Proceedings of the 2010 IEEE
International Conference on Mechatronics and Automation
August 4-7, 2010, Xi'an, China

Research on the Platform Design and Control System for the Wheel-side Steering-Driving Coordination Vehicle

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***Abstract*—In this paper, a new type vehicle with four wheel independent steering (4WIS) and four wheel independent driving (4WID) travelling mechanism is designed. Under careful analysis of the advantages and disadvantages of both the mechanical and electrical features, the design of platform is discussed. Besides, a corresponding control structure is addressed. Under the Co-simulation using ADAMS and MATLAB/Simulink, algorithms to generate longitudinal and lateral force are tested, with a coordinated torque control of the steering and driving motors. The results show the proposed mechanical design and control system could make a good combination that traditional vehicles are hard to reach.**

Keywords-component; four wheel independent wheel drive; four wheel independent wheel drive; adaptive control; coordinated control; torque control; ;tire force; platform; control system; electric vehicle

I. INTRODUCTION

Researches about the four wheel independent steering(4WIS) and four wheel independent driving(4WID) vehicle have been put forward recently. For this kind of vehicle, the driving and steering units are assembled to each wheel. Therefore there are eight degrees controlled by four driving motors and four steering motors, which is considered to have extended control flexibility to its maximum possibility. The potential of a impressive improvement for the driving quality and functionality (as shown in Fig. 1), along with the possibility to release environmental problems and energy problems provide this kind of car a bright future[1]. In this article we call it the Next Generation Electric Vehicle (NG-EV).

Universities and institutes, like HORI laboratory and State Key laboratory of Automobile Dynamic Simulation (ASCL) Jilin University have done much work in the area, which lays a solid foundation for the further study [2~5]. The traction control of the in-wheel motor is verified. Algorithms of the direct yaw control (DYC) and feasible ways of tire force distribution have been established [6]. In addition, the four wheel steering mode has been reconsidered by vehicle experts[7~8], because of the recently fast developed motor techniques. In this paper, we will give a further discussion about the features of NG-EV and how the mechanical platform and control system should be designed.

II. FEATURES OF THE NG-EV

The NG-EV has unique features by using a motor-driven steering and driving system and decentralizing the power-train system to the wheel-side. The advantages of NG-EV could be concluded into 3 points as follows:

- 1) The Torque generated by motor will act more precisely and quickly than the internal-combustion engine or hydraulic braking system. Generally, the response of a motor is 10-100 times as fast as the other kind of powers[9]. This is a major advantage of the realization of ABS or TCS. Besides, the properties of motors are more suitable for a vehicle than engines.
- 2) Steering and driving systems are distributed to four wheels. It would give the control system more flexibility and it is more convenient to produce longitudinal and lateral forces by the coordination of the steering and driving motor units.
- 3) An electric system is more flexible and intelligent to coordinate the different components of the vehicle, adapt the changing environment and satisfy the requirements of different drivers.

Nevertheless, along with the merits, there are also new problems occurred. The mechanical adaption between the right and left steering wheels no longer exists for NG-EV, after the essential tie rod component is removed. The

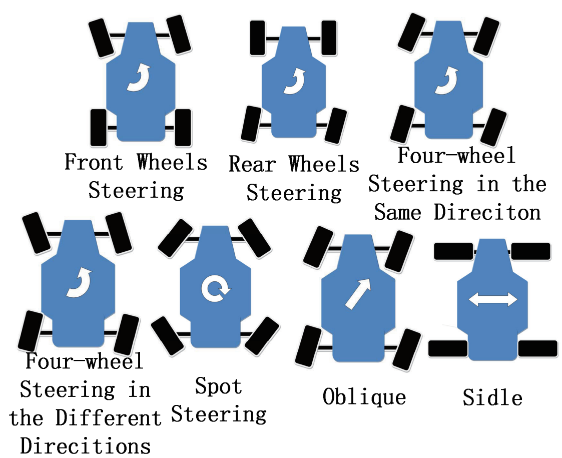


Figure 1 Motions of the NG-EV

same is true about the adaptation of the driving wheel, because of the absence of the differential. For NG-EV these functions are carried out by the electric system. Unfortunately, as for an electronic system, the "hysteresis effect" block it to act as fast as mechanisms. For instance, it takes only several milliseconds for the force passing through tie rods from the left steering wheel to the right one. However, it will cost approximately 100 milliseconds for this process of a electronic system: firstly, the left sensor detects the force on the left steering wheel, passes it to the main controller; then the main controller receives the signal, calculates for a solution and passes it to the right side motor; finally, the right motor makes corresponding motion. Even considered the boosting state of development of modern electric techniques, for quite a long time, the reaction speed of electric systems with reasonable price is not comparable to that of mechanical systems. This viewpoint could be demonstrated by the famous principle-Faraday's Law of Electromagnetic Induction: the electric field can be established at a glance, while the magnetic field is built rather slowly as a result of the hysteresis effect. This indicates that it might get stuck by using the electrical system to simply imitate the mechanics. To make the best of both mechanical and electrical systems, analyses of what is the appropriate mechanical structure and corresponding control structure applied on the NG-EV are beneficial.

III. Design of Platform for NG-EV

A. *Design strategy of the vehicle*

Mainly, we divide the NG-EV into 5 systems: the travelling system, energy system, control system, human-machine interaction system and body and frame system. The main assembles of the systems are shown in Table 1 .

To build the platform for a NG-EV scientifically, we follow the design strategy shown in Fig. 1. The process of construction is mainly divided into mechanical part and

Table 1. Constituent of the NG-EV

MAIN SYSTEMS	ASSEMBLES
Travelling System	Wheel Assembly
	Suspension Assembly
	Steering Assembly
Energy System	Battery
	Power Management System
	DC-DC
Control System	Motor Drive
	General Controller
Human-machine Interaction System	Steering Wheel Assembly
	Meter Displays
Body and Frame System	

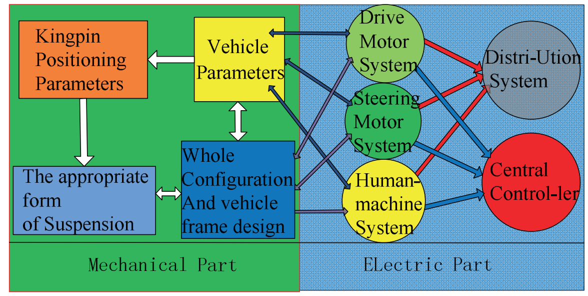


Figure 2 The design strategy of the NE-EV

electric part as shown in Figure 2. Mechanical part includes “Vehicle Parameters”, “Kingpin Positioning Parameters”, “Suspension Form” and “Whole Configuration and vehicle frame design”. Electric part consists of “Drive Motor System”, “Steering Motor System”, “Human-machine Interaction System”. Then the design of power system and central controller could be reached. Design relationship between them is illustrated by the arrows.

B. *Selection of steering wheel positioning parameters*

One of the main difficulties of designing the travelling mechanism is steering wheel positioning parameters, mainly including caster angel, caster offset, inclined angle and inclined offset (Fig. 2). These parameters are crucial for the performance of handling stability for a traditional vehicle[10].

As NG-EV applies the steer-by-wire four wheel

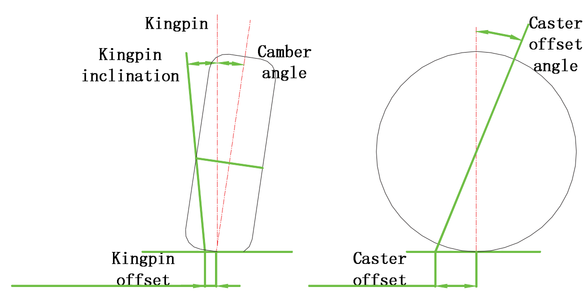


Figure 3 Steering wheel positioning parameters

independent steering format, the mechanical adaption between the left and right steering wheels no longer exists as we have discussed above. Therefore, the included angle is meaningless. In addition, for NG-EV uses motors to brake, the forward and

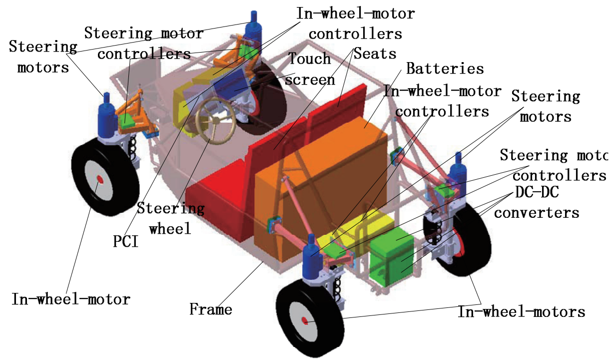


Figure 4 Configuration of NG-EV

backward forces on the wheel are nearly symmetrical, the existence of caster angle affects the braking stability, even though it would enhance the stability when the car accelerates. If we still adopt the traditional design experiences of vehicle kingpin parameters, there always would be a load torque applied on the steering motors which would waste electricity significantly.

So we should set the caster angel, caster offset, inclined angle and inclined offset to be zero. That means the line of kingpin is vertically across the contact plane of tire and road through the center point. The concept is called “zero off-set” in this paper. Therefore, the driving and steering systems are decoupled. Also, the front and rear, left and right tire forces would almost not affect each other. In this case the vehicle control is simplified.

Furthermore, a “zero off-set” kingpin gives the steering wheel a rather wide angle to rotate. We set the turning angle of a single wheel as ±90 degree. So the car could achieve the following motions in Fig1, which is very helpful for parking in a crowded street. The feature is generally called an “Omni-directional” character [11].

C. *The construction of the real prototype test vehicle*

A precise 3D model under the help of CATIA of NG-EV is shown in Fig. 4 and the test car and its crucial parts are presented in Fig. 5.

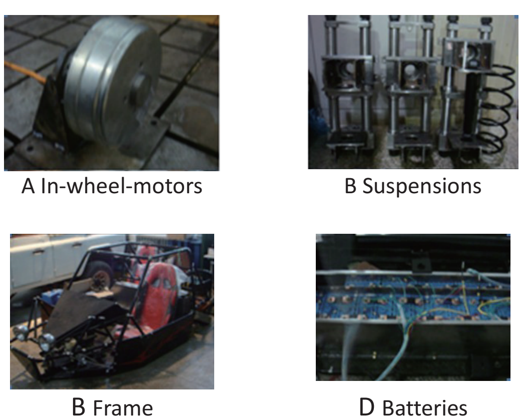


Figure 5 Crucial parts for the real NG-EV

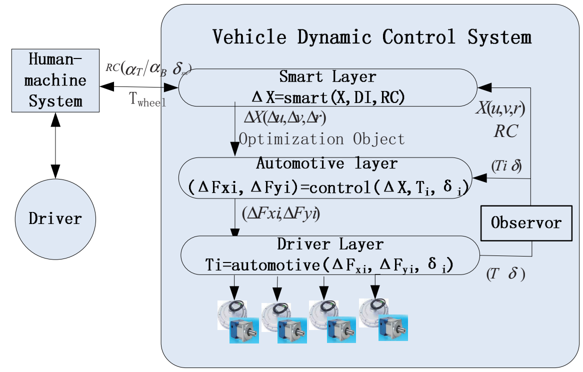


Figure 6 Control structure for NG-EV

IV. STRUCTURE OF CONTROL SYSTEM

As the NG-EV is designed with a unique "zero off-set" steering wheel positioning parameters and the configuration to set the driving and steering unit to the wheel side, a new structure of the control system is needed. As shown in Fig. 5, the vehicle dynamic control structure is divided into 3 layers: the “smart level”, “the automotive level” and the “driving level”.

The “smart level” would receive the signal from the steering wheel, accelerating or braking pedal and other commands with the access of Human-Machine Interaction System. Meanwhile, it would estimate the vehicle state parameters using a proper observer embedded with a vehicle dynamic model. Then it would decide what the desired vehicle state is and pass the error of that and the ideal state parameters to the "automotive level". The four-wheel vehicle is a typical over-actuated system. So there are myriad methods to distribute the tire forces among the four wheels due to the most important aspect, like the economy or safety. The “smart level” also should be “smart” enough to decide which kind of optimization object the next layer should adopt.

The "automotive level's" main job is to fulfill the object received from the upper layer based on a specific optical method. As NG-EV is a typical over-actuated system with two inputs and eight outputs, optimization method and control theory are needed here.

A way to achieve the tire forces is to control the speed of the driving and steering motors [12]. However, it will require an inverse tire model, which is too complex to calculate in real-time. Also, that means to reconnect the steering wheel and the driving wheel with an electric system geometrically, which has no advantages over traditional cars. Nevertheless, because of the errors of the vehicle model especially the tire model, errors of motors eg., the over-actuated system would be forced to make so severely uncoordinated motion that will cause tire slip dangerously, which would damage handling and stability performance of a car.

So maybe we could solve the problem from another angle: to use the torque control method. In this case, the speed of motor is followed. As it applies to a single wheel, the longitude and lateral force is produced by the driving motor and steering motor respectively. From the classic Pacejka 89 tire model[13], we could get the following equation:

Fx=(D*SIN(C*ATAN(B*k -E*(B*k-ATAN(B*k)))))
Fy=(D*SIN(C*ATAN(B*α-E*(B*α-ATAN(B*α)))))
Mz=(D*SIN(C*ATAN(B*α-E*(B*X1-ATAN(B*α)))))

where Fx,Fy,Mz,α,k, B, C, D, and E represent Longitudinal force, Lateral force, Self-aligning torque,, Sideslip angle, Longitudinal slip, Stiffness Factor, Shape Factor, Peak Factor and Curvature Factor respectively.

Also

$$Mt = Fx \times r_w + Iyy \times \frac{d\omega}{dt}$$

$$Mn = Mz + Izz \times \frac{d^2\delta}{dt^2}$$

where Mt, Fx, rw,Iyy,andω represent Drive motor torque, Longitudinal force of tire , Tire Radius, Wheel moment of inertia around the y-axis and Wheel angular velocity respectively. Mn, Mz, Izz and δ represent Steering motor torque ,Self-aligning torque of tire, Wheel moment of inertia around the z-axis and Wheel steering angle respectively.

That is

$$\begin{cases} Fx = f(Mt, \omega) \\ Fy = g(Mn, \delta) \end{cases}$$

Where f and g represent a single variable function.

As we could see, the longitude force is mainly produced by the driving motor via the longitudinal slip rate and lateral force is mainly caused by the steering motor via sideslip angle. However, the characteristics of a pneumatic tire are so complex that the longitude and lateral force will influence each other. So a correction factor should be applied to each motor and the steering and driving motors would have coordination without the information of the whole vehicle. The method to produce longitudinal and lateral tire forces is called “the wheel-side driving-steering coordinated control algorithm”. The idea could be expressed in the following equations:

$$\begin{cases} Fx = f(Mt, \omega) + K1 \times Mn \\ Fy = g(Mn, \delta) + K2 \times Mt \end{cases}$$

Where K1 and K2 is the correction factors.

V. Simulation and Analysis

To test our thought, the control algorithm is established under MATLAB/Simulink and a 14 freedom degree vehicle model is built in ADAMS. By using the co-simulation of the two mainstream softwares, it will be more convenient and professional to build the mechanical system and control system. Besides, in this way, it would be more authentic for the verification of the method.

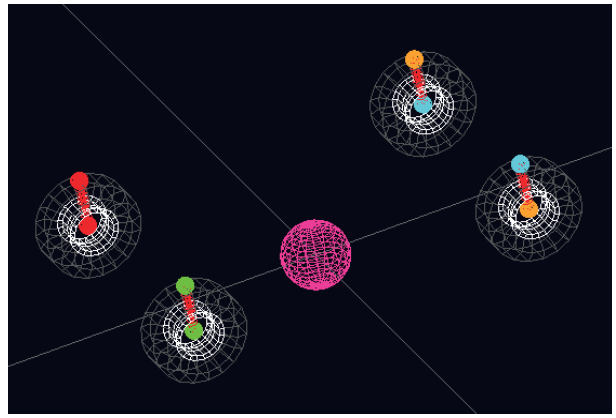


Figure 7 Model in ADAMS

A. Establishment of the model

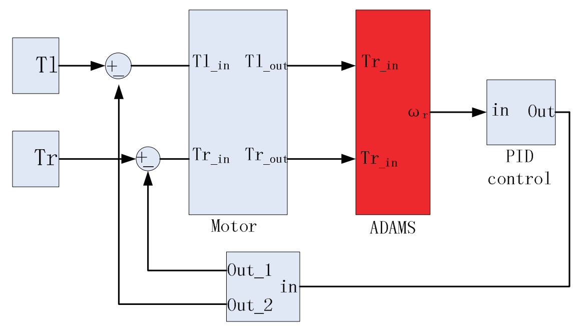


Figure 8 Co-simulation by ADAMS and Simulink

The car model is built in ADAMS with the same parameters with our real test car as shown in Table 2. The effect picture is shown in Fig. 7.

The control scheme and communication module between ADAMS and MATLAB are shown in Fig. 8.

The motor model is built in Simulink using a second-order system:

$$G(s) = \frac{Tm}{Tm^*} = \frac{1}{1 + 2\xi s + 2\xi^2 s^2}$$

Where ξ,Tm , Tm* is the time constant, motor output torque and input torque signal.

Table 2 the parameters of vehicle

Wheelbase	M	2.1
Track width	M	1.4
Izz of vehicle	$Kg \bullet m^2$	540
Iyy of vehicle	$Kg \bullet m^2$	411
Ixx of vehicle	$Kg \bullet m^2$	188
Tire Radius	M	0.25

Simulation

The ideal vehicle tire and the ideal vehicle dynamic state are shown in Fig. 9 and Fig 10. And the optical distribution of the tire forces is caculated by MATLAB optical toolbox with the object below.

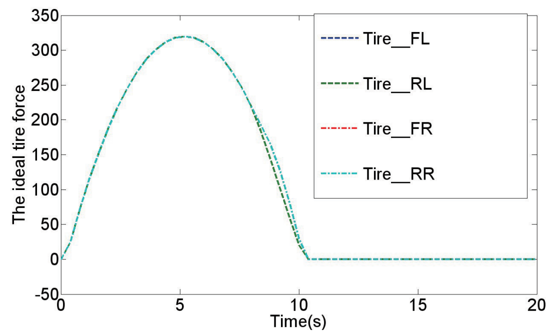
Minimize:

$$\left(\sum_{i=1}^{4} Fxi\right)^2 + \left(\sum_{i=1}^{4} Fyi\right)^2$$

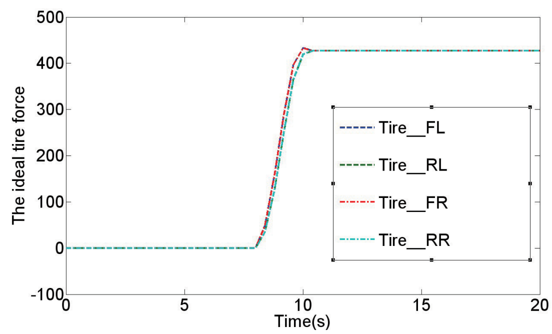
With the algorithm present above, the final tire force and control effect are shown in Fig. 11and Fig 12.

$$F_{x\_tirei} = F_{xi} \times \cos(\delta_i) + F_{yi} \times \sin(\delta_i)$$

$$F_{y\_tirei} = F_{yi} \times \cos(\delta_i) - F_{xi} \times \sin(\delta_i)$$



a. The ideal longitudinal tire forces



b.The ideal lateral tire forces

Figure 9 The ideal vehicle tire forces

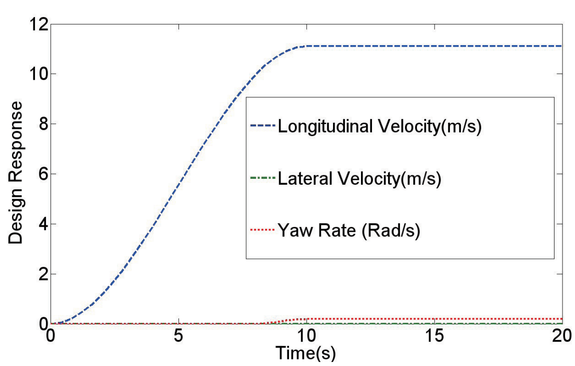
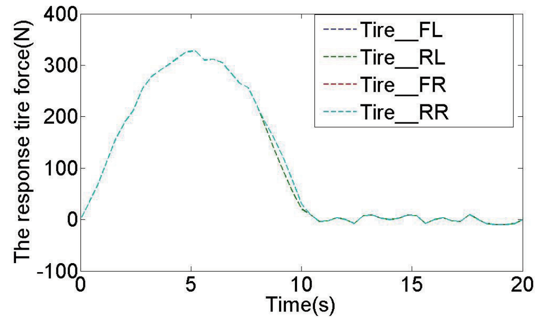
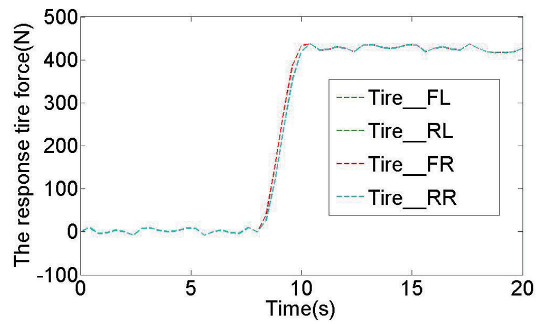


Figure 10 The ideal vehicle dynamic state



a. The final longitudinal tire forces



b. The final lateral tire forces

Figure 11 The final vehicle tire forces

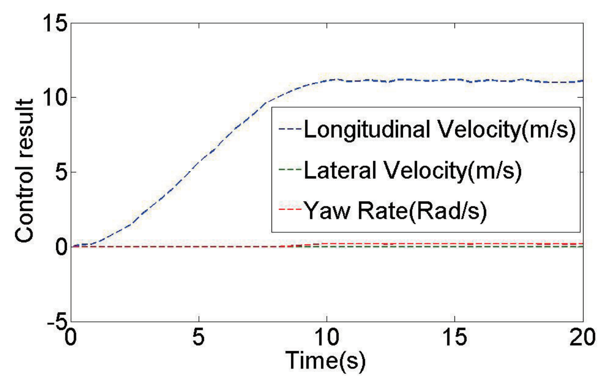


Figure 12 The final control effect

VI. Conclusion And Future works

In this paper, both advantages and shortcomings of the vehicle with four-wheel-independent wheel-side steering and driving electric vehicle are analyzed. According to this features, we make a bold vision of the mechanical platform and control system for the NG-EV. The usage of the "zero offset" steering wheel positioning concept is applied and a three layers of the control structure is established. By using algorithm with a coordination of driving unit and steering unit, longitude and lateral forces are generated directly. All the design is verified under the

Figure 13 The real test EV

co-simulation of MSC. ADAMS and MATLAB/SIMLINK. Results show the present method is suitable for the new type EV.

In the future, the algorithms will be tested on our newly built EV as shown Figure 13.

ACKNOWLEDGMENT

We would like to thank teachers and colleagues in State Key laboratory of Automobile Dynamic Simulation (ASCL) Jilin University for their cooperation of the experiments and many helpful discussions about this work. Especially we would like to express gratitude for professor Hsin Guan and professor Jun Zhan for the valuable guidance. Without their help, we could not fulfill the job.

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