Steering coordination control of front wheels for a four in-wheel-motor drive electric vehicle

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Abstract: The paper puts forward a novel vehicle-network architecture of the power system based on the 4WIDIS EV. And then, the steering coordination control system's design of the 4WIDIS EV based on the novel vehicle-network architecture is focused on the analysis. Finally, the experimental data shows that the system can meet the actual steering requirements of synchronicity, accuracy and real-time.

Keywords: steering control; in-wheel motor; electric vehicle; vehicle-network.

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1 Introduction

An electric vehicle (EV) is provided with such distinct advantages as low noise, zero emission and comprehensive utilisation for energy and just is the important way to realise the sustainable development for automobile industry depended on to solve such problems as energy and environmental protection currently.

Four-wheel independent steering (4WIS in short) is widely used in EV at present. It means rear wheel is provided with function of steering the same with front wheel. Generally, the reverse rotation of rear wheel and front wheel in turning at low speed can reduce the turning radius of automobile and increase the manoeuvrability of automobile to be provided with a more convenient parking and turning for automobile in increasing the shortage of urban space; In high speed rotation of rear wheel and front wheel in the same direction increases stability of automobile in turning at high speed and speeding-up overtaking and reduces circumnutating easily occurred in turning of vehicle at high speed. And central control unit automatically identifies the steering control of rear without intervention by driver for its operation to make operation of automobile more easier.

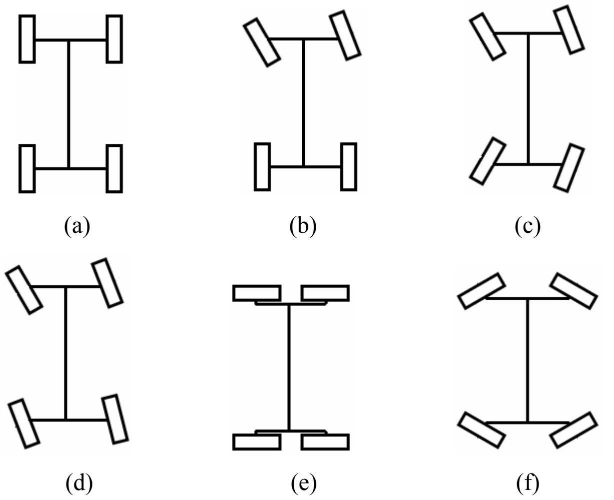
Driving system of EV mainly includes such popular forms at present as concentrated driving, individual driving with dual motors (dividing into front-driving and rear-driving), four-motor individual driving with four wheels (including individual driving of four hub motor) (Long and Zhang, 2005). Due to power of in-wheel motor limited to structure and volume, two-wheel driving of EV driven by in-wheel motor mostly are substituted by adopting four-wheel independent driving (4WID), and in conjunction with system of 4WIS that steering force is controlled by adopting four servo motors, thus novel EV studied in this paper is formed – four-wheel independent driving electric vehicle (4WIS and 4WIDIS EV), which not only takes full advantage of adhesive force and driving force of ground to wheel, but also is more easier to realise four-wheel steering system for improving steering qualities.

This paper puts forward novel control-network architecture of the power system based on the 4WIDIS EV, and analyses focus on 4WIS coordination control based on such control-network architecture.

2 Theoretical basis of 4WIS

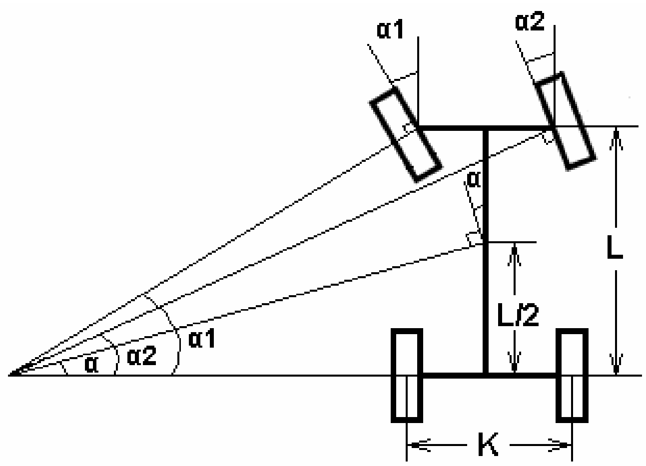
4WIS system means, during process of steering, four wheels of front and rear group play roles in steering according to requirement to effectively improve manoeuvrability and handling stability of vehicle (Qu and Liu, 1999). Six steering types of 4WIS are shown in Figure 1, in which, Figures 1(a) and 1(b) are state of straight driving and turning under normal mode; Figure 1(c) is anti-phase steering of front and rear wheels in turning of 4WIS EV at low speed, and turning radius of vehicle can be reduced; Figure 1(d) is in-phase steering of front and rear wheels in steering of 4WIS EV at high speed, and slip angle of centroid of vehicle can be reduced to reduce overshoot for stable state of yaw rate of vehicle to increase handling stability of vehicle further; for 4WIS EV, if steering angle of each wheel is large enough, such functions as lateral movement and auto gyration also can realised, refer to Figures 1(e)and 1(f).

Figure 1 Six steering types of 4WIS



To simplify deduction of formula, analysis is only made for steering of front wheel provided that no moving is made to rear wheel. Steering geometry principle of Ackerman front-wheel steering automobile can be referred, i.e., in steering of automobile, four tires all rotate approximately around a central point to guarantee stability under transport condition of automobile, under the condition without considering such situation as cornering of centre of mass, heading angle and change of pavement condition and crosswind, geometric model that steering of front wheel without moving of rear wheel is shown in Figure 2 can be obtained.

Figure 2 Geometric model for steering of front wheel without moving of rear wheel



In Figure 2, α_1, α_2 and α are command of turning angle of left front wheel, turning angle of right front wheel and turning angle of steering plate respectively, K is nodal distance of left and right steering, L is axle distance of front and rear wheel. Formula of turning angle deduced from figure is as follows:

$$2\cot\alpha_2 - \cot\alpha = \frac{K}{L} \tag{1}$$

$$\cot\alpha - 2\cot\alpha_1 = \frac{K}{L} \tag{2}$$

$$\cot\alpha_2 - \cot\alpha_1 = \frac{K}{L} \tag{3}$$

Formula (1) above is relation between command for turning angle of steering plate and turning angle of right front wheel, formula (2) is relation between command for turning angle of steering plate and turning angle of left front wheel, formula (3) is relation between turning angle of left front wheel and turning angle of right front wheel.

3 The whole scheme for a novel vehicle-network

3.1 Application object

The 4WIDIS EV is shown in Figure 3. It adopts four advanced hub-motors to realise the accurate torque control, continuous velocity control and electrical differential control, which replaces the complicated traditional mechanical structures, such as the differential, the transmission shafts and the transaxles. It also adopts four advanced steering servo motors to realise accurate, stable and fast steering angle control. Each wheel is able to rotate for 360° angle (180° for one side and 180° for the other side). This unique design allows the EV to drive in various attitudes, such as normal running, horizontal running, reverse-steering of fore-and-aft vehicles, forward-steering of fore-and-aft vehicles, and rotating (Zhu et al., 2011).

Figure 3 The appearance of the 4WIDIS EV (see online version for colours)

The novel vehicle-network architecture of the power system for the 4WIDIS EV is discussed below.

3.2 Scheme design of the vehicle-network architecture

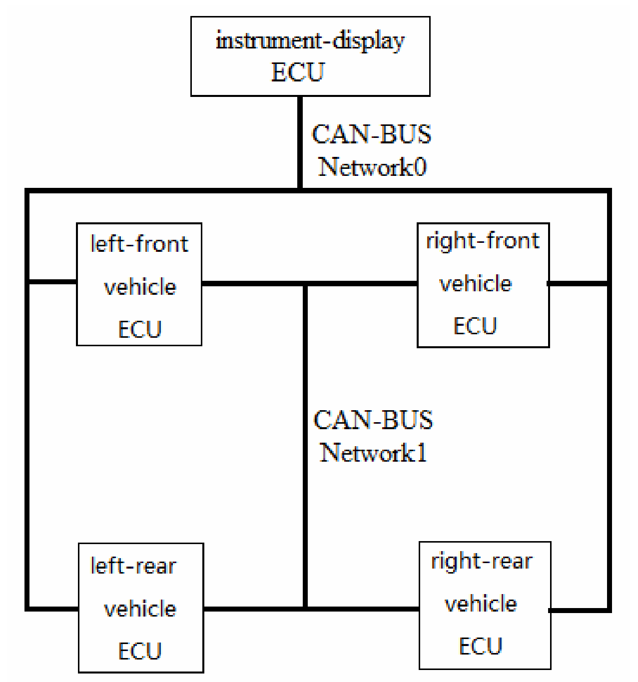
The power system which is vital in the car control systems determines the power, operation and safety of the vehicle. The power system is usually centrally controlled by one ECU, for the vehicle-network technology is not prevailing before. This way allows only one ECU to control the drive power, the steering power and the drive safety. So the power system ECU should be very powerful to fulfil all the requirements which results in high cost; The sensors and the actuators which are distant from the ECU are hard to control for the disturbance along the long lead; The worst of all, one trouble in the power system may lead to the collapse of the whole system.

The controller area network (CAN), which is a kind of multiplexing vehicle-network, characteristics in stable communication, simple structure, anti-jamming ability and so on. The CAN bus originates from the mature industrial field bus and the computer local area network (LAN), it has now become the main technology and standard of the car-bus. It is now widely used especially in the electric control system of the new energy vehicle (Zhou, 2007; Hu, 2006).

As the CAN bus technology is more and more popular, the modularised design becomes possible and prospective. Each module is independent, so the reliability is enhanced. Modules share the information by CAN bus without interferences. A modularised design of the power system for the 4WIDIS EV is introduced here. And this design makes the intelligent control scheme for the whole car possible.

The power system's vehicle-network of CAN bus is used as a high speed bus for the real time closed loop controlled multiplexing network. Its data transmission rate is about 1 Mb/s. The module ECU includes the four independent vehicle ECUs and an instrument-display ECU. The vehicle-network of CAN bus is shown in Figure 4.

Figure 4 The CAN bus network for the power system



As shown in Figure 4, a novel vehicle-network architecture is proposed in the text with regard to the 4WIDIS EV study platform. Such architecture consists of two CAN bus networks. One is the CAN bus network 0 comprised of instrument panel ECU of left front wheel, ECU of right front wheel, ECU of left rear wheel, and ECU of right rear wheel; the other one is the CAN bus network 1 comprised of ECU of left front wheel, ECU of right front wheel, ECU of left rear wheel, ECU of right rear wheel. The CAN bus network 0 is responsible for transmitting the signal of steering wheel, signal of accelerator pedal, signal of brake pedal and other driver control signals to the ECUs of the four wheels in a rapid period (such as at an interval of 10 ms), then the ECUs of the four wheels will transmit some of status information to the ECU of the instrument panel in a slower period (such as at interval of 200 ms); in the CAN bus network 1, the ECU of each wheel will send the real-time status information of the wheel to the ECUs of other wheels. By altering the network architecture, the network congestion that all the ECUs are stuck in one network can be solved, and in the meantime, reliable redundancy design will be provided so that when problems of one network occurs, the other network will enter the emergency mode as to prevent accidents. By altering the network architecture, the network platform can be provided for the coordination control of the turning of the four wheels.

4 Steering coordination control system's design

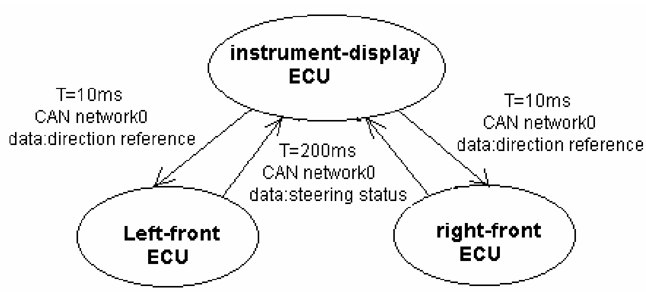
In the four-wheel steering electric automobiles with independent drive of four wheels, electronic differential algorithm, rear-wheel steering mode, and steering control strategy, which are closely related to the control of driving wheel, belong to two different control levels respectively in the whole control system, and the base-level control with regard to the upper-level control may be considered as the link where the closed-loop transfer function is 1.

Generally, the typical PID control is adopted for the steering control situated in the base-level of the control system as to achieve the control for the accurate position of the steering servo motor, while, the coordination control for steering control strategy of four wheels and electronic differential algorithm is located in the upper level of the control system. Both control levels are connected through the network architecture as shown in Figure 4. Since the base-level control with regard to the upper-level control may be considered as the link where the closed-loop transfer function is 1, the base-level control will not be further analysed in the text in the following, and only the steering control strategy in the upper-level control will be explained in detail. Based on the network architecture as shown in Figure 4, there are two control schemes for upper-level control of the coordination control as studied in the text.

4.1 Scheme 1: design of coordination control

The Scheme 1 is that the ECU of the instrument panel will send the instructed angle of the steering wheel to the ECUs of the four wheels during the period of 10 ms, then the ECU of each wheel after receiving the instructed angle of the steering wheel will perform the tracking control. The ECU of each wheel will send the steering status of the wheel to the ECU of the instrument panel at interval of 200 ms for use of instrument display and relatively slower coordination control. For the convenience of analysis, only the condition that the rear wheels are turned whereas the front wheels will not be considered with the data as shown in Figure 5.

Figure 5 The data flow chart of the Scheme 1



In Scheme 1, all the ECUs of the four wheels have completed tracking of the steering wheel, based on formula (1), the algorithm for the turn angle of the right front wheel may be concluded as:

$$\alpha_2 = arc\cot\left(\frac{\cot\alpha}{2} + \frac{K}{2L}\right) \tag{4}$$

From formula (2), the algorithm for the turning angle of the left front wheel may be concluded as:

$$\alpha_1 = arc\cot\left(\frac{\cot\alpha}{2} - \frac{K}{2L}\right) \tag{5}$$

4.2 Scheme 2: design of coordination control

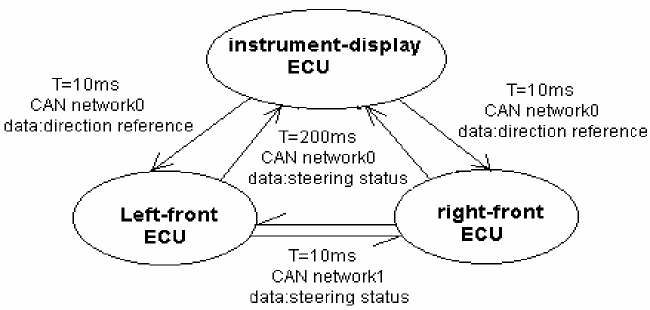
Scheme 2: For the CAN network, the ECU of the instrument panel will transmit the instructed angle of the steering wheel to the ECUs of the four wheels at interval of 10 ms, the ECU of target-tracking wheel (such as the left front wheel) after receiving the instructed angle of the steering wheel will turn to the tracking control of steering position, the ECU of each wheel will send the steering direction status to the ECU of the instrument panel at interval of 200 ms for use of display and protection of coordination control; for the CAN network 1, the ECU of each wheel will send the broadcast message of the steering direction status of the wheel to the ECUs of other wheels at interval of 10 ms, and the ECUs of other wheels (except for the target-tracking wheel) will then based on their own algorithm track the steering status of the target-tracking wheels. Of course, the whole system will change the target-tracking wheel at any time according to the steering status of each wheel, for example, when it is detected that the right front wheel fails to track the left front wheel for a long time (at the convexes and concaves of the road), the system will take the right front wheel as the target-tracking wheel. For the convenience of analysis, the condition that the front wheels are turned while the rear ones are not considered with data as shown in Figure 6.

In Scheme 2, the ECU of the target-tracking wheel has completed the tracking of steering wheel. Hereby, taking the left front wheel as the target-tracking wheel for example, the turning angle algorithm of the left front wheel tracking the steering wheel will be that as expressed in the above formula (5). Whereas the ECUs of other wheels are required to complete tracking of the target-tracking wheel, the turning angle algorithm for the right front wheel may be concluded from the formula (3):

$$\alpha_2 = arc\cot\left(\cot\alpha_1 + \frac{K}{L}\right) \tag{6}$$

In comparison with Scheme 1 and Scheme 2, the Scheme 1 is the open-loop control in terms of the upper-level control while the Scheme 2 is the closed-loop control. The following is the analysis for the experimental contrast of two control schemes.

Figure 6 The data flow chart of the Scheme 2



4.3 Experiment

The platform 4WIDIS EV studied in the text adopts Scheme 1 and Scheme 2 respectively for the real vehicle test, with the test data being transmitted by the ECU of each wheel in real time through the test communication port to the PC.

Figure 7 shows the experiment results of Scheme 1 under the road with concaves and convexes; Figure 8 shows the experiment results of Scheme 2 under the road with concaves and convexes.

Figure 7 The experiment results of Scheme 1 (see online version for colours)

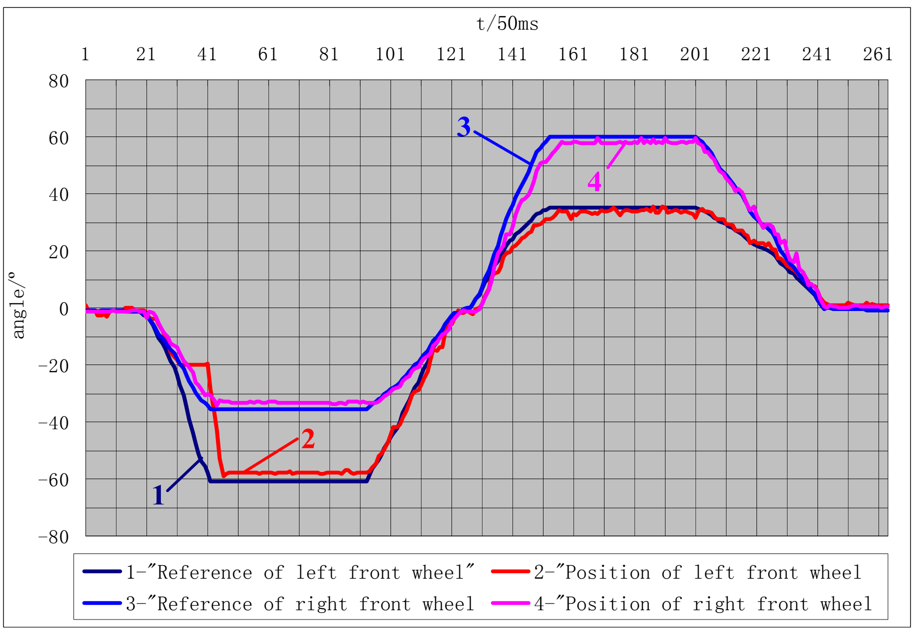
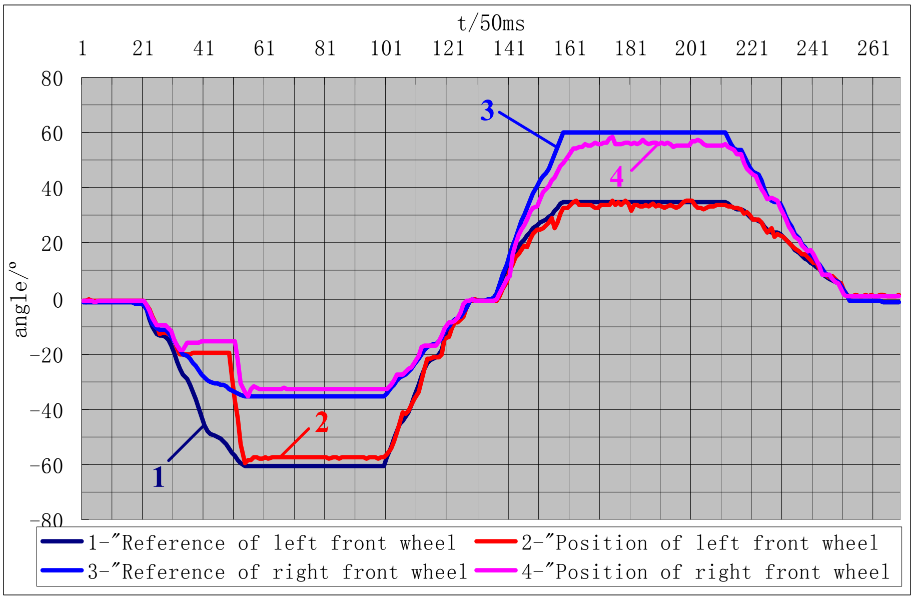


Figure 8 The experiment results of Scheme 2 (see online version for colours)



Through experimental comparison, it can be concluded that, under the suspension status of the driving wheel and the flat road status, the difference between the performance of Scheme 1 and Scheme 2 is small, whereas under the situation of road with concaves and convexes, Scheme 2 is better than the Scheme 1, as shown in Figures 7 and 8, while under the road with concaves and convexes, the steering control of left front wheel completely cannot track target angle in a short time, the steering control of right front wheel under the Scheme 2 can track the steering status of left front wheel, but under the Scheme 1, the steering control of right front wheel still track the steering plate.

5 Conclusions

In conclusion, Scheme 2 of the coordination control adopted in the new network architecture as proposed in the text not only will meet the requirements of network redundancy design and the reliability of communication data but also will meet the requirements for the technical performance of steering coordination control under all complicated road conditions. The next step of the work is to realise the electronic differential coordination control, and then, to realise other control strategy of the finished automobile based on the network architecture, such as brake control and energy recycling control, etc.

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