Design and Implementation of Tracking Smart Car with Wireless Communication Functions

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Abstract. In order to realize the rapid and stable automatic tracking of the smart car, this paper designs and implements a tracking smart car with wireless communication function in the background of the National College Students Smart Car Competition of China. The system of the smart car includes hardware design, signal processing, and software algorithms. The hardware design mainly includes track information acquisition sensors, auxiliary control modules and communication modules. The software algorithms mainly includes the filtering and difference-ratio-sum algorithm, incremental Proportion Integration Differentiation (PID) and communication control algorithm. Firstly, the electromagnetic signal in the track is acquired by the inductance-capacitor pairs, and the deviation between the actual position of the smart car and the position of the electromagnetic wire laid in the central track is calculated. Then, the incremental PID control algorithm is used to calculate the pulse width modulation (PWM) signal according to the deviation, and the PWM signal is acted on the motor to drive the smart car to always drive along the central track, so as to achieve the purpose of automatic track guidance. The wireless communication module is used to achieve the communication between the two smart cars. Finally, a large number of hardware and software tests are carried out using the upper computer debugging tools. Experiments demonstrate that the smart car of this design can complete the communication task of two cars, can accurately achieve automatic tracking, and obtain higher speed performance.

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1 Introduction

With the improvement of the level of scientific and technological innovation, various technologies are developing in the direction of intelligence. As a key part of intelligent transportation, intelligent vehicle is a typical high-tech complex that integrates environmental perception, decision-making, interconnection communication, which concentrates on the modern sensing, information fusion, communications, artificial intelligence and automatic control [1]. The modern self-driving vehicle is an intelligent system that navigates autonomously along the main road, and the smart car system is a microcosm of the self-driving vehicles, there are many similarities between the two in terms of information acquisition, information processing and interconnection communication.

The National College Students Smart Car Competition of China is a creative science and technology competition with smart cars as the research object, an exploratory engineering practice activity for college students, and one of the science and technology competitions advocated by the Ministry of Education [2]. In order to solve the problem of slow speed and insufficient effect control strategies of the smart car, and the instability between smart car communications, this paper proposes the hardware design and software algorithms to realize a tracking smart car with wireless communication function [3], based on the author's entry that won the first prize of the national finals of the dual-cars relay group in the 16th National College Students Smart Car Competition of China.

2 System Hardware Design

The physical image of the smart car in this design is shown in Fig. 1, whose length, width and height is 30 cm, 25 cm and 20 cm, respectively. The hardware design mainly includes the microcontroller, inductance-capacitor sensor pairs, HC-05 Bluetooth module, NRF24L01 wireless communication module, HC-SR04 ultrasonic ranging module, photoelectric speed measurement coded sensor and motor drive module, which are selected for different tasks. The main information perception sensor is five inductance-capacitor pairs. The HC-05 Bluetooth module and NRF24L01 module are used for wireless debugging and communication.

2.1 Microcontroller

This design use the 32-bit microcontroller MM32F3277G9P produced by MindMotion as the core controller, with a operating frequency of 120 MHz and a supply voltage of 3.3 V. There are many peripheral interfaces in the MM32 microcontroller, such as the pulse width modulation (PWM), analog signal to digital signal interface, and the Universal Synchronous Asynchronous Receiver Transmitter (USART), which is used for communication. So the MM32 microcontroller

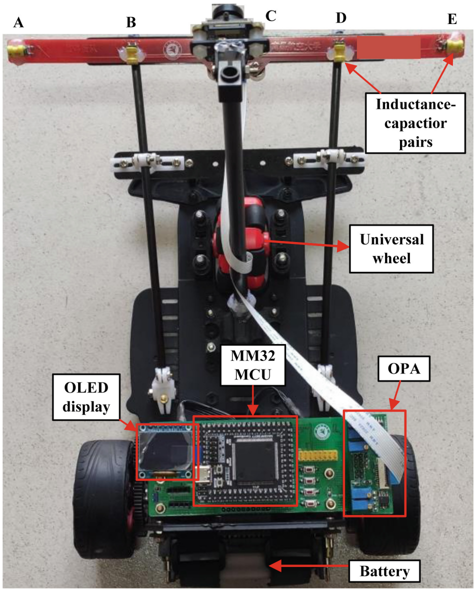

Fig. 1. Physical image of the smart car.

is sufficient to meet the needs of the competition. In addition, the MM32 microcontroller supports hardware division and hardware square operations, which can process the communication data more quickly.

2.2 Inductance-Capacitor Sensor Pairs

The race track is a closed curve, the center of the track is laid with electromagnetic guide line, that is a diameter within 0.1 to 1.0 mm enameled wire, which has the amplitude of 100 mA and frequency of 20 kHz alternating current. As uniformly changing electric field produces a constant magnetic field, the inductance is used to collected the information of the magnetic field, which reflects the relative position of the smart car and the center guide line. According to the formula for calculating the resonant frequency of a resonant circuit

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

So the 10 mH inductance and 6.8 nF capacitor pairs are used to collect the electromagnetic induction signal of the track. Five inductance-capacitor pairs A, B, C, D and E are used as sensors to detect the position of the smart car relative to the guide line, which is laid in the center of the track. The leftmost A and rightmost E inductance-capacitor pairs are used for normal tracking, the 45° oblique B and D are used to detect the cross road, and the intermediate C is used to assist in detecting roundbaout, as illustrated in Fig. 1.

According to the law of electromagnetic induction, the magnitude of the induced electromotive force in the circuit

$$E = n\frac{\Delta\Phi}{\Delta t} = nBLv\sin\theta \tag{2}$$

where E is the induced electromotive force by the inductance-capacitor pairs; n is the number of inductance coil windings; B is the strength of the induced electromagnetic field excited by the guide line; θ is the angle between the inductive coil and the electromagnetic wire. When the inductance and electromagnetic wires are perpendicular, θ is close to 90°, the induced electromotive force is the greatest. The closer the inductance coil is to the electromagnetic guide line, the B is greater, and the induced electromotive force E is greater.

2.3 Bluetooth Communication Module

The HC-05 Bluetooth module is a master-slave serial port module, which can be used for short-distance wireless communication. After pairing, the communication protocol inside the module is ignored, and the module is used as a serial port directly. The module can meet the communication needs of smart car within 10 m, so this design uses the HC-05 Bluetooth module to achieve the dual-cars communication [4]. In addition, the Bluetooth module can be connected using the Bluetooth of the mobile phone, so the mobile phone and the smart car can send data to each other, making the debugging of the smart car more convenient. The physical image of the HC-05 Bluetooth module is shown in Fig. 2.

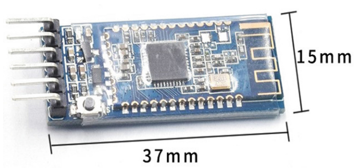

Fig. 2. Physical image of the HC-05 Bluetooth module.

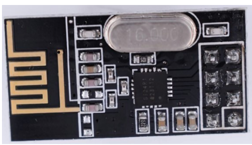

Fig. 3. Physical image of the NRF24L01 Module.

2.4 NRF24L01 Wireless Communication Module

Since the 16th dual-cars relay group requires the two smart cars to handover a ball and realize the accurate control of handover, this design uses the NRF24L01 wireless data transmission module for dual-cars communication [5].

The NRF24L01 module works in the 2.4 to 2.518 GHz frequency band, half-duplex, transceiver integration, using serial port for data transceiver, reducing the threshold of wireless applications. The NRF24L01 module transmits and receives 10 bytes of data with a test distance of about 70 m. And the module has the characteristics of automatic frequency hopping function, strong anti-interference ability, high transmission rate and small delay.

2.5 Ultrasonic Ranging Module

In order to realize the real-time, contactless distance measurement, this design uses the HC-SR04 ultrasonic ranging module to measure the distance between two smart cars. Ultrasonic ranging is calculated by means of the calculation of ultrasonic pulse echo crossing time, and then calculate the relative distance between the module and the measured target. The module can measure the distance within 0.04 to 4 m, and has the characteristics of accurate measurement, stability and high speed. The physical image of the ultrasonic module is illustrated in Fig. 4.

Fig. 4. Physical image of the HC-SR04 ultrasonic module.

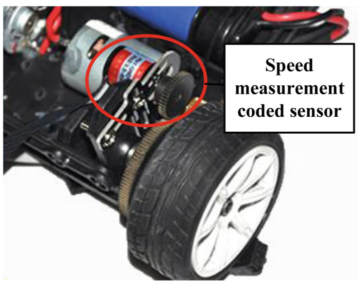

Fig. 5. Physical image of the speed measurement sensor.

2.6 Speed Measurement Sensor

In order to ensure the closed-loop control of speed and improve the stability of the control, this design uses the photoelectric speed measurement coded sensor to measure the real-time speed of the smart car. The photoelectric speed measurement coded sensor can measure the speed of each moment of the car, and by integraling the time, can obtain the distance driven. The physical image of the sensor is illustrated in Fig. 5.

2.7 Motor Drive Module

The motor drive circuit of this design uses the HIP4082 chip to form an H-bridge drive circuit, and two motors require two H-bridge drive circuits. This design uses the hardware PWM technology, the frequency of the PWM signal is 17 kHz, by changing the duty cycle of the PWM signal, changing the open-time of the CMOS tube, so as to change the voltage at both ends of the motor to control the speed of the motor. If the left wheel rotates faster than the right wheel, then the car turns right, so as to change the direction of the car by changing the duty cycle of the PWM signal. The circuit diagram of the motor drive module is illustrated in Fig. 6, where the "M3" and "M4" are connected to the motor.

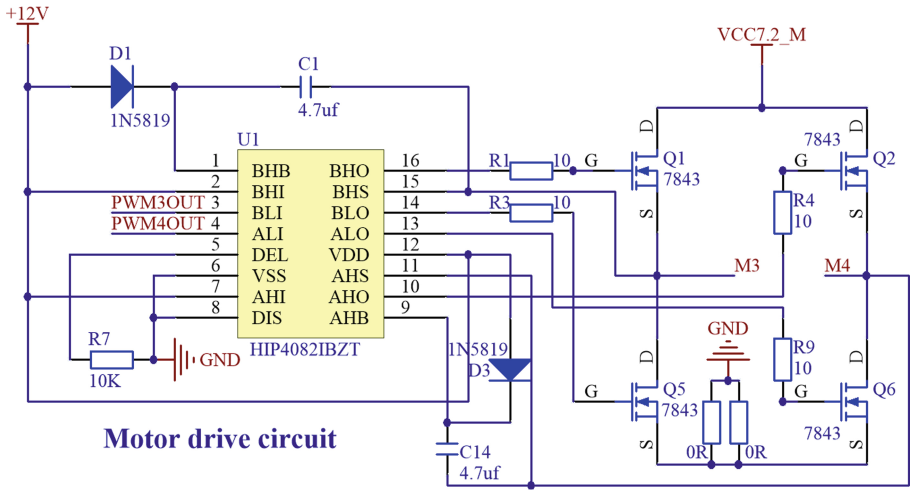

Fig. 6. Circuit diagram of the motor drive module.

3 Software Design

3.1 Electromagnetic Induction Signal Acquisition and Filtering

The process of software design is illustrated in Fig. 7. Firstly, the inductance-capacitor pairs, that is, the LC oscillation circuits installed in the smart car acquire the magnetic field information of the track. The acquired signal is an AC signal, which reflects the location of the smart car. The AC signal is input into the linear amplification circuit, and outputs a sine wave with larger amplitude, which is rectifying and filtering to a DC signal. Then the DC signal is sent into the 12-bit ADC interface of the microcontroller for ADC conversion.

Secondly, the converted digital signal is filtered to get the data of the information of the track. Then the data is normalized, the relevant information of the track is analyzed, which is used to classify the different track elements. And the difference-ratio-sum algorithm is used to calculated the deviation between the position of the smart car and the center guilde line of the track. Thirdly, the PID control algorithm is used to calculate the PWM signal corresponding to the deviation. Finally the PWM signal is acted through the drive circuit to the drive motor, which is used to control the smart car to go straight or turn. This design uses the wireless communication module to observe the intermediate variables of the real-time operation of the smart car.

Due to the presence of noise and interference in the system, it is important to perform the filtering algorithm. A weighted recursive average filtering method is used in this design. First take N sample values continuously as a queue, the length of the queue is fixed to N. Each time the new sampled data is input to the end of the queue, and the data of the team leader is removed. The weight of the team from tail to the head is decreased sequentially, then an average value is taken. The filtering algorithm is suitable for systems with the small sampling period, and changing the weights can change the sensitivity of the system. Besides, the median filtering algorithm is then used, and finally the Kalman filter is used for filtering. Filters can make the data smoother and reduce unnecessary jitter caused by sudden changes in the data.

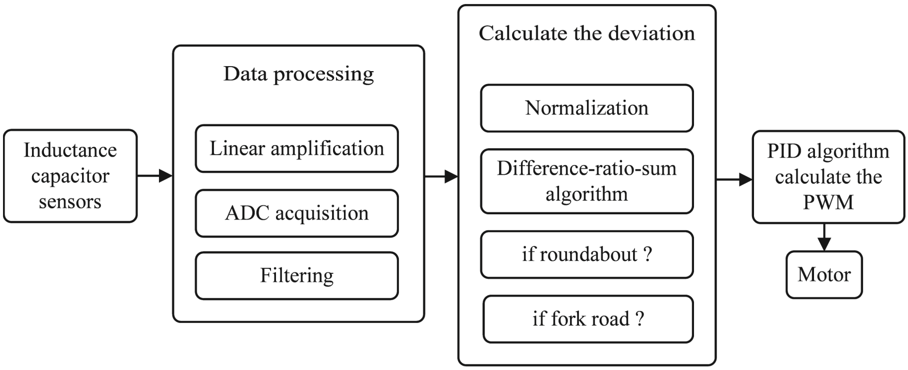

Fig. 7. The process of software design.

3.2 Normalization and Difference-Ratio-Sum Algorithm

Different tracks have different electromagnetic fields, the signal acquired by the inductance-capacitor pair sensor will also difference. In order to make the smart car adapt to different tracks, a normalization algorithm needs to be used. Firstly, acquire the maximum value of the inductance-capacitor pairs detected, the other values ratio to the maximum value, denoted as new values. Then the new values is multiplied by 4095, robustness of the algorithm will be better in that way.

If the values of the two symmetrically installed inductance-capacitor are ValueA and ValueE, the deviation calculated by the difference-ratio-sum algorithm is (ValueA-ValueE)/(ValueA+ValueE). The value of the deviation ranges from -1 to 1, and when multiplied by 4095, the value ranges from -4095 to 4095. According to the value and the positive situation of the deviation, the distance between the smart car and the center of the track can be quantitatively calculated.

The value calculated by the difference-ratio-sum algorithm do not vary with the fluctuation of the signal source, and the data is easy to use. Experiments demonstrate that it is possible to achieve a better implementation relying on electromagnetic sensors for basic tracking. As it is shown in Fig. 8, the A, B, C, D and E curves is the filtered value of five inductance-capacitor pairs senors.

3.3 Track Element Identification

Since the strength of the magnetic field at the roundabout is superimposed in the form of the vector, the strength of the magnetic field will become larger, and the value collected by the inductance will also be larger. The numerical variation of the five inductance-capacitor makes it easier to identify the roundabout. So, if the sum of the values extracted by the five inductance-capacitor pair is larger than a threshold. That is, when $\sum(A+B+C+D+E) > THR$, where the THR is a threshold set artificially, it is considered as a roundabout, as illustrated in Fig. 8. When the second crest arrives, the car begins to enter the roundabout.

At the fork road, the leftmost A and rightmost E inductance-capacitor are directly above the guide line, and the electromagnetic induction signal acquired will reach the maximum value 4095, it can be judged that the smart car drives to the fork road and is ready to communicate with the other car.

3.4 Discrete Incremental PID

This design uses the Proportion, Integration, Differentiation (PID) control algorithm. The PID algorithm structure is simple, widely used, easy to adjust, and with good stability. Since the microcontroller can only process the discrete digital signals, this design uses the discrete incremental PID. Below are the formulas of the discrete incremental PID [6].

$$\Delta u(k) = K_p[e(k) - e(k-1)] + K_i e(k) + K_d[e(k) - 2e(k-1) + e(k-2)] \quad (3)$$

where the K_p, K_i, K_d is proportion, integration, and differentiation coefficient respectively; $\Delta u(k)$ is the variation of the output; $e(k)$ is the error value between the target and the actual value this time; $e(k-1)$ is the error value between the target and the actual value last time, and $e(k-2)$ is the error value between the target and the actual value next-to-last time.

The leftmost and rightmost value of inductance-capacitor pairs are denoted as ValueA and ValueE, if the ValueA is larger than the ValueE, it means the car biases to the right. Then the deviation calculated by the difference-ratio-sum algorithm is positive, the output of the incremental PID control algorithm is also positive. So the right wheel runs faster than the left wheel, so as to drive the smart car to turn left, and vice versa. The PID control algorithm drives the smart car to always drive in the middle of the track. The impact of incremental PID is small when an error occurs, and the determination of the control increment is only related to the most recent k sample value, so it is easier to obtain better control effects by weighting.

4 Application of Wireless Communication Module

4.1 Bluetooth Module Communicate with the Upper Computer

When the smart car is dynamically debugged driving on the track, the data of the program running status and intermediate variables of the car should be monitored in real time, so as to detect the operation status of the car in order to improve the program. This design uses the HC-05 Bluetooth wireless transparent communication module to send the running status of the car, the distance between two cars and other information to the oscilloscope of the upper computer to observe the operation status of the program. The format of the communication protocol is { [0x03] [0xfc] [data] [0xfc] [0x03] }, so that a waveform transmission is completed. The waves of five inductance-capactior pairs is illustrated in Fig. 8, when these values skyrocket, it means the car come to the roundabout, and the program sets up a flag bit, as the light green curve illustrates.

When adjusting the parameters, uses the oscilloscope of the upper computer, outputs the PID intermediate variable waveform, according to the change range of the variable waveform as prior knowledge. And estimate the order of the magnitude and approximate range of the main amount of K_p, use this value as the starting point to adjust the parameters, and then increase K_i or K_d according to the performance requirements, which greatly reduces the time of parameter adjustment.

4.2 Communication Between the Two Smart Cars

In each edition of the annual smart car competition, communication between two smart cars is required to complete a specific task autonomously. Passing a ball and crossing each other are the tasks of the 16th smart car dual-cars competition, in this process, it cannot be directly contacted, and a wireless communication

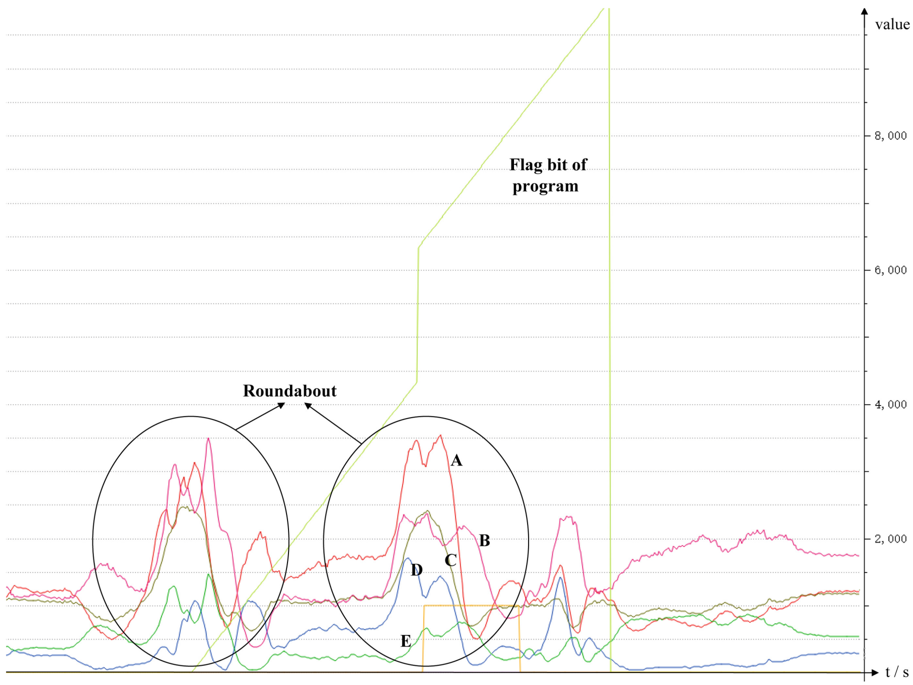

Fig. 8. Waves of virtual oscilloscope in the upper computer. Where the curves A, B, C, D, and E are the waves of five inductance-capacitor pairs, respectively. When two large crests are detected, it indicates that the car drives to the roundabout. The light green cure is the flag bit of the roundabout in the program. (Color figure online)

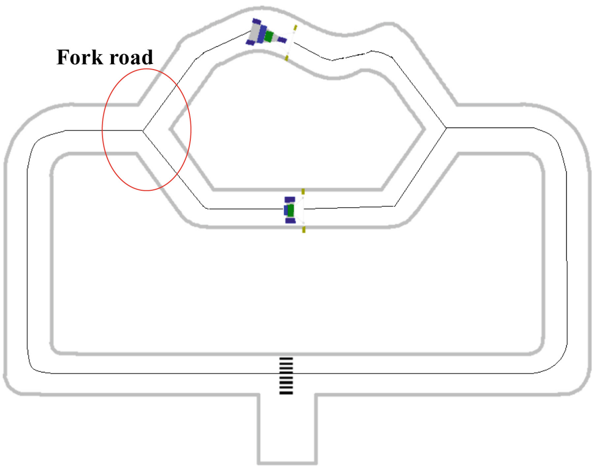

Fig. 9. Illustration of the fork road and the central black guideline. In the fork road, two cars handover a ball, and realize one car begins driving when the other car stops by wireless communciation.

module is required to complete the task of one car stopping and the other car starting to drive.

The receiving smart car is parked in the middle of the fork road, and the other ball delivery smart car takes the ping-pong ball from the starting line driving to the fork road, ready to pass the ball to the receiving car. When the ultrasonic sensor detects that the delivery car is within 40 cm away from the receiving car, the deceleration mark will be triggered, and the ball delivery car will slow down step by step, then the collision pass will be carried out.

The receiving car uses a infrared photoelectric switch module to detect whether the ball is successfully handed over. If the ball is successfully handed over, the receiving car immediately starts to drive forward, and the data [0x01] is sent every 10 ms through the NRF wireless communication module to the ball delivery car. If the rear ball delivery car receives the [0x01], the ball delivery car immediately stops to avoid the situation of crashing the receiving car out of the track, and sends seven answer data [0x02] continuously. As long as the receiving car receives a [0x02], the receiving car stop sending [0x01], and the communication ends.

When the receiving car runs around the track and drives to the fork road again, the data [0x60] is sent every 10 ms through the NRF wireless communication module to the ball delivery car. If the ball delivery car receives the data [0x60], the ball delivery car immediately begins to drive forward, and sends seven consecutive answer data [0x61] at the same time. Once the receiving car receives a [0x61], the receiving car stops sending [0x60], and the communication ends.

In the process of dual-cars communication, the data is repeated several times to prevent sensors and site interference and ensure the effectiveness of communication. After these multiple safeguard mechanisms, the success rate of the scheme used in this design to hand over the ball is more than 95.2%.

5 Conclusion

Taking the National College Students Smart Car Competition of China as the background, this paper designs a tracking smart car system with communication functions from the aspects of hardware design and software algorithms, and realizes a smart car with road information collection and analysis, automatic driving, and communication functions, which has good steady-state characteristics and fast dynamic response.

The actual test data is that the total length of the track is 68.6 m, and the two smart cars drive and relay for two laps, taking 57.1 s, and the average speed is about 2.4 m/s, which is faster than most smart cars in this competition. The test results demonstrate that the tracking algorithm, PID control algorithm and dual-cars communication scheme proposed in this design are stable and reliable, with low complexity, and can run on most 32-bit microcontrollers. This paper has a good reference for preparing for the National College Students Smart Car Competition, and has important theoretical significance and practical value in the field of automatic driving.

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