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Control Strategy and Simulation In Steer By Wire System

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Abstract-- The stability and manoeuvrability of vehicles have been gradually focused on and improved by the automotive industry. Therefore, the SBW system becomes a wonderful choice to improve the performance of the vehicle, because there are some advantages, such as stability and manoeuvrability for the vehicles, and safety can be guaranteed for the operators. However, disadvantages also exist: the feedback from the front wheel may not be as perfect as the traditional vehicles, which means the drivers can not feel the road condition as easily as without SBW. Therefore, how to improve the feedback on the hand wheel and enhance the driving feeling to the drivers is the focus of this paper.

Keywords—steer by wire, Gear ratio, steering angle, PID controller.

I Introduction

1.1 Control Strategy

The SBW system controller is divided into the steering wheel motor control and the front wheel motor control. The purpose of the steering wheel control is to improve the driver's steering feel by generating reactive torque. The purpose of the front wheel motor control is to steer the front wheel angle appropriately for improving the vehicle's maneuverability and stability. The proposed SBW control system is shown in Fig. 1.1 where the driver torque applied to the steering wheel is considered as the input, and the front wheel angle is defined as the output. The system is composed of two loops: upper loop, which mainly consists of steering wheel and torque feedback motor, and lower loop, which mainly consists of front wheel and a driving motor. To achieve the bilateral control performance, these two loops are controlled by two PID controllers, respectively[1]. The PID controller in lower loop is designed to control the actual front wheel angle to track the steering wheel angle. Its input is the error between the desired front wheel angle and the actual front wheel angle. tis output is the control voltage sent to the steering motor. [3] The desired front wheel angle is calculated based on the variable gear-ratio and the defined steering wheel angle. The actual front wheel angle is measured by an encoder installed with the driving motor. In the upper loop, there is another PID controller, which is used to provide the feedback torque to steering wheel so that driver can have a feeling about different steering situation. This feedback torque reflects the tyre-road contact and is generated reactive torque map in the system. When the front wheel turns to a certain angle, the torque will be generated in terms of this angle and vehicle velocity. This torque is regarded as a reference torque. The error between this reference torque and the measured torque from the torque feedback motor is defined as the input to the PID controller. The output of the PID controller is the control voltage, which is sent to the feedback torque motor so that the output torque of the motor can follow the reference torque. As this motor is connected to the steering wheel, the driver can feel this torque when steering the wheel. The output torque of the motor will be measured by a current sensor as the current of a DC motor is proportional to its torque[5]. In addition, the actual constraints on the steering wheel and the front wheel are also included in the too loops.

The PID controllers will be designed to reduce the tracking errors. The controller gains are adjusted according to the simulation results referring to the Ziegler-Nicholas rules. As for different velocities the gear-ratio will be different. To account for this variation, several PID controllers will designed for several typical velocities such as 20km/h, 5km/h, 60km/h, 70km/h, 80km/h, and for other velocities, the PID controllers will be scheduled by interpolating the relevant controller gains. [9]

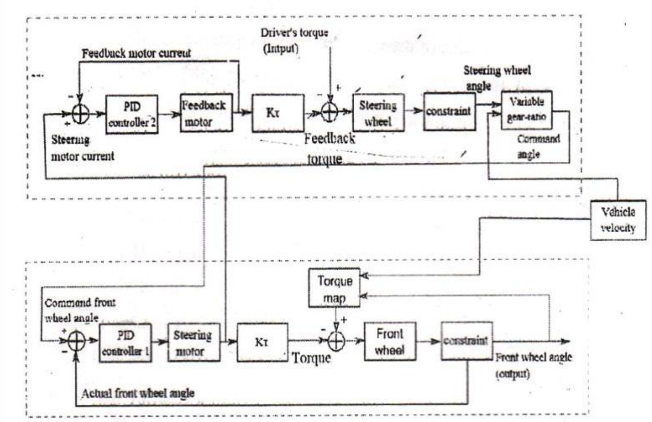


Fig 1.1 Control System Model Design

II Material and Methodology

2.1 Steering Wheel Motor Control

The basic purpose of the steering wheel motor control is to generate reactive torque like a real commercial vehicle when the driver steers[6]. Furthermore, it makes the steering wheel easy to steer at low speed or when parking the vehicle and to make steering wheel tight at high speed for improving the driver's steering feel by adjusting reactive torque. It is relied on the variable steering ratio. PID control method is used to control the steering wheel reactive torque motor in this thesis, as the fig.1.1 shown above.

2.2 Front Wheel Motor Control

For control of the front wheel, the signal from the HILINK board is very important because there is no mechanical linkage between the steering wheel and the front wheel like there is in a conventional steering system. [2] To control the front wheel motor, the PID control method is also used as shown in fig.1.1

2.3 Gear Ratio

The gear ratio is defined as the ratio of steering wheel rotation to steer angle at the road wheel. Normally these range from 15 or 20 to 2 on passenger cars. A steady-state control strategy for ideal gear ratio was introduced to keep the steering gain of the vehicle as a constant and make the characteristic of the SBW vehicle independent of the speed and steering angle. A stability control algorithm was proposed to correct the steering angle dynamically based on the vehicle state feedback. The results of the simulation and the test in a driving simulator showed that the introduced strategy does keep the vehicle steering gain constant to reduce the driver burden, allowing the unskilled driver to drive the vehicle easily and effectively. [2] The proposed stability control algorithm based on the vehicle state feedback improves safety and stability of the SBW vehicle.

In the mechanical vehicle, the gear ratio was fixed; therefore, the steering characteristic of the vehicle can be non-linear varying with the changes of the velocity and lateral acceleration in the vehicle. For the control of the vehicle following by the driver's desired trajectory, the driver must adjust constantly the steering wheel to ensure to control the steering of the vehicle, thus, these extra controls are actually increasing the burden for the drivers. [8]

2.4 The Steady-State Control Strategy for Vehicle Steering Gain

In the process of driving, keep the steering gain does not change while the steering wheel changes, in other words, it would keep the linear relationship between the angle of steering wheel and the yaw rate with the different velocity and lateral acceleration. [10] This would reduce the operations of the drivers to keep the vehicle steering along the desired route. It is an easier job for the drivers operating a vehicle because the less steering compensate was needed. In the same time, variable steering ratio used in SBW system could improve the safety and stability of the vehicle, which would be suitable for more different kinds of people to control the vehicles, especially for the non-professional drivers or young lady to control the dynamics of automotive.

It could be designed any steering ratio in SBW system, thus, designed a variable steering ratio could keep the steering ratio gain of the vehicle fixed in the steady – state.

2.5 The Desired Concept of Steering Ratio

Generally, there are two steering ratio gains that defined by us; the first one is the gain that the angle from front wheel (δ_f) to the vehicle response (y), which introduced by G_δ^y. In the steady state, $G_\delta^y = y/\delta$, which is related to tyre, wheel Alignment, suspension, etc. Another one is the gain that from angle of steering wheel δ_{SW} to response of vehicle (y), introduced by G_{SW}^y. In the steady-state, $G_{SW}^y = y/\delta_{SW}$, which is not only related to the tyre, wheel Alignment, suspension, but related to steering characteristics such as gear ratio. [7] [4] The relationship was shown below;

$$y = G_{SW}^y \, .\delta_{SW} = G_\delta^y \, .\delta_S . \delta_{SW}$$

Where

$G_\delta = 1/i$

$G_{SW}^y = G_\delta^y . G_S . K_S$

$.\delta_{SW} / .\delta_f = i$

If G_{SW}^y is equal to K_s in any velocities and steering angles, there is the equation of $G_\delta^y . G_S = K_S$. For SBW system, the steering gain (G_{SW}^y) from steering wheel to response of vehicle is a constant if the reciprocal of steering ratio (G_s) was designed reasonable. In summary, the desired steering ratio is the ratio when G_{SW}^y is equal to a constant, in other words, designed a reasonable desired steering ratio G_s to ensure $G_\delta^y . G_s$ to be fixed, which is also ensure the steering gain in vehicle is stable. In a word, the desired steering ratio is to ensure that G_{SW}^y to be a constant. In reality, the steering gain in the vehicle is also presented by the yaw rate gain or lateral acceleration gain [2]

The response of the vehicle can be represented by the yaw rate(ω_r), according to equations 26 and 27,

The ratio can be described like this,

$$i = G_\delta^y / K_s = \omega_r / (K_{wr} . \delta)$$

III Results and Tables

3.1 Simulation

The simulation model is built by Matlab/Simulink as shown in the Fig.3.1 the variable gear-ratio in the SBW system is included. The torque map as shown in Fig.is also considered in this simulation. The torque relates to the angle of front wheel (or considered as the steering wheel angle) and the velocity of the vehicle. The relationship between the steering wheel angle and the steering torque was shown.

The variable gear-ratio and the torque map both rely on the vehicle velocity and front wheel angle. The simulation is done by providing a defined steer torque to the steering wheel. The constraints on the inputs and outputs are considered, which are defined as the constraints of the steering wheel angle at the low speed according to the variable gear-ratio. [7] In this paper, the constraint of the steering wheel angle is set to 365.5 degrees because the maximum of the front wheel angle is about 40 degrees.

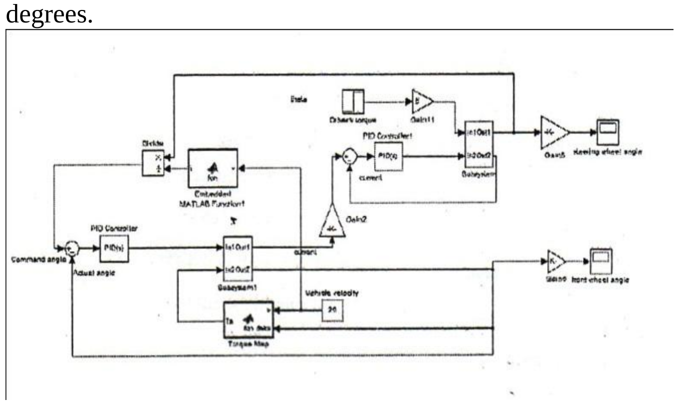


Fig 3.1 Simulation Model for SBW System

The simulation is done by providing a defined steer torque to the steering wheel. [2] The constraints on the inputs and outputs are considered, which are defined as the constraints of the steering wheel angle at the low speed according to the variable gear-ratio. In this paper, the constraint of the steering wheel angle is set to 365.5 degrees because the maximum of the front wheel angle is about 40 degrees. [5]

The relationship between steering wheel angle and front wheel is shown in equation ( )

$\delta_{SW} = i.\delta_f$

Where δ_{SW} is steering wheel angle, δ_f is the angle of front wheel and I is the variable gear-ratio.

As we know, the front wheel angle could always achieve to about 40 degree as its maximum turning angle. However, the constraint of the steering wheel angle is not considered because the steering wheel angle could not achieve to 365.5 degree in high speed according to our driving experience. [3]

For brevity, the simulation results on front wheel angle and feedback torque are shown in the following subsections when vehicle velocity is 10 m/s.

3.2 Front Wheel Tracking Results

To show the performance of the designed control system, the comparison between the SBW system with and without PID controllers is done. The results are shown in the following Fig.3.2 where the upper figure shows the output of the system without PID controllers (no feedback signal are considered) and the lower figure shows the results with the designed PID controller.

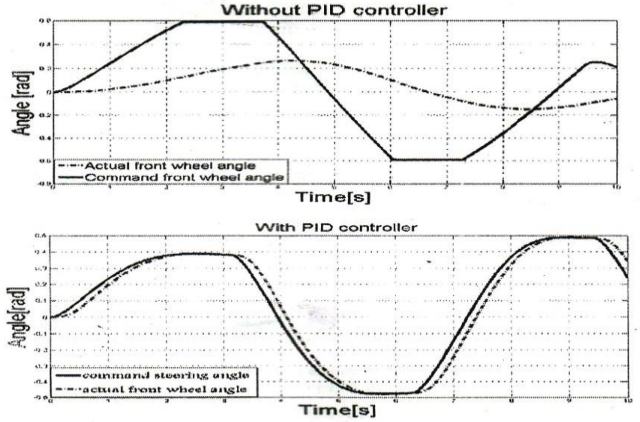
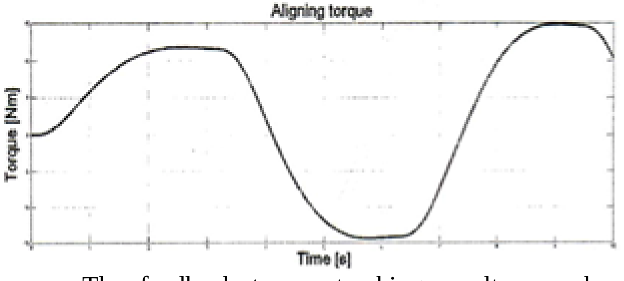


Fig 3.2 Front Wheel Tracking Results

In Fig.3.2 the solid line represents the command front wheel angle and the dotted line represented the actual front wheel angle. The upper figure shows that the results without the PID controllers. [10] It can be seen that the front wheel cannot track steering wheel if no appropriate controllers are applied. However, with the designed PID controllers, the dotted line can well track the solid line as shown in lower figure, which confirms the effectiveness of the designed control system.

3.3 Self-aligning Torque Results



The feedback torque tracking results are shown in Fig.3.3

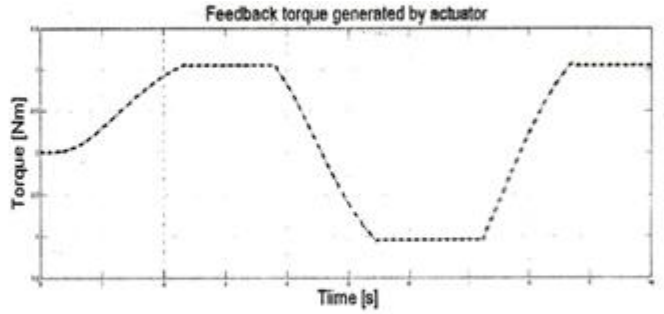


Fig 3.3 Self-aligning Torque Results

The solid line represents the actual aligning torque generated between the front wheel tyre and the road. [4] The dotted line represents the torque generated from the feedback motor The aligning torque is about 10 Nm and it is a litter heavier for the driver to feel the road condition, therefore, a PID controller is used to control the feedback motor to generate the feedback torque in order to guarantee that it can be proportional to the actual aligning torque and let the driver get the appropriate feeling as driving a conventional car. From Fig.3.3 it can be seen that the feedback torque is proportional to the aligning torque with smaller values.

3.4 Front Wheel Angles at Different Velocities

The front wheel angle at different velocities results are shown in Fig.3.4 The solid line, broken line and dotted line represent the front wheel angle at 108km/h, 90km/h and 72km/h, respectively. When the steering wheel angle is fixed, the front wheels have the different performances at different velocities with the design of variable gear-ratio. [5] These three lines illustrate that the front angles will decreases when the velocity increases, and the benefit is the vehicle can be avoided to roll when the steering wheel is turning suddenly by the driver. Compared with the conventional vehicle, the SBW system with variable gear-ratio is the advanced system because the safety of the vehicle is improved when the operator driver the car at the high speed.

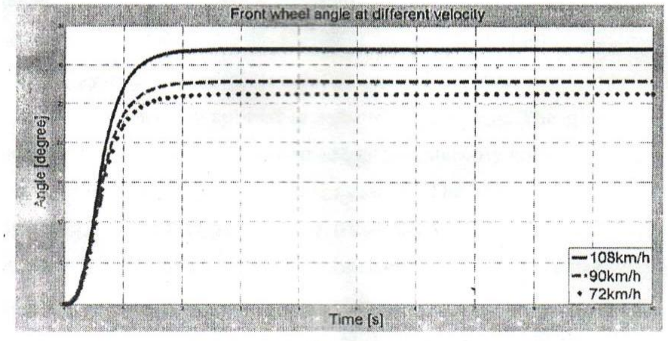


Fig 3.4 Front Wheel Angles at Different Velocities

As we seen the Fig.3.4 the front wheel angles are proportional to the steering wheel angles if the velocity of the vehicle is constant, like 36km/h. [8] For example, the maximum angle of the steering wheel is always 200 degree while the front wheel angle is 12.5 degree. The gear ratio is $\delta_{SW}/\delta_f = 16$, which is suitable to the setting in the simulation. Therefore, the results show that the experiment is totally perfect as we thought.

IV Conclusion

In this paper the method of get the desired variable gear-ratio has given and the simulation of the SBW model has also described. Two controllers are used in the SBW control system.

Front wheel tracking results and the self-torque results are illustrated by the figures, which shows the effectiveness of the two PID controllers. The front wheel can track the position of the steering wheel. At the same time, the operators can receive the force feedback when they turn the steering wheel.

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