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Research on Control Strategy of Distributed Articulated Robot Based on Vehicle-arm Coordination

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Abstract

In order to improve the steering ability of articulated mobile robot, an articulated robot equipped with encoder telescopic rod and distributed electric wheel is designed. The rationality of the structure is verified by finite element simulation. The dynamic modeling of the robot is carried out by Newton-Euler method, and a steering control strategy is proposed. Based on Adams / Simulink joint simulation, the steering control strategy model is built and the simulation experiment is carried out. The motion of the articulated mobile robot under various working conditions is analyzed. The lateral displacement of the rear body is greatly reduced, which effectively avoids the occurrence of ' tail flick '. The physical experiment shows that the turning radius and turning time of the articulated mobile robot under the steering control strategy are better, which can effectively improve the steering ability of the robot.

Keywords

Mobile robot; Distributed drive; Steering attitude control; Arm coordination.

1. Introduction

Articulated vehicles powered by electricity no longer require a differential for assisted steering, instead achieving independent control of each wheel. Their driving performance, steering performance, and driving stability are far superior to traditional articulated vehicles. However, due to the unique structure and steering mechanism of the entire vehicle, traditional driving methods have not considered the strong coupling relationship between wheel differential motion and the steering mechanism, resulting in the advantages of distributed drive not being fully realized[1].

Corke[2] conducted mathematical modeling of an articulated vehicle with rack-and-pinion steering based on kinematic geometric relationships, with the position and orientation of the front body serving as the model's output. This led to the derivation of a classic kinematic model for articulated vehicles. In this model, the two sets of wheels in the front and rear are differentially driven by differentials, but the impact of robotic arms on the mathematical model of the robot was not considered. Li He[3] conducted kinematic modeling of an articulated mobile robot chassis and simulated the control system using MATLAB software, verifying the effectiveness of the control system through prototype experiments. However, this structure did not include robotic arms.

A distributed drive system places individual motors in the wheel hubs, allowing for individual control of the driving force of each wheel[4]. Currently, differential control for articulated vehicles includes four categories: equal speed control[5], equal torque control[6], equal slip ratio control[7,8], and driving force distribution control[9]. Lian Jinyi et al.[10] proposed a method of controlling vehicle steering through differential drive in their research on independently driven electric wheel vehicles. Wang Qingnian[11], Wang Junnian[12], and Jin Liqiang[13] utilized differential torque to assist in steering for four-wheel independently

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driven electric vehicles with mechanical steering mechanisms. Iida M[14] implemented differential steering control for articulated chassis at a fixed articulated angle by referring to the differential steering method of ordinary rigid vehicles, reducing the vehicle's turning radius. Ji Zhiyong[15] proposed a differential articulated steering strategy based on real-time compensation of the yaw error of the articulated vehicle relative to a following target. MATLAB/Simulink simulation experiments and prototype tests demonstrated that this strategy offered superior trajectory tracking capabilities, but this structure did not include a robotic arm.

In this paper, we conduct mathematical modeling of the robot and propose a steering control strategy based on the dynamic model.

2. Structural Design and Mathematical Modeling of Articulated Mobile Robot

Structural design and mathematical modeling of the articulated robot. The chassis of the distributed drive articulated mobile robot is composed of the front body, the rear body, four drive motors, two electric telescopic rods, hinged structure and other basic structures of the robot. The manipulator part is composed of two steering engines, and the rotation axis is perpendicular to the ground.

In order to avoid the tail flick phenomenon, it is required that the rear body does not have lateral displacement, that is, the lateral acceleration is 0. At this time, the driving force F_{ZH} of the left rear wheel and the driving force F_{YH} of the right rear wheel are:

$$\begin{aligned} F_{YH} = (&-\left(I_{m1} + (m_2 + m_3 + m_4) \cdot l_{1xoy}{}^2\right) \cdot \dot{\omega}_1 + m_1 \cdot a_{x1} \cdot \frac{w_1}{2} \\ &- F_{QZx} \cdot \frac{w_1}{2} + \left(F_{R1y} + F_{L1y}\right) \cdot l_{2xoy} + \frac{n_2}{2} \cdot F_x \\ &- F_{YHx} \cdot \frac{w_1}{2} - F_{L2} \cdot L_L - F_{R2} \cdot L_R) / w_1 \end{aligned} \tag{1}$$

$$F_{ZH} = m_1 \cdot a_{x1} - F_{YH} + T_{R2y} - F_{TR1} + F_{Jxr} \tag{2}$$

In the formula, F_{YH} is the driving force of the right rear wheel, F_{ZH} is the driving force of the left rear wheel, F_{QZx} is the driving force of the left front wheel in the x_2 direction, l_{2xoy} is the moment of inertia of the rear body, F_x is the sum of the driving forces of the four wheels in the x direction.

According to the steering control algorithm, the input parameters of each power component are calculated, which can reduce the turning radius required for steering and reduce the lateral displacement of the rear body.

3. Finite Element Simulation

Set the chassis material, mesh and constrain, and analyze the deformation. In view of the complexity and irregularity of the frame structure, the tetrahedral mesh is divided by default setting according to the characteristics of the frame. On this basis, the minimum size of the grid is adjusted to 3mm. The grid division of the front wheel fixed bracket is shown in Figure 3.

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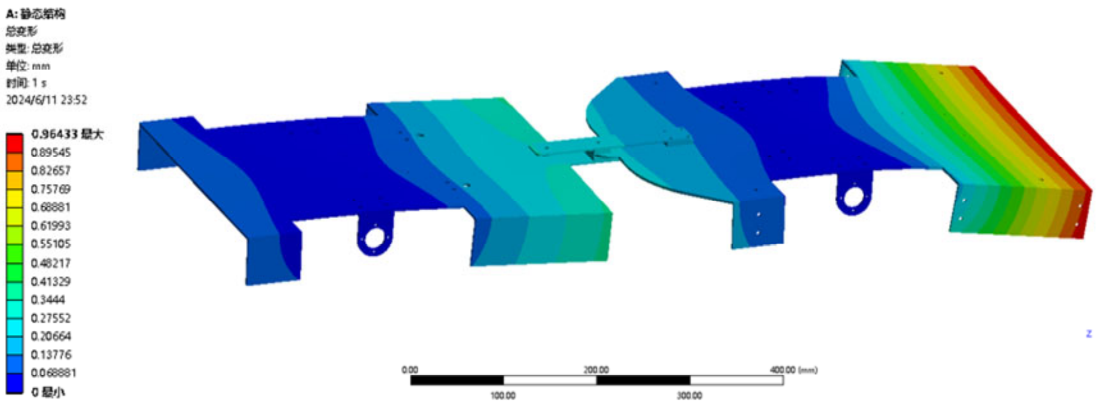

Figure 3. Deformation analysis of robot chassis

The front end of the rear frame and the hinged parts have obvious displacement, the maximum displacement is 0.964 mm, which is located on the engine mounting beam, because it carries the load of the container and the engine. The deformation of the longitudinal beams on both sides is consistent, indicating that the load distribution of the frame is reasonable.

4. Adams/Simulink Co-simulation Experiment

The geometric model of the robot is established in SolidWorks software and imported into Adams software. After setting the input and output, it is packaged as a mechanical system unit, and Simulink is imported to set the motor model and control system model.

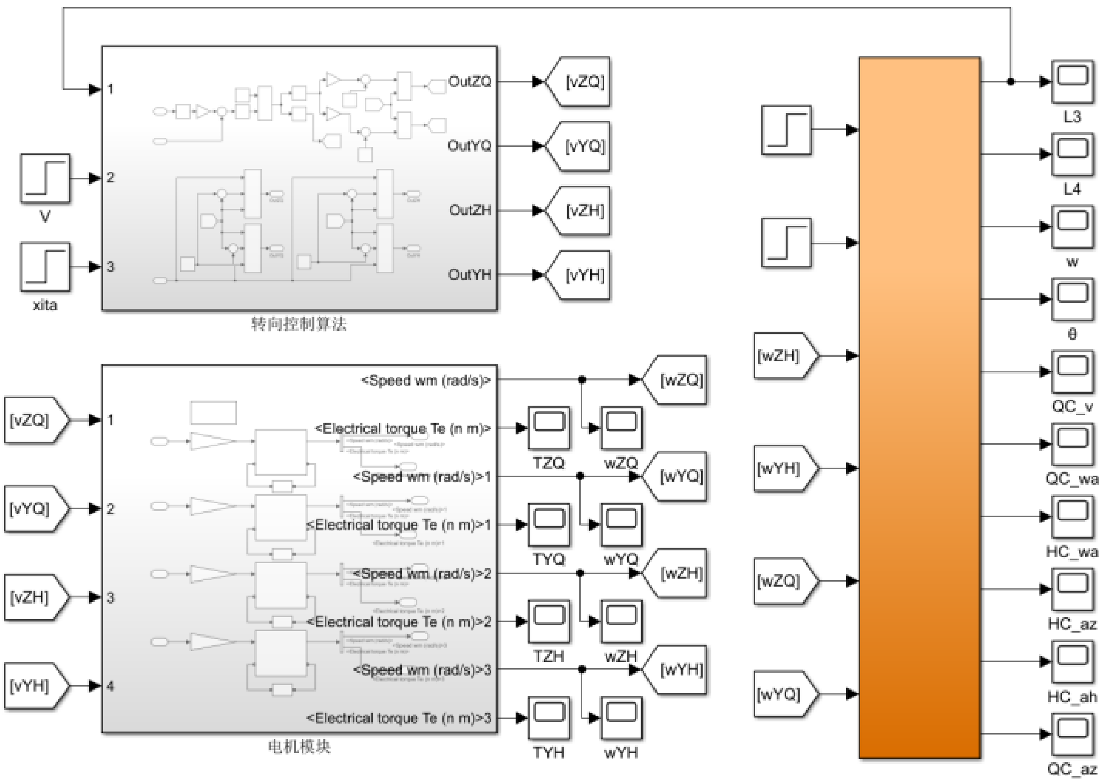

Figure 4. Steering control system based on Adams/Simulink co-simulation

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4.1. Adams-based mechanical system model

In Adams, the material properties of the drive pair and each component of the motor and the electric telescopic rod are set up, and the constraint relationship and system unit are established.

The input and output parameters are set as system variables and encapsulated as mechanical system modules that can be imported into MATLAB / Simulink.

4.2. Steering control model based on Adams / Simulink

The DC motor model is added to Simulink, and the steering controller is built according to Formulas (1)-(2). The steering control module is composed of mechanical system module, swing angle calculation module, drive calculation module and motor module, as shown in Fig.4.

5. Physical Verification

The robot prototype is made. The domain controller EAXVA04 is used as the host computer to send motion instructions. STM32 is used as the lower computer and equipped with steering control algorithm. The robot is shown in Fig.5.

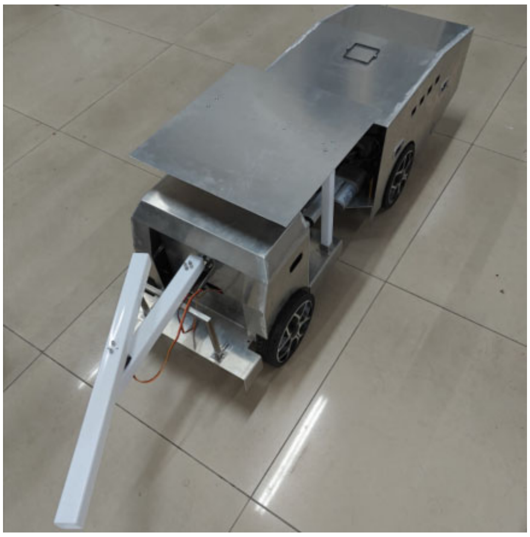

Figure 5. Articulated mobile robot prototype

The robot is started in a static state to complete a 90° steering motion, and the displacement of its center of mass in the longitudinal direction is analyzed. The robot speed is set to be 2m/s and 3m/s, and the target heading angle is set to be 10°, 20° and 30°. When the longitudinal displacement reaches a peak, the robot is considered to have completed a 90° turn. The time required to reach the target command and the turning radius. from which the turning radius and turning time are calculated. The specific values are shown in Tab.1 and Tab.2.

Table 1. Motion on under steering control strategy

		10°	20°	30°
Times	2m/s	2.821	2.624	2.391
(s)	3m/s	2.896	2.655	2.422
radius	2m/s	2.487	1.960	1.551
(m)	3m/s	2.005	1.631	1.205

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Table 2. Motion on under steeringless control strategy

		10°	20°	30°
Times	2m/s	3.218	3.101	3.054
(s)	3m/s	3.451	3.196	2.984
radius	2m/s	2.998	2.385	2.068
(m)	3m/s	2.399	2.014	1.547

The trajectory of the robot is analyzed. Compared with the general model, the average turning radius of the articulated mobile robot equipped with the steering control algorithm is reduced by 23.37 %, and the average steering time is shortened by 20.2 %. There is no obvious lateral displacement of the rear body, and the steering ability of the robot is greatly improved.

6. Conclusion

(1) The structural design of the articulated mobile robot is carried out. A distributed drive chassis equipped with an electric encoder push rod is proposed, which makes the robot have more degrees of freedom in structure and more flexible steering process.

(2) The dynamic modeling of the articulated mobile robot is carried out, especially the lateral velocity of the rear body is analyzed. A steering control strategy is proposed to improve the steering speed and avoid the " tail flick " phenomenon during the steering process.

(3) The simulation results show that the steering control strategy can effectively avoid the occurrence of lateral displacement of the rear vehicle body.

(4) The prototype of articulated mobile robot is made and tested. The results show that the structure has better steering flexibility than the ordinary structure with the steering control algorithm.

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