplitude-frequency response of each speed segment:

\[
G_1 = \frac{0.0006824s + 1.008 \times 10^{-5}}{16.16s + 1}
\]

\[
G_2 = \frac{0.003064s + 2.278 \times 10^{-5}}{14.24s + 1}
\]

\[
G_3 = \frac{0.008869s + 4.578 \times 10^{-5}}{1.309s + 1}
\]

To facilitate the distinction between steering performance transfer function when the selection of transfer function \(G_6\) to \(G_8\), according to each speed segment transfer function diagram as shown in figure 12:

Figure 12 Bode under each speed section

To sum up, we can draw the following conclusions:

1. When the speed is between 10-20 km/h, 20-30 km/h and 30-40 km/h, the lateral acceleration (the gain) increases with the increase of the speed segment.
(2) With the increase of the speed segment, the lateral acceleration delay is also increasing, that is, 10-20 km/h delay is smaller, 30-40 km/h delay is larger.
(3) Through the transfer function and the instability analysis of the vehicle when the lateral acceleration is 0.4 g, the instability will not occur when the speed is 10-30 km/h, but when the steering wheel angle is more than 591° at 30-40 km/h.

4. conclusions
Based on the frequency domain analysis method, the real-time data of vehicles are collected and processed. The main purpose of this study is to analyze the acceleration performance and steering performance of vehicles during the operation of vehicles. Considering the horizontal and vertical data, the driver's style analysis is carried out. The following conclusions are drawn:
In the driving performance analysis, with the increase of gear, the speed is also increasing. When moving from one gear to the second gear, that is, the speed gain of the low speed gear does not change much, and the speed gain is obvious when it is in the third, fourth and fifth gear of the gear at high speed. Each gear "acceleration- throttle percentage" relative speed change trend and the existing dynamic simulation model obtained the same results. In the analysis of steering performance, the lateral acceleration increases with the increase of the speed segment, that is, the gain increases, and the lateral acceleration delay increases with the increase of the speed segment. The variation trend of "lateral acceleration-rotation angle" with the speed is consistent with the existing dynamic simulation model.

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