Design of the Control Module for Road Feeling Motor Based on MC9S12XS128

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Abstract

In order to make the DC motor of steer-by-wire system accurately and reliably realize the road feeling control function, this paper designs a control module for road feeling motor based on MC9S12XS128 microcontroller. First, this paper presents a model of road feeling control system and studies road feeling algorithm with module controlled by closed loop current PID. Then it designs the hardware and software of road feeling control modules. Finally, it conducts a simulation test under steering condition in the test bed. The results shows that the road feeling control system can give the driver a good knowledge of road conditions and thus improve maneuverability and comfort of the vehicle.

Keywords

Steer-by-wire system; road feeling control; closed loop; PID.

1. Introduction

Steer-by-wire system cancels the mechanical connection between the steering wheel and the directive wheel, and in theory, its force transfer and angle transfer can be designed freely without interference[1]. As a result, the road effect on the steering wheel torque cannot be transmitted to the steering wheel, and so the driver will not be able to grasp the vehicle state and road conditions. Therefore it is quite important to study on driver's road feeling control[2]. Based on the information of front wheel angle and speed of vehicle, Shi Luo [3] established the SBWS steering wheel torque model, then designed the road feeling control strategy and verified its effectiveness through Simulink simulation. Jie Tian [4] proposed a hierarchical control strategy of SBWS Road and designed Fuzzy-PID controller for real-time control of road-feel simulation motor. In order to solve the problems that the road feeling control simulation is susceptible to external disturbances and that modeling is difficulty. Xuyun Qiu [5] designed road simulation control algorithm based on the control technology of linear auto disturbance rejection, and established the road feel control simulation model and verified the stability of the algorithm. Domestic scholars have tried many different strategies for the SBWS road feeling control technology and have made some breakthroughs, but most of them are just theoretical study and simulation. In this paper, we combine road feeling control method and road feeling motor control strategy, and finally verify the feasibility and effectiveness of our designed control module of road feeling motor in the test bed.

2. System overview

In this paper, the design of the steer-by-wire road feeling of control system mainly includes: sensors of angle and vehicle speed, main control ECU, road feeling motor and its control circuit and so on. The structure diagram is presented in Figure 2.1.

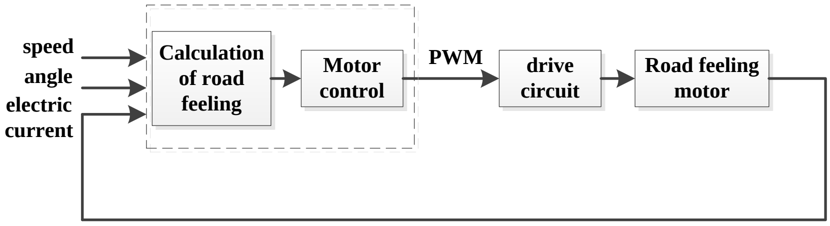

Figure 2.1 structure diagram of road feeling control system

The road feeling control is realized through the main control ECU controling torque motor t. Road feeling is calculated according to the speed of vehicle and steering wheel angle signal to determine the road feeling motor target torque. The motor control module is receiving road sense module output target torque calculation. With reference to the current state of motor to adjust the output signal of the motor to PWM. Because there is a linear relationship between the motor current and motor torque, the torque control can be detected by the current value and current loop to control the realization.

In this design, the road feeling motor using Y260 permanent magnet brushless DC motor and the output torque range of 0-12N.m. ECU uses MC9S12XS128 chip [6], the bus speeds up to 40 MHz and can configuration 8, 10 or 12 bit ADC, 3 µs conversion time, 4 channel 16 bit counter. PWM channel 8, is easy to realize the motor control. Angle sensor selection developed by Bi company in the United States, SX-4300 LH3 phase differential coding sensor, which uses resistance measurement principle. The output voltage is the percentage of working voltage.

3. Algorithm strategy of road feeling control

3.1 Calculation of road feeling

In this paper, through the analysis for the generating mechanism of the traditional automobile steering road feeling [7], we calculate the returning moment, namely road feeling. The aligning torque (M_{sw}) acting on the steering wheel includes directive wheel moment (M_z) and the moment produced by the inertia and damping of steering system itself, and that is

$$M_{sw} = J_{sw}\ddot{\delta}_{sw} + B_{sw}\dot{\delta}_{sw} + M_z / i_l \tag{3.1}$$

Among them, M_z is produced by the effects of the interaction between (aligning torque produced by the kingpin inclination aligning torque) M_A and (aligning torque produced by lateral force) M_{zv} , i.e.

$$M_z = M_A + M_{zv} \tag{3.2}$$

and

$$M_{zv} = \frac{mv^2 b}{\left| L^2 + mv^2 \frac{k_2 b - k_1 a}{k_1 k_2} \right|}(\varepsilon' + \varepsilon'')\delta \tag{3.3}$$

$$M_A = \frac{QD}{2}\sin 2\beta' \sin\delta \tag{3.4}$$

In the formula, Q-- wheel load, can be understood as the half of the mass D-- kingpin shift β'-- kingpin inclination δ -- the front wheel angle F_y -- lateral force m -- vehicle quality

v -- speed a -- the vertical distance from the front wheel to the centroid. b-- the vertical distance from the rear wheel to the centroid L-- wheelbase $L = a + b$ R_t -- turning radius k_1 -- the front wheel cornering stiffness k_2 -- rear wheel cornering stiffness J_{sw} -- the steering wheel moment of inertia δ_{sw} -- steering angle $\delta_{sw} = i_l \cdot \delta$ B_{sw} -- the steering wheel viscous damping coefficient i_l -- steering gear ratio

The Combination of type (3.1), (3.2), (3.3) and (3.4) shows that when the vehicle structure parameters and the directive wheel alignment parameters are determined, the aligning torque of the steering wheel just relates to the vehicle speed and the steering wheel angle. After measuring the speed and the steering wheel angle signal by the sensor, we can use the formula to calculate the aligning torque of the steering wheel.

3.2 The motor PID control strategy

In the control system of road feeling, when the drivers steer, the steering wheel torque is caused by road feeling motor [8]. There is a linear relationship between the armature current and electromagnetic torque, so in this paper we designs a current closed loop controller for the simulation of the aligning torque. The control diagram of road feeling motor PID is shown in figure 3.1:

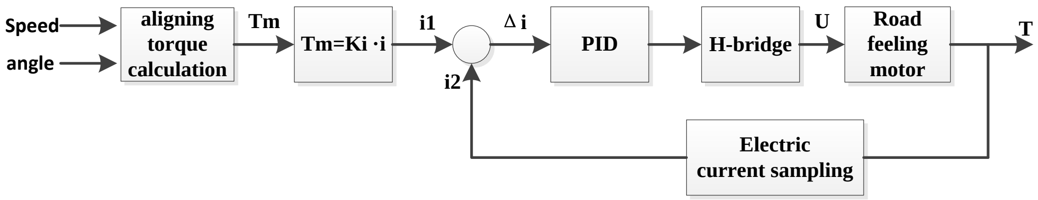

Figure 3.1 the control diagram of road feeling motor PID

One side, we can use the aligning torque calculation method in the section above to get the motor current setting value i_1, on the other side, the motor current is sampled periodically by ECU through the AD conversion module, from which we can obtain the motor current actual value i_2. As the input, the deviation between i1 and i2 determines the duty cycle of the PWM signal by the PID controller, and then drive the road feeling motor through the H bridge.

The incremental PID control is adopted in this paper [9], and the algorithm can be expressed by the following formula:

$$\Delta u(k) = Ae(k) - Be(k-1) + Ce(k-2) \tag{3.5}$$

Where, $A = K_p\left(1 + \frac{T}{T_i} + \frac{T_d}{T}\right)$, $B = K_p\left(1 + 2\frac{T_d}{T}\right)$, $C = \frac{K_p T_d}{T}$

From the above all, it can be seen that the incremental PID calculation process just requires three deviations. So the calculation is simple, and the control increment is the output which will not deviate from the normal value large-scale even if there is a fault of the controller. The actual output control amount from the controller can be obtained through the following formula:

$$u(k) = u(k-1) + \Delta u(k) \tag{3.6}$$

In the type, u(k)-- k control, u(k-1)-- k-1 control. The flow chart of incremental PID control program can been seen in the fifth chapter.

4. The realization of the system hardware

The hardware part of road feeling motor control system mainly includes the Power amplifier of PWM [10], motor current feedback etc.. This chapter mainly introduces the DC motor power drive circuit. System uses optocoupler control circuit to separate power supply of SCM (Single Chip Micyoco) system and the power of motor system. Then the optocoupler control the on or off of MOSFET IRFS8403.

(1) Optocoupler control circuit. The IR2110 chip is used as the driving power tube. The output signal level range is 10 ~20V. HIN and LIN by the pin to achieve common control. When HIN and LIN is low, LO is high, otherwise LO is low. When HIN and LIN are high, HO is high, otherwise HO is low. This circuit will boost 5V to 12V by LM2576 for the VCC pin driver of IR2110, optocoupler control circuit as shown in figure 4.1:

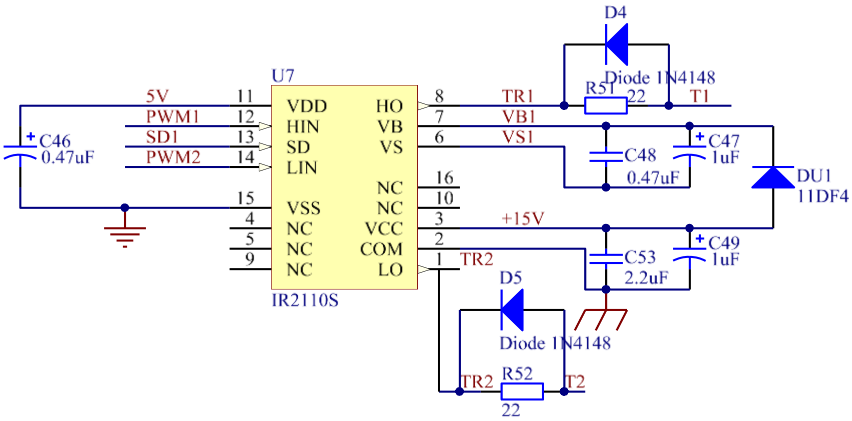

Figure 4.1 optocoupler control circuit.

(2) H bridge. Upper and lower bridge arm using N channel MOS tube. When N-channel MOSFET turn-on, the gate g voltage must be than the source S 10 ~ 16V to ensure perfectly conducting. N-channel ia small internal resistance and small loss than the p-channel. Figure 4.2 shows the H MOS bridge control circuit:

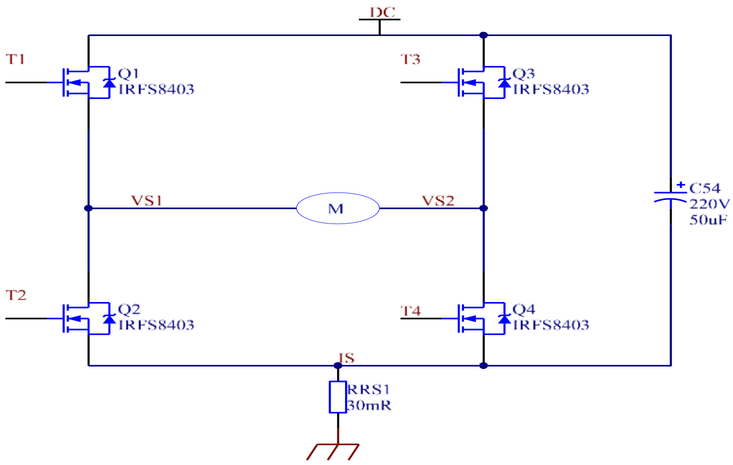

Figure 4.2 H bridge control circuit

In the figure, MOS tube driver using the photoelectric isolation was isolated from the power supply working power supply of the single chip microcomputer system and DC motor. It improves the reliability of the system. By four MOS tube consisting of a full bridge circuit to facilitate the control DC motor reversing, we should note in motor change to control for a group of pipes. Turning off the rear another group can be conducted. And it should be avoided on the same side of the pipe and conduction caused by short circuit burned MOS tube.

5. System software design

5.1 The main program design

Initialization process of each module is completed by the main program when the system is powered. When self-test and initialization of each module is done, the interruption is opened, and then signal acquisition and PWM duty cycle adjustment work are completed in interrupt handling.

5.2 The implementation of PWM pulse:

PWM signal is generated by using MCU xs128 microcontroller. Some key points set in the software includes: (1) set the cycle of the timer/counter (2) set the turn-on time in PWM control register (3) set the PWM output direction start the timer (4) start the timer (5) enable the PWM

The output subroutine of the PWM is shown in figure 5.1:

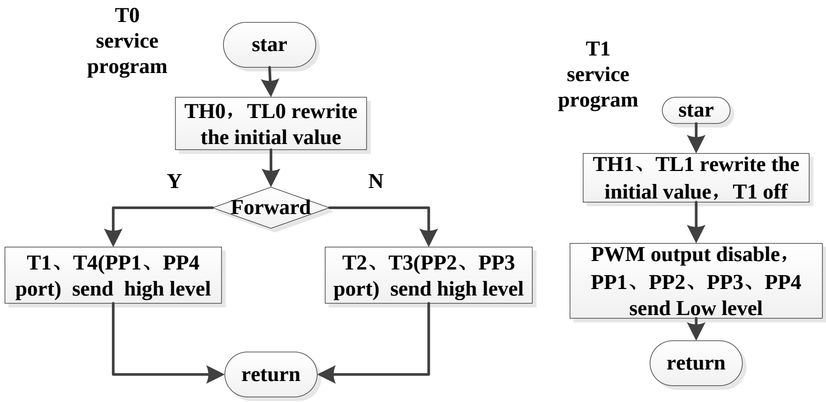

Figure 5.1 PWM output subroutine flow chart

5.3 Incremental PID control

The incremental PID control algorithm can be obtained according to the formula (3.5) and (3.6). The flow chart is shown in figure 5.2:

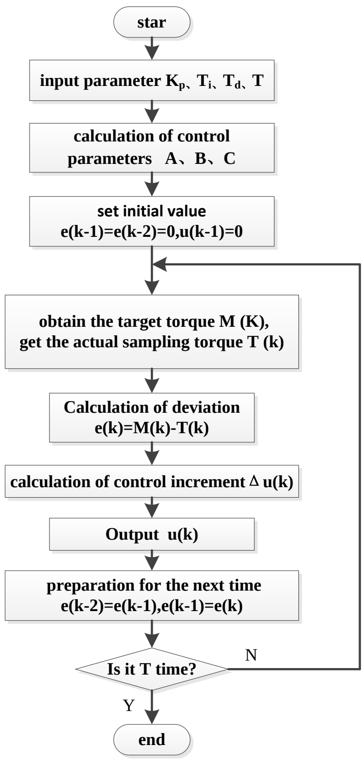

Figure 5.2 the incremental PID control program flow chart

First of all, we input proportional coefficient Kp, the integral time constant Ti, differential time constant Td, sampling period T, and calculate the control parameters A, B, C according to these parameters. At the second time, set the initial value: e(k-1)=e(k-2)=0, u(k-1)=0, and we will obtain the target torque M(k) and the actual output torque T(k) of the motor. For the third time, the torque error value e(k)=M(k)-T(k) is calculated, then the control increment $\Delta u(k)$ and the output control variable u(k) are calculated. Fourthly, prepare for the next moment. At last, detecting that whether the last cycle time is up, and when it is up, we will finish the time cycle, otherwise continue the circulation.

6. Test and verification

Through the simulation of steering driving condition, the model can test the feedback road feeling information in the process of steering driving. Moreover, we can obtain the key information in the process of testing, such as angle, torque, speed. The vehicle speed is set to 35 km/h and 50 km/h by using the signal generator, then record the test data when the steering wheel is under different angles. This test only take left steering condition into consideration.

In the test, in order to measure the actual torque, we select the static torque sensor, the range of which is 0~25N / m. During the test, the data such as AD sampling angle signal value of P1, P2, P3, T of torque signal , the vehicle speed signal V, the steering wheel angle θ calculated by ECU, and the target torque M value of road feeling motor are concerned.

The experimental results are as follows:

Test data:

Select 10 data samples from the steering test data, and specific data presented in the table. The left steering test data as shown in table 1. The output characteristic curve According to the angle sensor, the left (counter clockwise) angle value of which is negative, corresponding to the calculated target torque is negative. However, the data measured by torque sensor can only be positive. Therefore, we make the target torque of the motor to the contrary. The data analysis diagram as shown in Figure 6.1.

Table 1 the left steering test data sheet

Num	P1(V)	P2(V)	P3(V)	T1(V)	*v*(km/h)	*θ*(˚)	*M*(N m)	*T*(N m)
1	1.1	1.39	2.6	1	35	-50	-5.080	5.0
2	0	2.5	2.5	1.8	35	-90	-9.144	9.0
3	1.25	3.77	2.2	2.72	35	-135	-13.716	13.6
4	3.01	4.5	2.1	0.72	35	-38	-3.861	3.6
5	3.9	3.55	2.04	2.2	35	-113	-11.481	11.0
6	3.2	1.67	1.56	2.7	50	-156	-14.022	13.5
7	2.7	0.22	1.50	1.7	50	-100	-8.988	8.5
8	1.06	1.4	1.6	1.12	50	-62	-5.573	5.6
9	0.56	3.1	1.03	0.64	50	-35	-3.146	3.2
10	2.03	4.5	1.1	1.42	50	-82	-7.370	7.1

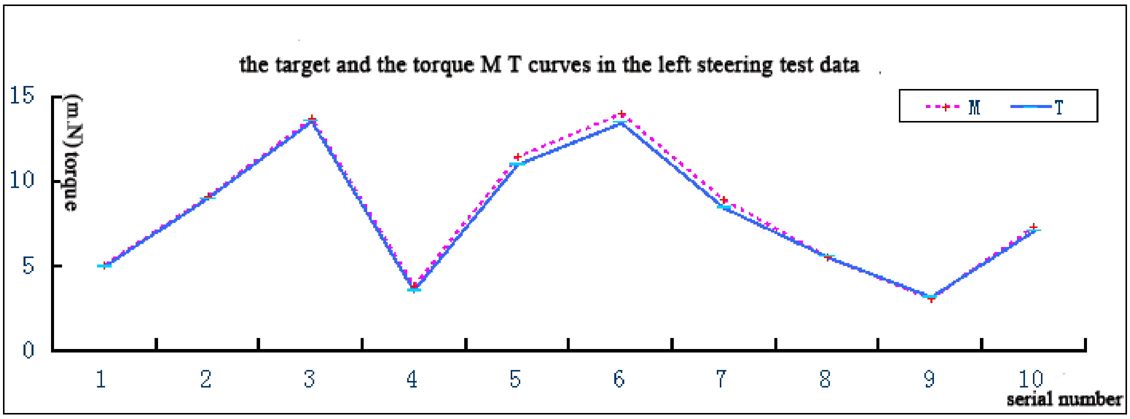

Figure 6.1 Diagram of the test data analysis on left turn

It can be conclude through the analysis of the test data:

1. The target torque value M of the motor is close to the actual torque value of T, indicating that the closed-loop control effect is achieved.

2. At the same speed and different angle, the target torque of the motor is different, which means different road feeling information. This is to say, under normal steering conditions, the road feeling control module which designed in this paper can help the diver get realistic feedback road feeling information.

7. Conclusion

Firstly, this paper proposes a model of road feeling motor control system, then select the appropriate motor, sensor, ECU for this model. In the second part, the road feeling control algorithm is studied and the strategy of closed-loop current PID control is designed for the module. Thirdly, we design hardware conditions and software conditions for the road feeling module. Finally, confirmatory analysis is performed on the test bench. We arrived at the conclusion that when the target torque M value of the motor is close to the actual torque T value, good following effects can be achieved. Under normal steering conditions, the road feeling control module which designed in this paper can help the diver get more realistic feedback road feeling information.

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