Design of Motion Control System of Smart Car

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Abstract. Based on the design of Freescale intelligent tracking car, the kinematics model is established according to the motion characteristics of the car after introducing the control system and the composition of each functional module of smart car. In order to make the smart car move stably and quickly in the predetermined track, the corresponding PID control algorithm is proposed to control the steering system and power system of the car, respectively. The experimental verification shows that the car basically achieves the goals of "stable", "accurate" and "fast" operation in the automatic control theory.

1. Introduction
Smart car is a collection of environmental perception, planning and decision-making, multi-scale auxiliary driving and other functions of integrated system. It focuses on computer and modern sensing, information fusion, communication, artificial intelligence and automatic control technology, which is a typical combination of new technology and high-tech.

The core idea of smart car is to imitate human thought and action to achieve or partially realize some control tasks that people can complete. The design of “humanoid car controller” has become the ultimate goal of smart car design.

2. Overall design of smart car
In this design, the B-type car model designated by the organizing committee is selected, which is a four-wheel operation mode. The power system of the car is composed of two wheels driven by a single motor, and the steering system is composed of two front wheels controlled by steering gear.

The goal of smart car race is to finish the given track stably, accurately and quickly, so it is required that the car must detect the track information accurately and quickly, and make corresponding control and implementation in time. In order to achieve the above control objectives, the system adopts two groups of infrared sensors ST188 of a total of eight channels installed in line in the front of the car to detect the track information [2]. The steering gear installed on the front wheel controls the direction of travel, and the DC motor installed on the rear wheel provides power for the car. The hall sensor is used to collect the motion state of the car, that is, the speed detection, then the sampling data is sent to AT89C52 SCM for processing. According to the PID control algorithm, the movement state of the car can be effectively controlled in real time to achieve the purpose of fast tracking.

The system consists of six parts: SCM module, power supply module, step-down module, infrared sensor module, speed sensor module, steering gear control and motor drive module [3].
3. Power system and control algorithm of the car

After software programming, PID parameters can be continuously debugged, but it is too tedious and difficult to adjust. Therefore, this design adopts MATLAB simulation software to derive the motor mathematical model to get PID parameters more quickly and conveniently.

3.1 Mathematical model of DC motor

Since the closed-loop control of speed is necessary, the mathematical model of the motor has to be established first. According to the method mentioned in the article "The Realization of Digital PID DC Motor Speed Control System Based on MATLAB", the mathematical model of motor can be obtained, which is realized by the following basic common equations for motors:

**Electrical equation of DC motor:**

\[
\frac{d\omega}{dt} = \frac{u_a}{L}\omega - i_a - Ce\omega
\]  

(1)

**Mechanical equation of DC motor:**

\[
J \frac{d\omega}{dt} = T - T_L
\]  

(2)

Where: \( Ce \) is the coefficient of potential of the motor; \( T \) in formula (2) is the moment of inertia converted to the motor shaft.

The transfer function of DC motor speed relative to output voltage can be obtained by Laplace transform of formula (1) and (2):

\[
H(s) = \frac{\Omega(s)}{U_a(s)} = \frac{1/C_e}{T_aT_0s^2 + T_0s + 1}
\]  

(3)

Where: \( T_m = \frac{JR_a}{CeC_T} \) is the mechanical time constant; \( T_a = \frac{L_a}{R_a} \) is the electrical time constant.

It can be seen from formula (3) that the transfer function of DC motor is a second-order nonhysteretic transfer function, which is:

\[
G(s) = \frac{K}{(T_1s + 1)(T_2s + 1)} = \frac{K}{T_1T_2s^2 + (T_1 + T_2)s + 1}
\]

The motor selected for this design is the RS-540 with the following parameters.

- Working voltage: DC7.2V
- No load current: 1.72A
- Maximum current: 9.71A
- No load speed: 23400RPM±10%
Load speeds: 19900RPM±10%
Maximum power: 61.75W
Motor moment of inertia: \(1.47 \times 10^{-5} \text{kg} \cdot \text{m}^2\)

From the above parameters, \(Tm\) and \(Ta\) can be derived, and:
\[
H(s) = \frac{3.6127}{9.63 \times 10^{-7} s^2 + 2.4 \times 10^{-3} s + 1}
\]

3.2 Implementation scheme selection of PID algorithm
PID algorithm is generally divided into two categories: incremental algorithm and positional algorithm. The incremental algorithm does not need to do the accumulation, so the calculation error and calculation accuracy have little influence on the calculation of the control; the positional algorithm needs to use the accumulated value of the former deviation, which is easy to produce large cumulative error.

The motor used in the car is DC motor, and incremental PID is used for closed-loop control of the car.

The derivation formula of incremental PID algorithm is as follows:

According to the recursive principle, it can be obtained that:
\[
u(k-1) = k_p(error(k-1) + \sum_{j=0}^{k-1} error(j) + k_d(error(k-1) - error(k-2)))
\]

Where: \(u(k)\) is the output value of the controller at the kth sampling; \(Kp\), \(Kd\) and \(Kp\) correspond to integral, differential and proportional coefficients, respectively.

Therefore, the incremental PID control algorithm is as follows:
\[
\Delta u(k) = u(k) - u(k-1)
\]
\[
\Delta u(k) = k_p(error(k) - error(k-1)) + k_d(error(k) + k_d(error(k) - 2error(k-1) + error(k-2)))
\]

3.3 Parameter setting method
When setting the parameters of PID controller, it can be adjusted continuously with MATLAB simulation according to the parameters of the controller and the dynamic and steady performance of the system. [5-7]

In order to reduce the number of parameters that need to be adjusted, PI controller can be used first. In order to ensure the safety of the system, parameters should be set more conservatively at the beginning of debugging. For example, the proportion coefficient should not be too large, and the integration time should not be too small, so as to avoid the instability of the system or excessive overshoot. A step signal will be given. According to the output waveform of the controlled variable, the system performance information, such as overshoot and adjustment time, can be obtained. The PID parameters should be adjusted continuously according to the relationship between PID parameters and system performance.

If the overshoot of the step response is too large to be stable until many times of oscillation or is unstable at all, the proportional coefficient should be reduced and the integration time should be increased. If the step response has no overshoot, but the controlled value rises too slow and the transition time is too long, the parameters should be adjusted inversely.

If elimination of the error is slow, the integration time should be appropriately reduced to enhance the integration effect.

In a word, the debugging of PID parameters is a comprehensive process in which the parameters influence each other. It is very important and necessary to try many times in the actual debugging process.
3.4 MATLAB simulation debugging
The use of MATLAB software aims to derive effective and practical PID parameters through continuous simulation and debugging by mathematical modeling. Firstly, according to the mathematical model of the motor, the controlled object is determined as follows:

\[
H(s) = \frac{3.6127}{9.63 \times 10^{-7} s^2 + 2.4 \times 10^{-3} s + 1}
\]

The controlled variable is the motor speed, and the incremental PID algorithm is used in the specific operation scheme.

According to the simulation results, the system has two conjugate imaginary roots located in the left half plane of S, so the system is stable and is a second-order underdamped system with damped oscillation.

The system with good dynamic performance should have the characteristics of zero overshoot and small adjustment time. Next, Kp, Ki and Kd are determined using the parameter setting method mentioned in the previous section.

We take the following set of parameters for simulation:

\[
kp = 0.01;
\]
ki=0.05;  
k_d=0;

The simulation results are shown in Figure 5, from which it can be seen that there is an overshoot in the system, so the Ki parameter should be reduced. Set Ki = 0.01, with the simulation results shown in Figure 6. It can be seen that there is no overshoot of the system and the adjustment time is very small. Therefore, K_p = 0.01, K_i = 0.01 and K_d = 0 are determined as the PID parameters of this control.

4. Software design scheme
The software design is programmed in C language and written in the keil development environment. The C language is designed to provide a simple way to compile, process low-level memory, generate a small amount of machine code and run without any support of the operating environment. Compiling in keil software allows errors to be detected and corrected in time. The software design takes the speed control as the core, mainly using the incremental PID algorithm. The PID controller is introduced into the software, which is composed of three parts: detection, comparison and execution. The detected signal is compared with the expected value, and then the response of the system is adjusted by this error, which can ensure the stability and improve the dynamic performance of the system.

4.1 Steering gear control
The steering gear is a simple position servo system, with a PWM signal as the control signal. Through the internal position feedback, the output angle of the steering wheel is proportional to the given control signal [8], so the open-loop control can be used for the control of the steering gear. When the load torque is less than its maximum output torque, its output angle is proportional to the given pulse width.

The control pulse period of the steering gear is 20ms, and the pulse width is 0.5-2.5ms, corresponding to the position of -90° to +90°, respectively. The control method of the steering gear is to input a pulse width signal to the steering gear, and it will rotate to a suitable position. The control relationship is as follows:

| Pulse width | Output shaft angle of steering gear |
|-------------|-----------------------------------|
| 0.5ms       | -90°                              |
| 1.0ms       | -45°                              |
| 1.5ms       | 0°                                |
| 2.0ms       | 45°                               |
| 2.5ms       | 90°                               |

Open-loop control strategy of steering gear: deflection angle of steering gear and path curve angle

4.2 Speed control strategy
The speed control refers to that the speed of car will change according to whether the infrared sensor detects the black line or not. First, a given speed is set, and then the real-time speed is calculated by the pulse signal detected by the hall sensor. The two form a feedback loop. Because of the need to track stably at the fastest possible speed, two problems should be considered when the car is in motion:
4.2.1 Straight acceleration
In the software design, the given speed of the car is 1500r/min. If the front infrared sensor does not detect the black line, that is, the P1 port connected to the sensor outputs low level to the SCM, then the given speed of the car will be increased by 10 each time, with the maximum value of 2000r/min, which allows the real-time speed of the motor to be input into the PID controller for effective tracking and acceleration.

4.2.2 Curve deceleration
The sensors are installed in line at the front section of the car about 10 cm. When the two sensors at the left and right ends detect the black line, that is, the output is high level, the given speed of the car will be decreased by 20 each time. After that, when the inner sensors detect the black line in turn, the reduction of the given speed increases, with the minimum speed of 1000r/min. The scheme allows the car to slow down in real time according to the situation, so as to pass the curve as fast as possible.

5. Design results
The above control strategy for the steering system and power train enables the car to finish the whole course of the track stably at a fast speed. With the participation of PID controller, the goal of "stable", "accurate" and "fast" operation is realized for straight acceleration and curve deceleration, which proves that the control strategy is effective and feasible.

References
[1] Yang X.L.(2010)Application of PID arithmetic in aptitude vehicle. Experimental Science and Technology.,8 (4): 187-189
[2] Shi Y.(2012) Research and development of the embedded intelligent automobile kinetic control system. Xiangtan University, Changsha.
[3] Zhuo Q., Huang K.SH., Shao B.B.(2007)How to design a smart car: challenging the "Freescale" Cup . Beijing University of Aeronautics and Astronautics Press,
[4] Kang K.,(2010) Realization of digital PID DC motor speed control system based on MATLAB. Computer Knowledge and Technology. , 06 (022): 6372-6374
[5] Liu J.H.(2005) Advanced PID control and MATLAB simulation. Beijing: Electronic Industry Press.
[6] Zhang X.H.(2006) Digital simulation and CAD of control system, 2nd Edition. Beijing: China Machine Press.
[7] Yao J. (2005)Simulink modeling and simulation. Xi'an: Xi'an University of Electronic Science and Technology Press.
[8] Yao P., Zhang S.X., Wang D.P.(2009) Cai E. Physical model and parameter estimation of electromechanical actuator and its PWM driver. Journal of Projectiles, Rockets, Missiles and Guidance, 29 (5): 90 ~ 95