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Research on Train Visualization of Different Resolution in TCS Simulation

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Abstract

Train control system is to control the velocity and the distance between trains in the railway and to protect the safe and high efficiency of train running. An ideal train control system testing and simulation platform should simulate the real railway operating environment and the train running. There are different requirements for the train visualization in the train control system testing and simulation platform. According to the specific analysis of the train running behavior and multiresolution theory, this paper raised the train visualization modeling of different resolution. Meanwhile the aggregation and disaggregation process between different resolution models were analyzed in detail. After all, the availability of this method was certified by 3D train simulation cases.

Keywords*: train unit; visualization; multiresolution; train control system; virtual environment*

1. Introduction

Train control system, abbreviated as TCS and its task is to control the velocity[1,] and the distance[2] between trains in the railway and to protect the safe and high efficiency of train running[3,4]. The train position is very important in the TCS simulation environment. An ideal TCS testing and simulation platform should simulate the real railway operating environment and study the TCS theory. In testing and simulation platform, different people have the different concern about the train, such as the policymaker and researcher, etc. Therefore, the 3D visualization of train can be separated two aspects.

The one model is the train visualization looking from the view point of driver. This is the main window of TCS visualization, in which the 6 freedom degrees of train can be displayed when a train is running the different place in the railway line, such as the straight line, the curve line or the ramp, etc. This is a visualization based on the detailed resolution that a train can be described by some units.

The other model is the train visualization looking down at high altitude. The tracing situation between trains in railway line can be showed in TCS testing and simulation platform. This is a visualization based on the rough resolution that a train can be seen as one unit.

Hence, in the TCS testing and simulation platform, the train should be described by the different resolution, i.e. the visualization of the train should have the different description. According to the change of view point, the external characteristics that the different visualization model of train are described should keep the consistency. The resolution is the accuracy and the detailed degree that the model describes the real world in the simulation or modeling, which is the common definition of SISO/SIW[5]. The different resolution model should have the relative independent and stable external characteristic. When the resolution described has changed in dynamic simulation, the external state should keep the consistency[6,7]. This paper introduced the multiresolution idea to achieve the train visualization of different resolution in the TCS simulation.

2. The train visualization model of single resolution

The train visualization model of single resolution is the simulation that the whole train is seen a single particle object and the force impacted between the train units is zero. This model

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can describe the motion state of train as a whole running on the railway line, such as the EMU (Electric motor train units) looking down at high altitude.

2.1. The local coordinate system of train

The motion character of train is one of the basic research of train visualization, which is the base of train motion simulation. The local coordinate system of train can be used to analyze the motion character of train in the space.

The hypothesis is that the mass of train focuses on the center of train. This point can be regarded as the origin point of the train coordinate system. The *X* axis is parallel to the ground and the arrow direction is the direction of train running. The direction of the *Y* axis is the left of driver. The *Z* axis is to direct at the sky which stands for the up and down. The coordinate system is shown as Figure 1.

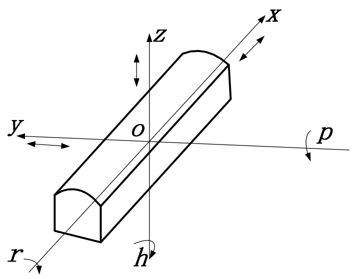


Figure 1 the local coordinate system of train

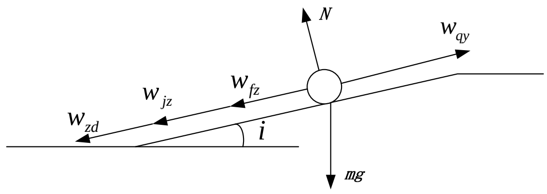


Figure 2 the single particle model of train

Based on this coordinate system, the six freedom degrees of train include the forward and back motion along the *X* axis, the left and right motion along the *Y* axis, the up and down motion along the *Z* axis, and three angles rotated around the three axis, such as the roll angle, the pitch angle and the yaw angle. This six freedom degrees can well describe the motion of train as the rigid body.

As the fast development of computer technology, many researchers have studied the more complicated dynamic model of train for the more accurate description for the operation optimization and the energy saving[8,9], etc. But in this paper, the train control system only pays attention to the position of train in the line, not cares the force between the train units. Therefore, a train is generally regarded as a single particle or the multiple particles in the TCS research.

2.2. The kinetics analysis of train as a single particle

The kinetics model of the single particle regards a train as a single particle and the force between train units can be ignored. The position change of train is based on the traction calculation. The draw-drag model of train as a single particle is shown as Figure 2.

The external forces *W* acted on the train as a single particle include the draw force w_{qy}, the basic drag force w_{jz}, the additional drag force (generated by the curve and the ramp) w_{fz} , the brake force w_{zd}, the part gravity of the train *mg* and the support force from the railway line *N*, etc. And the part gravity of the train and the support force from the railway line are a pair of balance forces. Hence the computation formula of *W* is shown as formula 1.

$$W = w_{qy} - w_{jz} - w_{fz} - w_{zd} \quad (1)$$

When a train is seen as a rigid body, the mass is stable and constant. Hence the external forces relation as formula 1 can be described by the acceleration relation as formula 2.

$$A = A_{qy} - A_{jz} - A_{fz} - A_{zd} \quad (2)$$

Among formula 2, *A* stands for the total acceleration, A_{qy} is the draw acceleration, A_{jz} is the basic drag acceleration, A_{fz} is the additional drag acceleration, A_{zd} is the brake acceleration. Their different states can stand for the different motion of train, such the traction, the brake, the idling, etc. The additional drag acceleration is the proportionate relationship with the ramp, shown as formula 3. Among formula 3, i stands for the gradient of the ramp line, the unit is ‰.

$$A_{fz} = A_{jz} \times i \tag{3}$$

2.3. The train visualization modeling of single resolution

The train visualization modeling of single resolution mainly computes the six freedom degrees of train in the reference coordinate system and achieves the motion simulation that the train runs in the railway line. The position and the poster of train, i.e. the six freedom degrees of the single particle are computed based on the distance that is far from the original point in reference coordinate system and the line situation where the train runs, such as the straight, the curve and the ramp.

1 The computation of the running distance

In the train control system, the position of train can be known by the initial distance *S*, the current velocity of train *V*, and the running time *T*. The distance at *k+1* moment can be expressed as the formula 4. In formula 4, S_k and V_k stand for the distance and the velocity at *k* moment respectively, A_k is the acceleration of train from *k* to *k+1* moment, and T is the running time from *k* to *k+1* moment.

$$S_{k+1} = S_k + (V_k + \frac{1}{2} \times A_k \times T) \times T \tag{4}$$

2 The computation of the train visualization modeling of single resolution

The train visualization modeling of single resolution describes the position and the poster of train in the line when the time and the velocity have changed. The train only runs on the railway line and its running path is the specific path. Hence, the paper here analyzes the change of train position and train poster when the train runs during *T* time and gets the computing formulas of the train visualization of single resolution.

Because the railway is built along the terrain, there are the straight, the curve and the camp. The six freedom degrees of train have changed when the train run from *k* to *k+1* moment.

The hypothesis is that the position of train at *k* moment is described by X_k, Y_k, Z_k, the poster is by H_k, P_k, R_k , the distance is *L* when the train run *T* time from *k* to *k+1* moment, and the six freedom degree Q_{k+1} of train at *k+1* moment are X_{k+1}, Y_{k+1}, Z_{k+1},H_{k+1}, P_{k+1}, R_{k+1}. According to the line situation, the computing formulas of the six freedom degrees at *k+1* moment are shown as following.

1) When the train runs in the straight, the computation is shown as formula 5.

$$\begin{cases} X_{k+1} = X_k + L \times \cos(H_k) \\ Y_{k+1} = Y_k + L \times \sin(H_k) \\ Z_{k+1} = Z_k + L \times \sin(P_k) \\ H_{k+1} = H_k \\ P_{k+1} = P_k \\ R_{k+1} = R_k \end{cases} \tag{5}$$

2) When the train runs in the circle curve, the computation is shown as formula 6. In formula 6, $\pm$ and $\mp$ stand for the situation that the circle curve runs the left or the right.

3) When the train runs the transition curve that is the spiral curve. If the length of the transition curve is *L*, and the radius of the circle curve near the transition curve is *R*, the contingence angle of the transition curve is β, the computation is shown as formula 7. In formula 7, $\pm$ and $\mp$ stand for the situation that the circle curve runs the left or the right.

$$\begin{cases} X_{k+1} = X_k + x \times \cos H_k \pm y \times \sin H_k \\ Y_{k+1} = Y_k + x \times \sin H_k \mp y \times \cos H_k \\ Z_{k+1} = Z_k + L \times \sin(P_k) \\ H_{k+1} = H_k \pm \dfrac{L}{R} \\ P_{k+1} = P_k \\ R_{k+1} = R_k \end{cases} \quad \text{and} \quad \begin{cases} x = L - \dfrac{L^3}{6R^2} + \dfrac{L^5}{120R^4} \\ y = \dfrac{L^2}{2R} - \dfrac{L^4}{24R^3} + \dfrac{L^6}{720R^5} \end{cases} \qquad (6)$$

$$\begin{cases} X_{k+1} = X_k + x \times \cos H_k \pm y \times \sin H_k \\ Y_{k+1} = Y_k + x \times \sin H_k \mp y \times \cos H_k \\ Z_{k+1} = Z_k + L \times \sin(P_k) \\ H_{k+1} = H_k \pm \beta \\ P_{k+1} = P_k \\ R_{k+1} = R_k \end{cases} \quad \text{and} \quad \beta = \frac{L^2}{2RL_s} \qquad (7)$$

In formula 7, x and y are determined by the transition curve. When the transition is connected from the straight to the circle curve, x and y are computed by formula 8

$$\begin{cases} x = L - \dfrac{L^5}{40R^2 L_s{}^2} \\ y = \dfrac{L^3}{6RL_s} - \dfrac{L^7}{336R^3 L_s{}^3} \end{cases} . \qquad (8)$$

When the transition is connected from the circle curve to the straight, x and y are computed by formula 9.

$$\begin{cases} x = L - \dfrac{L^3}{6R^2} + \dfrac{L^4}{8R^2 L_s} + \dfrac{L_s{}^2 - 3R^2}{120R^4 L_s{}^2} L^5 - \dfrac{L^6}{72R^4 L_s} + \dfrac{L^7}{112R^4 L_s{}^2} \\ y = \dfrac{L^2}{2R} - \dfrac{L^3}{6RL_s} - \dfrac{L^4}{24R^3} + \dfrac{L^5}{20R^3 L_s} + \dfrac{L_s{}^2 - 15R^2}{720R^5 L_s{}^2} L^6 + \dfrac{R^2 - L_s{}^2}{336R^5 L_s{}^3} L^7 \end{cases} \qquad (9)$$

When the train runs from k to $k+1$ moment and the ramp of the line has changed, it is paid attention to Z_{k+1} that is computed by the vertical curve and P_{k+1} is computed by the gradient of the ramp line. Here, these formulas are elliptical.

3. The train visualization modeling of multiple resolutions

The train visualization modeling of multiple resolutions considers the whole train as a particle chain with multiple particles. Each train unit is considered as a single particle, and when calculating its force and displacement, each was an independent particle. The train visualization modeling of multiple resolutions is used to describe accurately the running states of train on the different straight/cure line and the ramp sections, when the trains are observed by the view points in the train driver's cab or on the train station, and so on.

3.1. The coordinate relation between train units

In the train visualization model of multiple resolutions, the whole train is considered as multiple particles. Each train unit is a single particle, so every train unit has different spatial positions. Since the length of the train unit is constant, the coordinate relation between different train units is easily achieved, as shown in Figure 3.

3.2. The kinetics analysis of train as the multiple particles

The multiple particles model uses the particle chain to describe the external force of the whole train. Taking the train as a particle chain with multiple particles, the relation between different particles is considered rigid. The train’s running situation is depended on the resultant force of the whole train, as shown in Figure 4.

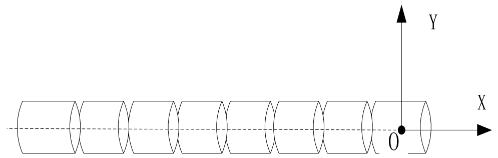


Figure 3. The coordinate relation between each train unit

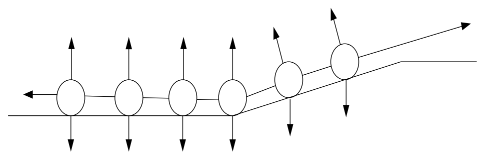


Figure 4. The multiple particles model

The multiple particles model is different from the single particle model. The multiple particle model can calculate the interaction force between each train unit. Because the particle chain with multiple particles was not simplified to the train’s length, the whole force changing process of train can be calculated and displayed when the train runs through the ramp section and the curve line. This gradual changing process is not considered in the single particle model. In addition, the head train unit or the middle train unit could be used as the initial calculation coordinate that the position of other train unit could reference to, on which the train runs through the ramp changing point and the curvature changing point, etc. This paper takes the head train unit as the initial calculation coordinate for the effective transformation to the driver’s view point.

As shown in Figure 4, the multiple particles model can more really reflect the train’s running situation than the single particle model. But the multiple particles model need to take into account the different running conditions of the line, and the computing formulas are very complicated based on the regulation of locomotive traction calculation[10]. The high speed railway is used in recent years, and the Ministry of Railways hasn’t published any regulation about the traction calculation of EMU. Most data have to achieve from the real train test. The EMU is different from the traditional locomotive. It adopts the power dispersion, so that the force between each train unit is different from the draw-drag way of traditional locomotive. When simulating the EMU running situation, it’s more reasonable and more simplify in calculation with the multiple single-particle chain model than the multiple particles model.

The multiple single-particle chain model combines the single particle model with the multiple particles model. It regards the whole EMU as a particle chain with multiple particles, but regards each train unit as a single and independent particle which cannot be affected by other train unit. And when calculating the force and the movement, each train unit’s force is same in one EMU, and the distance between train units is constant, shown as Figure 5.

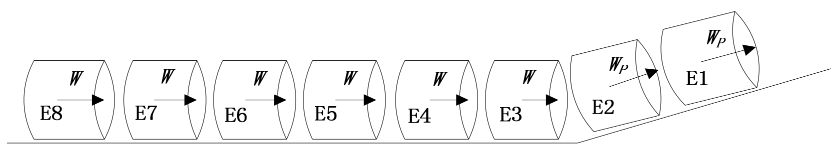


Figure 5. The force analysis of the multiple single-particle chain model

Since each train unit is rigid and independent, it can think that each train unit’s acceleration and velocity are consistent. When calculating the spatial movement of the EMU, it just considers the position relation of each train unit. Thus, the calculation of the EMU visualization model could be greatly simplified. When the EMU runs on the ramp section, it should pay attention to put the gradient information into the force calculation.

4. The aggregation and disaggregation of train visualization simulation

Aggregation/Disaggregation Modeling [11] is one of the most popular multiresolution model, in which the entities keep the interaction in the same level through the disaggregation of the low-resolution model or the aggregation of the high-resolution model. From the point of view of object-oriented, the aggregation is the process that the low-resolution object is taken the place of some objects of high-resolution. The disaggregation is the inverse process of the aggregation, which some objects of high-resolution are described by one object of low-resolution.

4.1. The Aggregation/Disaggregation analysis of train visualization simulation

Train visualization simulation of single resolution is mainly used to observe the operating and control of trains in railway line from the view point of the high altitude. Because the view point always lies at the high altitude, the whole train can be thought as a single particle and described by the rough resolution. But as the view point is nearer and nearer to close to the ground, the whole train should be described by the detailed resolution. When the train is regarded as a single particle, the train visualization will be off the railway line and become an unreal simulation, such as the train at the curve or the ramp, shown as Figure 6(a). Therefore, The whole train should be regarded as a multi-particles chain and each train unit be a single particle. And there is the best train motion simulation at the ramp or the curve, shown as Figure 6(b).

(a) the single particle model (b) the multiple particles model

Figure 6. The change points situation of gradient

Hence when the view point changes from the high altitude to the ground and becomes the view point of driver, the train should disaggregate into the multiple resolution description in which every train unit is the single model. This is a typical example of the aggregation/disaggregation modeling. It is paid attention that the aggregation and the disaggregation are just relative. The train visualization model of single resolution is a disaggregation model when the train is observed through the view point of driver, but it is also an aggregation model when the trains are observed as the train group from the hight altitude.

4.2. The disaggregation process

The disaggregation is the process that the train visualization of single resolution goes to the train visualization of multiple resolution, shown as Figure 7. The information that the train visualization of single resolution includes is different from one of multiple resolution. In the train visualization of single resolution, the whole train is a single particle which is short of the information of every train unit. But the information is necessary in the train visualization of multiple resolution. Hence, EMU in Figure 7 should be disaggregated into E1……E8. The information lacked should be supplemented.

In the visualization simulation of train, the velocity and the position are the main factors that affect the position and the poster of train in the virtual environment, so they are the main factors of train visualization. The following will introduce the disaggregation of the velocity and the position when the train visualization model changes from the single resolution to the multiple resolutions.

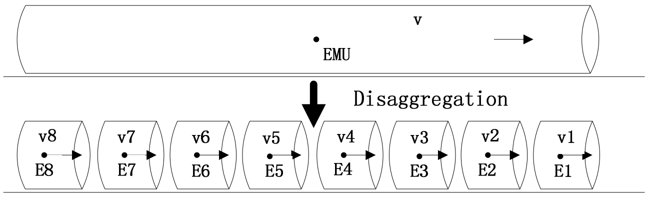


Figure 7. The disaggregation of EMU

1. The disaggregation of position

The six freedom degrees of the train visualization model of single resolution are computed by two parts. Firstly, the distance of train in the line should be computed. Then the position and the poster of train are computed based on the line situation that the train runs from the original point. Hence, the multiple resolution model of train's position disaggregation process is below.

Step1 : To get the distance *S* of train as a single particle in the running line.
Step2 : To get the distance S_1 of head train unit based on the reference coordinate that describes the position relation of every train unit.
Step3 : To judge whether S_1 is located on the straight or the curve, then compute the *X* and *Y* of S_1 point.
Step4 : To get the ramp value of S_1 and compute the *Z* value.
Step5 : To compute the *H, P,* and *R* of S_1 based on the *X,Y,Z*.
Step6 : To put the train model into the relevant position and the poster in the virtual railway scene.
Step7 : To loop Step 2 to 6 until the all units of train have put the right position and the right poster, then exit the disaggregation process.

2. The disaggregation of velocity

The disaggregation of velocity can be described as the following. The hypothesis is that there are the entities $M_1, M_2, \ldots, M_8$ in the train visualization model of multiple resolution. Their velocity are $v_1, v_2, \ldots, v_8$ respectively. The entity *M* of the train visualization model of single resolution is the aggregation of $M_1, \ldots, M_8$ and its velocity is *v*.

An object of low resolution with the velocity can be disaggregated into many objects of high resolution with the different velocity. Hence, the rules of disaggregation should be limited by the constraint condition, otherwise it is meaningless.

Based on the mentioned above multiple single-particle chain model, the disaggregation rule is that every train unit is rigid and independent. Hence the velocity and the acceleration of every train unit is same, then the disaggregation of velocity can be described as formula 10.

$$v = v_1 = v_2 = \cdots = v_8 \qquad (10)$$

4.3. The aggregation process

The aggregation is the process that the train visualization of multiple resolution goes to the train visualization of single resolution, shown as Figure 8. the aggregation is the inverse process of the disaggregation. The aggregation will be used when the observing view changes from the ground to the high altitude.

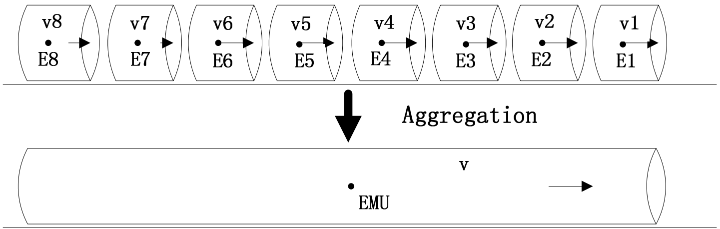


Figure 8. The aggregation of EMU

In figure 8, because the train visualization of multiple resolution belongs to the high-resolution model, the information of model is rich and includes the positions and the velocities of each train unit. Hence this information should be aggregated to the position and the velocity of the train visualization model of single resolution.

1 The aggregation of position

The distance of the train visualization model of single resolution should be gotten through the distance choice of every train unit in multiple resolution model. This value can be computed by the mean of the head unit and the end unit, or the mean of two middle units of train. According to the coordinate system that describes the position relation of every train unit, the EMU is the symmetrical hanging together. Then the particle position of the whole train can be easy to compute. The aggregation of position D_{EMU} can be gotten by the formula 11.

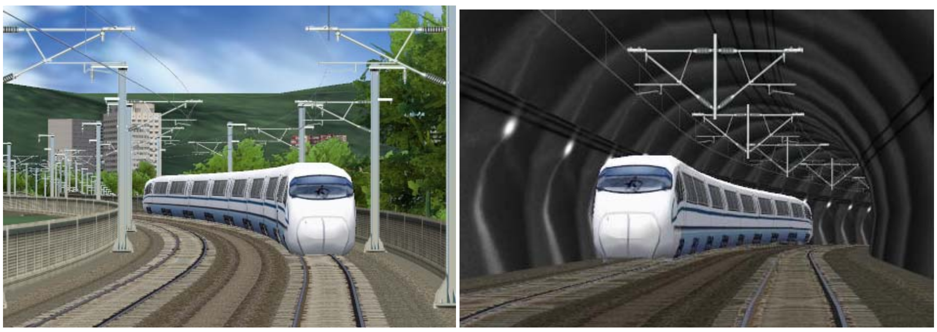
$$D_{EMU} = D_{E5} + \frac{D_{E4} - D_{E5}}{2} \tag{11}$$

The display of train model should be paid attention. Because the multiple resolution model changes to the single one, one train model will replace eight train unit models, so the time of aggregation is very important that the observer cannot find the sudden change of models. If it happens, the reality of train model will be destroyed.

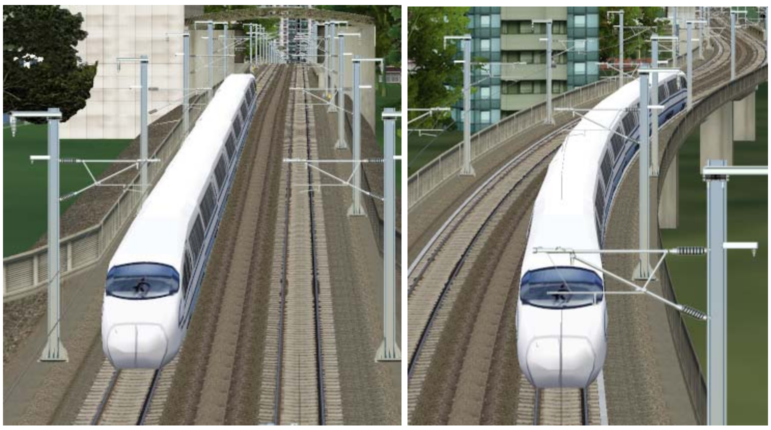
2 The aggregation of velocity

Because EMU is power-distributed, the velocity of each train unit could be same and equal to the velocity of the whole train. Then the aggregation of velocity is that the velocity of the whole train is equal to anyone train unit.

Figure 9 shows the 3D simulation of EMU on the curve line and the ramp line from the different view point. The EMU can be good to attach to the line and the tail units don't deviate from the line.



(a) The ground



(b) The high altitude

Figure 9. The simulation effect of EMU's multiple single-particles chain model

5. Conclusion

There are different requirements for the train visualization in the TCS testing and simulation platform. According to the specific analysis of the train running behavior and multiresolution theory, this paper raised the train visualization modeling of different resolution. Firstly, it is analyzed the coordinate system and the kinetics model of train as a single particle. And the train visualization model of single resolution was built. Then, based on the aggregation and disaggregation idea, the train visualization model of multiple resolution was proposed according to the position relation of train units and the force analysis of train units running. Meanwhile the aggregation and disaggregation process between different resolution models were analyzed in detail. After all, the availability of this method was certified by 3D train simulation.

Acknowledgement

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