Study on the Design of The Railway Vehicle Running Control System Based on the Virtual Reality Technology

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Abstract

Virtual reality technology is a computer system that can construct a virtual world and achieve the actual experience by wearing the related devices. The core idea of virtual reality technology is to form a virtual environment by using the computer and build the interactive three-dimensional dynamic scenario with the multi-source information fusion and the system simulation of physical behaviors, so that the user can be integrated into the more real environment. Virtual reality technology has wide application prospect in medical, entertainment, military, aerospace, design, industrial and transportation fields. In the railway vehicle running control, virtual reality technology has the problems by itself, and there is little application and study on virtual reality technology in the railway vehicle running control, so there is still certain difficulty for the use of virtual reality technology in the railway vehicle running control. Therefore, in this article, the railway vehicle running control system based on the virtual reality technology has been deeply studied, which has played a lesson and reference role in the application of virtual reality technology in the railway vehicle running control system.

Keywords: Virtual Reality, Railway Vehicle, Running Control System.

1. STUDY OVERVIEW

1.1 Study background

Railway is the important transport infrastructure and is also the main artery of national economy and the public means of transportation, playing an important role in mobilizing economic development in the surrounding area, promoting the economic prosperity and constructing the harmonious society. High emphasis is laid on the railway construction in China, and after the development for years, the railway undertaking has achieved far-reaching progress. But there is still large gap between railway transportation capacity and the passenger transportation and freight transportation, and a large amount of cargoes cannot be transported every day, while during the Chinese Spring Festival, May 1st (International Labor Day) and October 1st (National Day), there is the peak period for railway transportation, easily resulting in the problem of being difficult to get one ticket. To address the relative deficiency of the transportation capacity, it is possible to construct the virtual railway vehicle running control environment by using the virtual reality technology, so that the researchers can have deeper understanding of the vehicle running, construction and dynamic performance, thus effectively correcting the design defects, and building the railway tracks with higher safety, economy, controllability and high efficiency, and effectively improving the development level of the railway undertaking in China.

1.2 Literature overview

In the railway transportation, the virtual reality technology is used in three aspects, first, virtual design, that is, track design, rail transit vehicle design and rail transit environment design; second, virtual assembly, that is, guaranteeing that the design and equipment of the rail transit vehicle shall comply with the hydrodynamic and engineering mechanic requirements, facilitate the check of the compatibility and consistency of the accessories, and improve the design and assembly level of the rail transit vehicle; third, virtual running, that is, before the rail transit vehicle is put into use, virtual reality technology is used for simulation, with analysis on the change status of the railway body and the components in the environment, check the operability of the train, and thus improve the running level of the railway vehicle (He and Zhou, 2016). With virtual reality technology, the researchers can intuitively present the infrastructure, such as station, line and signal, and the actual conditions in the driver cabin, thus realizing the remote observation of the train running effects. Besides, the researchers can analyze the indexes, running status, dynamic properties and passenger comfortability in the train running.
resolve the problems appearing in the train running in a timely manner, and thus effectively improve the construction level of the train (Zhang and Rong, 2016). With virtual reality technology, the railway vehicle running simulation system is built, which can on one hand, provide richer data for the researchers, intuitively reflect the vehicle running, help the designer in the analysis, judgment and design modification, and effectively improve the railway vehicle development and performance; on the other hand, the vehicle running simulation system based on virtual reality technology has high reality and restorability, having provided new method for the simulation exercise of the transportation departments of the train and light rail (Yi and Nie, 2016).

2. VIRTUAL REALITY MODELING OF THE RAILWAY VEHICLE AND ITS RUNNING SCENARIO

2.1 Composition of railway vehicle

2.1.1 Overall composition of railway vehicle

After the development for years, great transformation has taken place on the shape and structure of the railway vehicle, with the addition of multiple functions, but the basic structure is still composed of the following aspects,

First, vehicle body. The vehicle body is the overall structure of the railway vehicle, and is also the important basic part connected with other parts. The body of the railway vehicle is mainly made of light metal or steel structure, and there is the underframe in the bottom of the vehicle body, and it is possible to choose whether to add the end wall, side wall or vehicle top according to the need.

Second, bogie. Bogie is situated in the running part of the railway vehicle, between the vehicle body and the track, not only capable of guiding the railway vehicle for normal run in the track direction, but also capable of having the buffering effect on the load undertaken by the vehicle, being the key to guarantee the stable and normal operation of the railway vehicle.

Third, braking device. Braking device is the key device guaranteeing the normal running and accurate parking of the railway vehicle. Different from the common vehicles, the railway vehicle has high speed and high weight, and due to the influence of inertia, there will be retained with a very long brake space. Therefore, to guarantee more accurate brake of the railway vehicle, it is required not only to install the braking device in the locomotive, but also to install the braking device in every coach, thus realizing accurate braking of the railway vehicle (Zhang, 2016).

Fourth, connecting and buffering device. Connecting device also refers to the device linking every coach in certain distance in the railway vehicle, thus having the buffering effect on the impact and longitudinal force produced during the running and braking of the coaches of the railway vehicle.

Fifth, the devices in the vehicle. The devices in the vehicle mainly serve the tourists and railway vehicle management personnel, such as electrical, water supply, heating, ventilation, air-conditioning, seat, sleeping berth, and luggage carrier and so on. Different railway vehicles have different functions, and thus have different internal devices. For example, the passenger trains will provide the passengers with many resting places, and have relatively high comfortability, while the freight trains are required to provide the storage and cold storage devices, to guarantee safe transportation of the cargoes (Wang et al., 2016).

2.1.2 Railway vehicle characteristics

According to the functions, the railway vehicles are mainly classified into passenger car and freight car. The passenger cars mainly include semi-cushioned seat coach, cushioned seat coach, semi-cushioned berth sleeping car, cushioned berth sleeping car, dining car and baggage car, while freight cars mainly include flat car, gondola car, boxcar, tank car, side dump car, hopper car, and refrigerator car, as shown in Fig. 1 below.

Railway vehicle generally has the following characteristics,

First, low running resistance. To guarantee high-speed run of the railway vehicle and effectively save the resources, the railway vehicle has generally small running resistance. The resistance of the railway vehicle
mainly comes from the slope, bend, air, track, and bearing. The materials for wheel and track generally has high carbon content, not only being free from deformation in the contact place, but also having relatively low content.

Second, self-guide. With high-speed development of technological level, the railway vehicle has basically reached automatic running, capable of completing the whole running process without needing the manual manipulation by the specified personnel in the most time (Sun and Li, 2013).

Third, running in row. Since the railway vehicle has the above two characteristics, it is possible to realize the different coach marshalling and link the coaches to form the train. Since the railway vehicle has high inertia, it is required to set the braking device in every coach to play the buffering role, so as to achieve accurate braking.

Fourth, strict specifications and dimensions. During the running, the railway vehicle is required to drive according to the designed line and track, with poor flexibility, thus it is impossible to actively avoid the common vehicles. Therefore, before the design of the railway vehicle, it is often required to guarantee the safe run of the railway vehicle by developing the strict skeleton sizes according to the actual situations of the line.

<table>
<thead>
<tr>
<th>Types of freight cars</th>
<th>Physical map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat car</td>
<td><img src="image" alt="Flat car" /></td>
</tr>
<tr>
<td>Gondola car</td>
<td><img src="image" alt="Gondola car" /></td>
</tr>
<tr>
<td>Boxcar</td>
<td>![Boxcar Image]</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Tank car</td>
<td>![Tank car Image]</td>
</tr>
<tr>
<td>Special vehicle</td>
<td>![Special Vehicle Image]</td>
</tr>
<tr>
<td>Refrigerated truck</td>
<td>![Refrigerated Truck Image]</td>
</tr>
</tbody>
</table>

**Figure 1.** Main Types of Freight Trains
2.2 Modeling of the railway vehicle and its environment

2.2.1 Preliminary preparation

To construct the 3D scenario for the running simulation system of the railway vehicle, it is required to collect the information according to the terrain, texture and geometrical space position in the region, as shown in Fig. 2 below.

![Hierarchical Structure Diagram of Railway Vehicle Running Simulation System](image)

**Figure 2.** Hierarchical Structure Diagram of Railway Vehicle Running Simulation System

The railway vehicle running scenarios mainly include the mountain terrain, railway line, railway vehicle and environmental landscape. The railway line includes three parts, first, track, including steel rail, sleeper and ballast bed, second, subgrade, and third, bridge building, including bridge and tunnel. These are the railway building infrastructure. The railway vehicles mainly include the vehicle body, running part, braking device, connecting and buffering device, and internal devices of the vehicle. The environmental landscape includes the station facilities, surrounding trees and buildings and so on (Zhao, 2016)

2.2.2 Subsequent processing

The main work in subsequent processing is the model integration and optimization. Through accurate modeling software and the modeling tool of virtual reality, it is required to construct the scenario in the railway vehicle running simulation system, as shown in in Fig. 3,
Figure 3. Scenario Modeling Process

3. THREE-DIMENSIONAL GEOMETRICAL MODELING OF RAILWAY VEHICLE AND ITS LINE

3.1 Geometrical modeling of railway line

3.1.1 Mathematical model of the railway line

Railway vehicle is the important foundation for the running of the railway vehicle, mainly composed of the subgrade, track and bridge and tunnel building. The track can develop the fixed line of the railway vehicle on one hand, and can undertake the pressure imposed by the railway vehicle on the ground on the other hand, gradually distributing the huge strength produced by the railway vehicle through the ballast bed, sleeper and steel rail within the acceptable range (Hao, 2017).

According to the geographic environment of the steel rail, the steel rail can be mainly classified into three segments, that is, first, straight line, guaranteeing the linear run of the railway vehicle, second, gentle curve, being the relatively gentle slope before the turn, and third, line, round curve, that is, the bend with certain bending degree. Supposing that there is a straight segment with the length of S, the function is shown below,

$$ F(s) = s $$  \hspace{1cm} (1)$$

To solve the expression formula of the gentle curve, it is possible to use the gentle curve parameter equation, with the expression formula given below,

$$ \begin{aligned}
    x &= s - \frac{s^5}{40 \times (RI_0)^2} \\
    y &= \frac{s^3}{6RI_0}
\end{aligned} $$  \hspace{1cm} (2)$$

Where, S represents a point in the gentle curve, $l_0$ represents the length of the gentle curve, and R is the radius of the round curve.
The parameter equation of the round curve is shown below,

\[
\begin{align*}
    x &= x_1 + R\cos\theta \\
    y &= y_1 + R\sin\theta
\end{align*}
\]  

(3)

Where, \( R \) is the radius of the round curve, and \( \theta \) is the turning angle (Xu and Zhou, 2017). So from the above equation, supposing that the starting straight line is \( l_1 \), gentle curve is \( l_2 \), round curve is \( l_3 \) and final straight line is \( l_4 \), it is possible to construct the segmented function for a segment of the line. Suppose that the starting straight line is \( l_1 \), gentle curve is \( l_2 \), round curve is \( l_3 \) and final straight line is \( l_4 \), as shown below,

In case of \( 0 \leq s \leq l_1 \), \( F_1(s) = s \leftrightarrow \begin{cases} \ x_1(s) = s \\ \ y_1(s) = 0 \end{cases} \)  

(4)

In case of \( 0 \leq s \leq l_2 \), \( F_2(s) = \begin{cases} \ x_2(s) = x_1(l_1) + s - \frac{s^5}{(40R^2l_1^2)} \\ \ y_2(s) = \frac{s^3}{(6R^2l_1^2)} \end{cases} \)  

(5)

In case of \( 0 \leq s \leq l_3 \), \( F_3(s) = \begin{cases} \ x_3(s) = x_2(l_2) + R\cos\frac{s}{R} + x_{03} \\ \ y_3(s) = y_2(l_2) + R\sin\frac{s}{R} + y_{03} \end{cases} \)  

(6)

In case of \( 0 \leq s \leq l_2 \), \( F_2(s) = \begin{cases} \ x_4(s) = x_3(l_3) + s - \frac{s^5}{(40R^2l_2^2)\cos\alpha_1} \\ \ y_4(s) = y_3(l_3) + \frac{s^3}{(6R^2l_2^2)\sin\alpha_1} \end{cases} \)  

(7)

In case of \( 0 \leq s \leq l_4 \), \( F_5(s) = \begin{cases} \ x_5(s) = x_4(l_4) + s\cos\alpha_2 \\ \ y_5(s) = y_4(l_4) + s\sin\alpha_2 \end{cases} \)  

(8)

where, \( x_{03}, y_{03}, \alpha_1, \alpha_2 \) are the coordinates and turning angle obtained from the connecting information based on the continuity of the line.

3.1.2 Geometrical modeling of the bridge building

The bridges and tunnels are mainly used in some special geographic environment. To overcome geographic obstacle, shorten the line length and evade the poor geological conditions, the bridge and tunnel construction is relatively complicated, which requires refined modeling for reasonable design and construction, thus improving the bridge and tunnel construction level (Kuang et al., 2015), with the modeling as shown below,
3.1.3 Geometrical modeling of railway vehicle and components

The railway vehicle mainly includes vehicle body, running part, braking device, connecting and buffering device, internal device in the vehicle. The vehicle body is the important basis for the constitution of the railway vehicle, and there is large difference in shape and appearance for the vehicle bodies with different models, types and functions. Besides, different vehicle bodies have great difference in the corresponding parts, such as bogie. Therefore, it is required to make the modeling accordingly for the characteristics. In the vehicle running simulation, emphasis is often laid on the geometrical and running characteristics of the vehicle, which can effectively reduce the resistance of the railway vehicle, improve the performance of the railway vehicle and have relatively small influence on the internal structure and running details, which may be ignored (Sun, 2011). The modeling of the railway vehicle body is shown in Fig. 5.

![Figure 5. Body Modeling of Railway Vehicles](image)

On the whole, the railway vehicle has the streamlined design scheme, which can effectively reduce the resistance produced by the air friction, not only saving the energy by the railway vehicle, but also elevating the running speed of the railway vehicle.

3.2 Virtual reality modeling of railway vehicle

3.2.1 Conversion of mock-up

The models for the aspects of railway vehicle and line are constructed with accurate modeling software Pro/E, including a large amount of precise data and programs, capable of being used in the engineering calculation. To meet the visual experience, virtual reality technology usually is required to construct the surface model, which generally needs the use of Creator software, while the solid model cannot be directly converted with the surface model, which requires the format conversion (Li, 2015). Since in different CAD systems, there is significant difference in the means of describing an object, it is required to construct a clear standard interface, and convert the data packet of multiple CAD systems, and such standard interface is generally reflected in the IGES specification. Thus, it is required to take the IGES specification as the standard, converting 3D solid model into
IGES format, which is then converted by 3DMax software into 3DS format, and then into FLT format, with the result shown in Table 6.

**Table 6 The Conversion between 3d Solid Model and Virtual Reality Model of Some Components**

<table>
<thead>
<tr>
<th>Component name</th>
<th>CAD model</th>
<th>IGES format</th>
<th>3DS format</th>
<th>FLT format</th>
<th>Conversion effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center plate</td>
<td>20838K</td>
<td>3568K</td>
<td>507K</td>
<td>68.7K</td>
<td>good</td>
</tr>
<tr>
<td>Brake shoe</td>
<td>40222K</td>
<td>6524K</td>
<td>896K</td>
<td>154K</td>
<td>Missing presence</td>
</tr>
<tr>
<td>Bolster</td>
<td>243454K</td>
<td>54354K</td>
<td>Cannot</td>
<td>Cannot</td>
<td>Cannot achieve</td>
</tr>
</tbody>
</table>

From the above Figure, it may be known that, though IGES format is the commonest standard with the widest use, it still has some defects. First, in the data conversion format, it requires multiple conversions, which easily result in the problem of the loss of the raw data due to the error (Li and Han, 2015). In many cases, if one or more entities cannot be converted, then the whole figure cannot be converted. For example, the bolster is the device with high precision in the railway vehicle and cannot be converted into 3DS format. Second, in constant conversion of the data format, it is very easy to have the loss of one or more cambers. In case of any loss of the camber, the system will automatically generate new camber according to the original camber boundary, but with relatively low accuracy, difficult to meet the demand of the railway vehicle running control system for accuracy. In addition, IGES format has the problems, for example, the information of two parts and components cannot be systematized, the related attribute information cannot be converted, there is too large data quantity and too dense grate, and too many triangles are generated (Guo, 2011).

3.2.2 Conversion technology based on STL format

At present, there are many problems with IGES format so that it is impossible to completely and accurately define the geometrical information of the entity, and to resolve these problems, it is possible to choose STL file format. The precision of such format is higher than IGES format, and the algorithm is relatively simple, capable of meeting the demand of more users. The conversion of the data format is easier for realization, and the data structure is relatively simple and has high developability. But STL format still has some problems, which is mainly reflected that there is certain difficulty when handling the triangular structure. If STL format is chosen, it is required to guarantee the closure and continuity of the 3D entity in CAD modeling, thus effectively alleviating the defects in STL format, improving the accuracy and usability of the results, and constructing more accurate railway vehicle running control system (Lu, 2010).

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