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Dynamic Simulation of Differential Driving Cargo Transport Vehicle

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Abstract: With the rapid development of industrial technology, the application fields of AGV are constantly expanding. In this article, a differential vehicle is selected to construct a dynamic model of differential vehicle and establish a co-simulation platform of MATLAB/Simulink and ADAMS, which fully considers the nonlinear friction between wheels and the ground, the body mass and its own moment of inertia during steering, simulates the actual motion trajectory of the vehicle under different paths, and compares the ideal trajectory with the actual ADAMS output, which is generally consistent with the theory, and the basic path trend tends to be consistent. The deviation between them also reflects that the differential vehicle is a multi-degree-of-freedom strong nonlinear system, so the platform can better simulate the actual motion process of the vehicle.

Keywords: Differential driving; Fixed path; Co-simulation

1. Introduction

Automatic Guided Vehicle (AVG) is a kind of mobile intelligent autonomous or semi-autonomous robot, which has broad application prospects in modern logistics and warehousing, flexible manufacturing, military fields and operations in dangerous environments [1], its existence not only fills the work of humans in daily life, robots are also used in the industrial field, which can improve productivity and reduce labor costs [2]. In places with heavy workload and strong dynamics of cargo transportation, the transportation process always needs to be dynamically adjusted according to the demand in a dynamically changing environment [3]. Because of its automation, intelligence and flexibility, AGV can well meet the requirements of cargo transportation in the above occasions [4].

In this study, the dynamic model can be divided into mathematical model and simulation model, and the mathematical model involves Lagrange equation and Newton-Euler method. When there are nonholonomic constraints in Lagrange equation, the description of constraints must be attached; when Newton-Euler method is applied to modeling, although nonholonomic constraints can be directly integrated into the equation, the modeling process will become extremely cumbersome as the modeling object is a complex mechanical system [5]. Many researchers have studied the kinematics and dynamics model of two-wheeled differential mobile robot, and obtained many theoretical achievements. For example, reference [6] derives the nonlinear differential equation between velocity and torque of mobile robot, based on which the system state equation of mobile robot is obtained; reference [7] establishes the dynamic model of wheeled mobile robot by Newton-Euler method. Because the contact between wheels and the ground is highly nonlinear, and the whole vehicle model is a multi-degree-of-freedom strong nonlinear system, it is usually necessary to simplify the model analysis, which is difficult to be used in practice. In fact, the actual analysis will emphasize the establishment of mathematical model and theoretical derivation, and it is even more difficult to use direct and effective dynamic theory for analysis.

In order to solve the above problems well, based on kinematic analysis, this article uses the mature software ADAMS to construct the dynamic system of two-wheeled differential vehicle, and carries out the co-simulation with MATLAB/Simulink. In the process of establishing the system, the moment of inertia of the body mass and the nonlinear friction between the wheels and the ground are fully considered, and the actual motion of the vehicle under different paths is analyzed to verify the correctness of the dynamic system of the differential vehicle.

2. Physical Model and Kinematic Analysis

2.1 Physical Model of Differential Vehicle

At present, the common differential guide wheeled mobile robots are divided into three-wheeled, four-wheeled and six-wheeled mobile robots. In this article, the four-wheeled with strong bearing capacity are selected [8], and universal wheels, McNam wheels and orthogonal wheels are usually used in driving steering [9]. This article adopts the front and rear universal wheel steering and the form of left and right wheel differential driving; double differential driving wheel train can not only actively bear load, but also actively drive steering, thus realizing omni-directional motion forms such as straight, transverse, oblique, arbitrary curve motion and zero radius of gyration in two-dimensional plane [10, 11]. At present, the chassis is roughly divided into circular contour and rectangular contour. This article selects the circular contour, which has more application scenarios and can pass through narrow aisles, as shown in Figure 1. Also, when describing the trajectory of the vehicle, it is usually determined by the trajectory of the center of gravity of the vehicle. In the circular contour selected, the axes of two differential wheels are completely parallel to one diameter of the circular contour in space. When the velocity of differential wheels is solved by inverse kinematics [12], the midpoint trajectory between two differential wheels is completely parallel to the trajectory of the center of gravity of the vehicle in space.

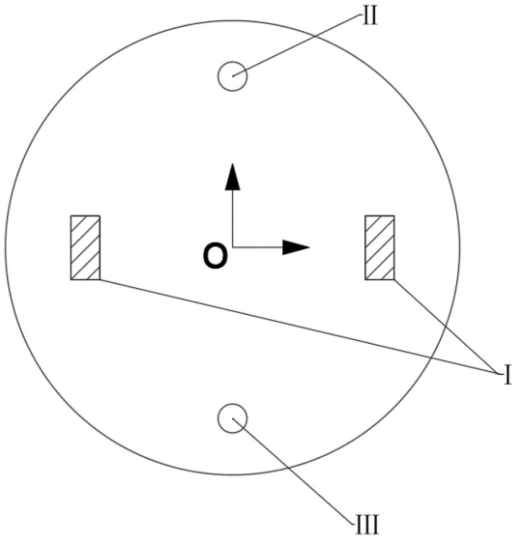

Figure 1. Physical model of differential vehicle
O-Gravity Center, I-Differential Driving Wheel, II-Front Guide Wheel, III-Rear Guide Wheel

2.2 Kinematics Analysis

Firstly, the following assumptions are made for the research model [13]:

(1) Assume that the vehicle is a rigid structure, that is, the positions of its four wheels relative to the geometric center of AGV vehicle body will not change during the motion;

(2) Assume that the motion plane is flat, that is, there are no gullies and undulating terrain in the motion scene;

(3) The four wheels have the same size and do not deform during the motion, That is, the interaction of rigid wheels with rigid ground [14, 15], the load is evenly shared among the wheels, and the wheel surface is perpendicular to the contact surface and keeps point contact, ignoring the influence of all wheel thicknesses on the vehicle body;

(4) There is no axial sliding between the wheel and the contact surface, that is, the transverse drift is not considered, and only pure rolling around the axis direction of the wheel occurs;

(5) Assume that the radial friction between the universal wheel and the ground is small, which will not affect the steering of the guide wheel set.

Figure 2 is a structural schematic diagram of the differential vehicle (only the key differential driving wheels are drawn in the figure). O_l and O_r are the wheel centers of the left wheel and the right wheel, the wheel spacing O_lO_r is L, O_c is the center of O_l and O_r and the center of the whole circular contour differential vehicle in the two-dimensional plane, and V_l, V_r and V_c are the linear velocities of the left wheel, the right wheel and the center of the vehicle body respectively. Assuming that the position coordinates of O_c are (x, y), and its attitude angle is expressed by the angle between the center linear velocity V_c and the x axis, the position and pose of the differential vehicle on the earth is expressed by vectors (x, y, θ) [16-18].

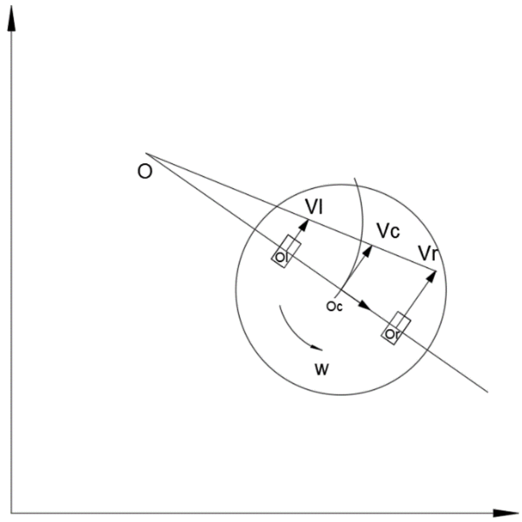

Figure 2. Kinematics model of differential vehicle

Considering the low-velocity motion, no centrifugal motion occurs, and the central linear velocity V_c can be obtained from kinematics knowledge as follows:

$$V_c = \frac{V_l + V_r}{2} \tag{1}$$

Assuming that the rotational angular velocity of the vehicle is w, the vehicle rotates counterclockwise as shown in Figure 3, then:

$$\begin{cases} V_l = \omega\left(R - \frac{L}{2}\right) \\ V_l = \omega\left(R + \frac{L}{2}\right) \\ \omega = \frac{(V_r - V_l)}{L} \end{cases} \tag{2}$$

According to the principle of rigid body translation, the motion of the vehicle at any time can be regarded as the rotating motion of the vehicle around the instantaneous center point O, and the rotating radius R is:

$$R = \frac{V_C}{\omega} = \frac{L}{2}\frac{V_r + V_l}{V_r - V_l} \tag{3}$$

The linear velocity of the left and right wheels determines the motion form of the vehicle:

(1) When V_l=V_r, R=∞, the vehicle moves in a straight line along the velocity direction;

(2) When V_l=V_r, R=0, the vehicle rotates around the center of the vehicle body;

(3) When V_l<V_r, the vehicle moves in counterclockwise arc, and the radius around the center of rotation:

$$R = \frac{L}{2}\frac{V_r + V_l}{V_r - V_l} \tag{4}$$

(4) When V_l>V_r, the vehicle moves in a clockwise arc, and the radius around the center of rotation:

$$R = \frac{L}{2}\frac{V_r + V_l}{V_l - V_r} \tag{5}$$

Therefore, the kinematic equation of the whole vehicle can be expressed as [19]:

$$\begin{pmatrix} V_c \\ \omega \end{pmatrix} = \begin{pmatrix} 1/2 & 1/2 \\ 1/L & -1/L \end{pmatrix} \begin{pmatrix} V_r \\ V_l \end{pmatrix} \tag{6}$$

$$\begin{pmatrix} \dot{x}_c \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} V_c \\ \omega \end{pmatrix} \tag{7}$$

In this article, inverse kinematics analysis is needed to obtain the velocity of left and right wheels as follows:

$$\begin{pmatrix} V_r \\ V_l \end{pmatrix} = \begin{pmatrix} V_c + \frac{L}{2}\omega \\ V_c - \frac{L}{2}\omega \end{pmatrix} = \begin{pmatrix} 1 & \frac{L}{2} \\ 1 & -\frac{L}{2} \end{pmatrix} \begin{pmatrix} V_c \\ \omega \end{pmatrix} \tag{8}$$

where, the central velocity:

$$V_c = \sqrt{\left(\dot{x}_c{}^2 + \dot{y}_c{}^2\right)} \tag{9}$$

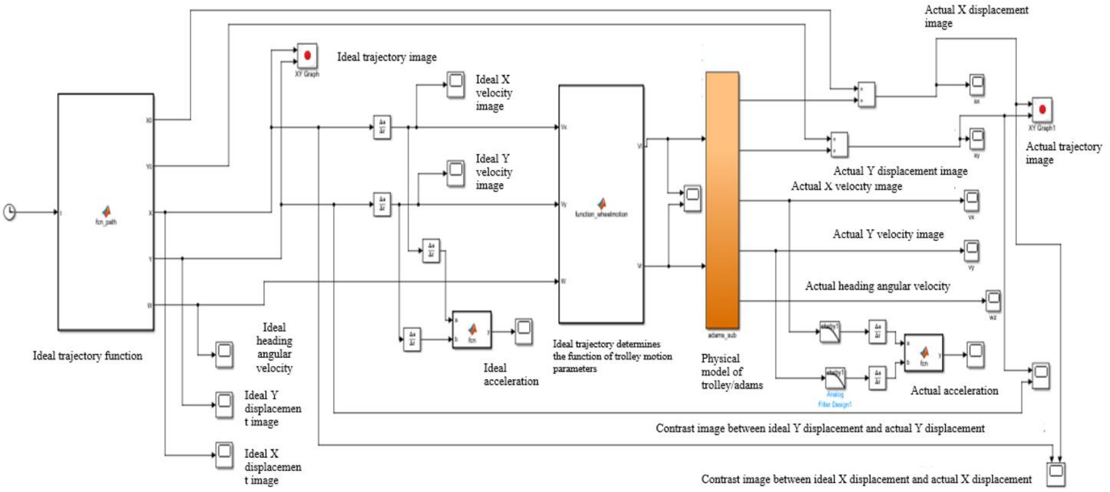

Figure 3. Dynamic simulation model

From the above analysis, the differential driving vehicle selected in this article can control the center velocity and the rotational angular velocity of the vehicle. Because the guide wheel and the drive wheel of the vehicle are constrained by motion, the difference lies in that the guide wheel increases an extra degree of freedom compared with the latter. The rolling constraint of the wheel forces all the motions of the wheel in the plane direction to be accompanied by the wheel rolling, so there is pure rolling at the contact point, and any position and pose of the vehicle in the two-dimensional plane can be realized [20]. The relevant physical parameters obtained under the fixed path can be used as the input end of the vehicle, thus making the differential vehicle move according to the ideal fixed path.

3. Construction of Dynamic Model of Differential Vehicle

3.1 Differential Driving Vehicle Model

The differential driving vehicle model selected in the above includes differential wheels on the left and right, and guide wheels on the front and back. The whole model is to better simulate the actual motion trajectory, so certain physical attributes including but not limited to mass, moment of inertia, etc. are given in ADAMS, as shown in Table 1. The overall size of the whole vehicle is not large, and the order of magnitude is millimeter. The whole vehicle does not increase any related load, so it is simulated by actual no-load situation. Of course, these parameters can be slightly modified in the follow-up study.

Table 1. Simulation parameters of differential vehicle

Simulation parameters	Mass m/kg	Moment of inertia J/(kgmm^2)	Distance between driving wheels L/mm	Driving wheel radius r/mm
Numerical value	1.36	798.01	60	10

3.2 Co-simulation Interface Settings

In order to realize the co-simulation of MATLAB/Simulink and ADAMS, it is necessary to set the input and output interfaces. Input and output variables are set as shown in Table 2. The input and output in the table are relative to ADAMS, and the transverse and vertical are determined according to the global coordinate system, regardless of the local coordinate system.

Table 2. Definitions of input and output variables

Input/output	Variable name	Variable meaning
Input	youve	Right wheel rotation angular velocity
	zuove	Left wheel rotation angular velocity
Output	Sx	Trolley transverse displacement
	Sy	Trolley longitudinal displacement
	Vx	Trolley transverse velocity
	Vy	Trolley longitudinal velocity
	w	Trolley rotation angular velocity

The co-simulation model built by using the kinematics theory and simulation parameters mentioned above is shown in the figure. MATLAB/Simulink calculates the rotational velocity of the left and right wheels and inputs it into the ADAMS_SUB vehicle model. The output variables of ADAMS includes the actual transverse displacement velocity, the actual longitudinal displacement velocity, and the angular velocity of the local coordinate system rotation of the vehicle.

4. Dynamic Model Verification

4.1 Linear Motion Without Steering

The dynamic model of two-wheeled differential vehicle constructed in this article mainly considers that it will keep certain steering function during the motion, and before that, it should consider the situation that the vehicle completes linear motion. Select X=20*t, and compare the displacement of the differential vehicle as shown in subgraph (c) of Figure 4, the transverse velocity as shown in subgraph (a) of Figure 4 and the rotational angular velocity of the local coordinate system of the vehicle as shown in subgraph (b) of Figure 4. As a whole, it is not difficult to see that the coordinate system of the whole vehicle with linear motion does not actually rotate, which accords with the condition of linear motion. From the forward velocity, it can be seen that although the actual velocity fluctuates up and down, the fluctuation range is not large and always fluctuates near the actual velocity curve. The displacement of the whole vehicle basically coincides and the forward direction is basically consistent.

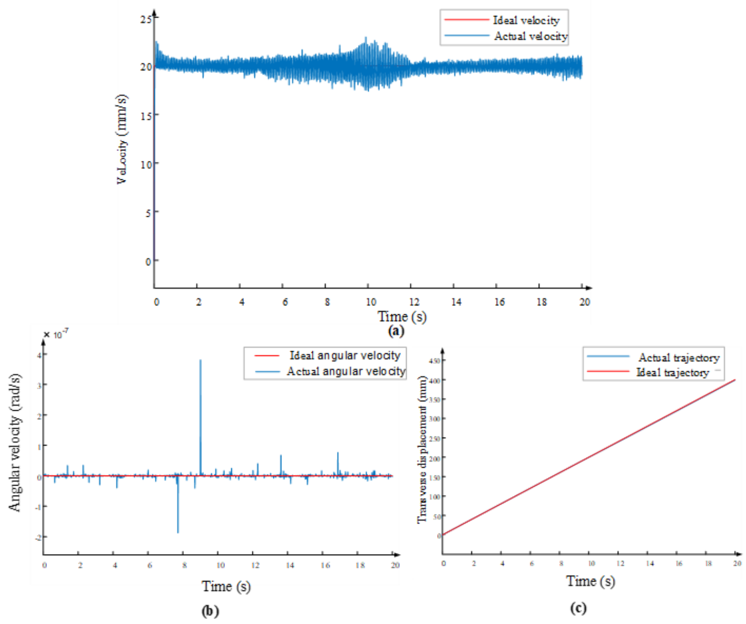

Figure 4. Simulation of linear motion trajectory

4.2 Ellipse

In order to better explore the dynamic simulation of differential driving vehicle under the premise of linear motion, the article chooses the curve motion which is different from the straight line. Assuming that the given curve is ellipse, the major semi-axis is 100 and the half minor semi-axis is 80, and considering the initial position and pose of the trolley, the ideal transverse trajectory equation X=100 (cos (3π/2+t/8)), the ideal longitudinal trajectory Y=80 (sin (3π/2+t/8)), and the units of X and Y are mm. Compare the velocity, acceleration and trajectory under the dynamic simulation run built above as shown in Figure 5. After fully considering the nonlinear friction between wheels and the ground, the acceleration of the whole vehicle will have a small peak value above and below the ideal acceleration at some time after Simulink filtering; the transverse and longitudinal velocity actually fluctuates slightly under the ideal state, and the overall trajectory trend of the vehicle is the same, forming a slightly deviated path at different positions but almost an ellipse.

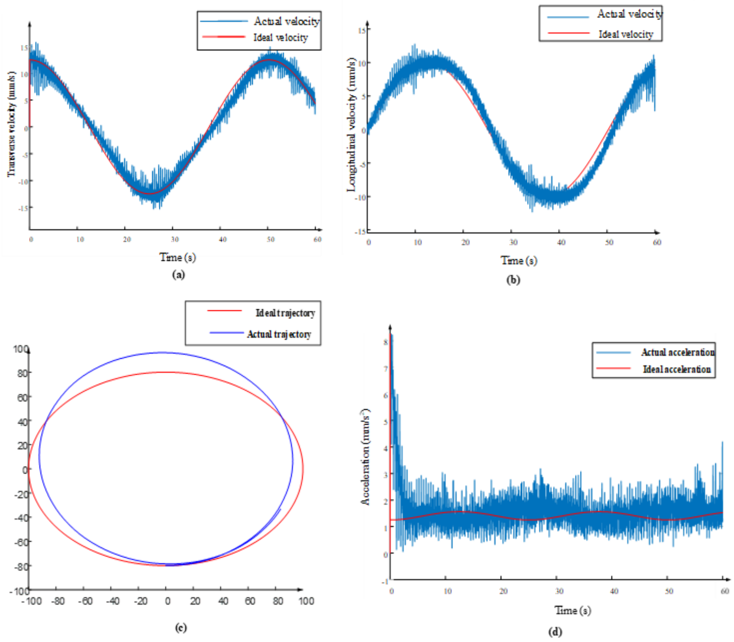

Figure 5. Simulation of elliptical motion trajectory

4.3 General Curve

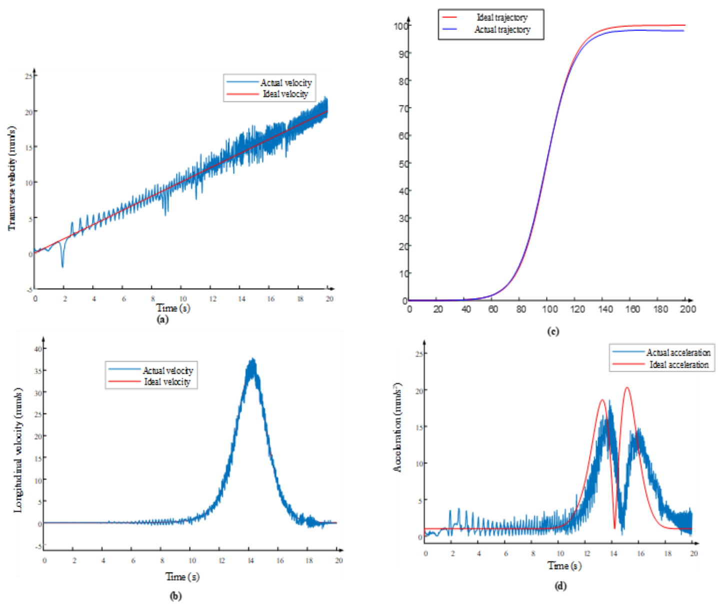

Figure 6. Simulation of general curve motion trajectory

After verifying the straight line and closed curve models, in order to be more suitable for the simulation under each path, a general curve which is different from the first two curves is added. Set the curve Y=100/(1+e^(-(X/10-10))), select the appropriate transverse trajectory X= (t^2)/2, and compare simulated trajectory, velocity and acceleration according to the dynamic model constructed above, as shown in Figure 6. From the motion trajectory alone, the trajectories in the first half are almost completely coincident, and there are some deviations in the second half, but the deviation is not large and the trend is consistent. The peak time of acceleration is different, but the difference between the first half and the second half is less than one second, and the contrast of acceleration is not large. The transverse and longitudinal velocity are almost the same as those mentioned above.

5. Conclusion

In this article, the dynamic model of two-wheeled differential vehicle is constructed, and a co-simulation platform based on MATLAB/Simulink and ADAMS is established to verify the correctness of the dynamic model. The above simulation results show that, under the linear motion trajectory, the simulation comparison curves almost completely coincide, and the rotational angular velocity is almost negligible, which basically meet that complete linear motion trajectory. However, the actual transverse velocity, longitudinal velocity, acceleration and general motion trajectory of the two-wheeled differential vehicle model with elliptical trajectory and general curve trajectory are generally consistent with those in theory, and the basic direction of the path tends to be the same; although there is a deviation between them, the overall is not large, which also reflects that the differential vehicle is a multi-degree-of-freedom strong nonlinear system. In this article, the two-wheeled differential vehicle dynamics system based on ADAMS can better represent the motion state of the vehicle in a certain range.

Data Availability

The data supporting our research results are included within the article or supplementary material.

Conflicts of Interest

The authors declare no conflict of interest.

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