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Research on Three Wheeled Electromagnetic Vehicle Based on Fuzzy Control

Lihong Liu[1,#], Minjia Mo[2,#], Yining Huang[1,#]

[1]School of Electrical Engineering, University of South China, Hengyang, 421001, China
[2]School of Electrical Engineering, Nanjing Institute of Technology, Nanjing, 211167, China
[#]These authors contributed equally.

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Abstract: This article studies a small car motion control system based on the principle of electromagnetic induction, aiming to achieve functions such as positioning and navigation, remote control, and differential control of the car on the track. The system adopts the STC series microcontroller as the main control chip, and realizes the motion control and position positioning of the car through components such as motor drive module, encoder, electromagnetic tracking sensing module, operational amplifier module, etc. In terms of control algorithm, a cascade PID controller based on fuzzy algorithm is adopted to adjust the position of the car, ensuring that it always remains at the center of the track. The experimental results show that this system exhibits good adaptability and stability on different tracks, providing reliable technical support for the promotion and application of electromagnetic cars in practical applications.

1. Introduction

With the rapid development of artificial intelligence and autonomous driving technology, unmanned intelligent cars are attracting widespread attention. Autonomous intelligent vehicles refer to vehicles that can operate and navigate independently, without the need for human drivers to control them. By integrating various sensors, cameras, radars, advanced computer vision technologies, as well as machine learning and deep learning algorithms, unmanned intelligent vehicles can perceive the surrounding environment, understand road conditions, and make intelligent driving decisions. The research and development of small cars require technology from multiple fields such as mechanics, electronics, and control, which will greatly promote technological innovation and development in related fields[1].

This article is based on the 19th National College Student Intelligent Car Competition, and designs a three wheeled automatic tracking car with electromagnetic navigation. For a complex and uncertain track environment, traditional PID controllers have limitations such as poor control performance, poor adaptability to nonlinear and time-delay systems, and sensitivity to external disturbances in certain situations. To solve this problem, this paper combines specific scenarios and requirements to design a fuzzy rule-based cascade PID controller. In different working states, the controller can automatically adjust PID parameters according to fuzzy rules to adapt to system changes, greatly improving the adaptability and robustness of electromagnetic vehicles.

A three wheeled electromagnetic vehicle based on fuzzy algorithm is a vehicle that can use fuzzy logic control strategy to achieve autonomous navigation and motion. The vehicle is equipped with electromagnetic sensors to perceive obstacles and landmarks in the surrounding environment, in order to make corresponding motion decisions. In such systems, fuzzy logic control algorithms are used to process information obtained from sensors to determine the vehicle's speed, direction, and steering angle, in order to maintain stable tracking on the track. One of the main advantages of fuzzy logic control is its ability to handle fuzzy, uncertain, and imprecise inputs, and output corresponding fuzzy and uncertain results, which makes it very effective in dealing with complex situations in practical environments[2].

2. Overall design scheme of electromagnetic car

The overall structure of the three wheeled electromagnetic car in this article mainly consists of a power module, a main controller module, a motor drive module (DRV8701E), a motor, a 1024 line directional mini encoder, an electromagnetic tracking sensing module, an RS824 operational amplification module, an IPS LCD screen, an IMU660 attitude sensor, and a wireless module[3].

The car control chip of this car adopts the STC series microcontroller STC32G12K128, and the motor drive module realizes the motion control of the car. The encoder can obtain the real-time speed of the car, provide feedback information for closed-loop control of the car speed, the electromagnetic tracking sensing module collects AC signals, OPA4377 can amplify and detect the collected signals, and after software filtering and deviation fitting, the degree of deviation between the car body and the track center can be obtained. The direction deviation signal is input to the cascade PID controller, and under the action of the control algorithm, the car position is adjusted to always be at the track center. The LCD screen displays the vehicle status for easy debugging. The IMU660 attitude sensor provides attitude information, and the wireless module realizes communication with the upper computer in each module. With the cooperation of, functions such as motion control, positioning navigation, and remote control of the electromagnetic car have been achieved, as shown in Fig 1.

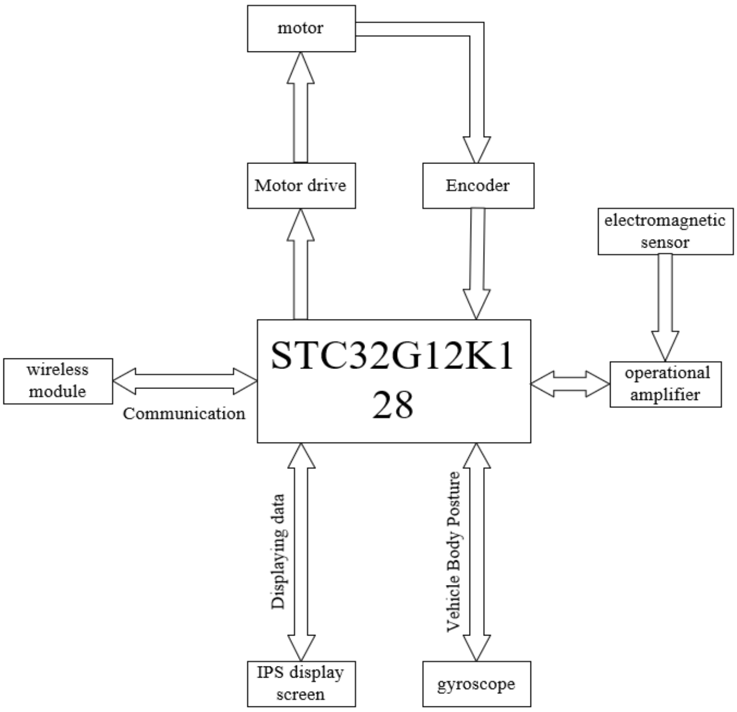

Figure 1: Overall diagram of the car system

3. Direction control strategy

3.1 Inductor placement and deviation handling

An electromagnetic wire is laid at the center of the track and a 20kHz alternating signal is transmitted, so an alternating magnetic field with the same frequency is generated around the electromagnetic wire. I-shaped inductor coils usually have a large induction area and good sensitivity, making them very suitable for magnetic field detection. After selecting a 10mH I-shaped inductor and a 6.8nF capacitor in parallel, a resonant circuit can be formed[4], which enables the circuit to have higher gain and sensitivity at a frequency of 20kHz, thereby better detecting changes in the magnetic field. The parameters need to meet the formula:

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

The inductance coil of an electromagnetic sensor is located in this alternating magnetic field, and the position away from the magnetic induction line constantly changes. The magnetic field strength at different positions varies, and the induced current of the inductor will also vary. The closer the distance to the wire, the greater the current value. According to Faraday's law of electromagnetic induction, it will generate an induced electromotive force on its own. By filtering, amplifying, and detecting the induced electromotive force, a stable signal can be obtained, that is, each inductor will have a corresponding inductance value, which is used to identify track information[5].

The collected signals may be affected by various interferences and noises, which may come from electromagnetic interference, sensor uncertainty, environmental changes, and other factors. Therefore, in order to accurately obtain the degree of deviation between the vehicle body and the center of the track, it is necessary to process the collected signal, that is, perform software filtering: continuously collect inductance values five times, then bubble sort to remove the extreme values and calculate the average, which improves the accuracy and stability of the measurement results. Due to the different shapes, materials, and sizes of different tracks, the inductance characteristics of the tracks themselves may also vary. For example, circular tracks may have different inductances and impedances, resulting in different inductance values collected on different tracks. In addition, environmental factors around the field can also affect the inductance value, such as the surrounding metal structure, electromagnetic interference, ground humidity, and other factors that may affect the inductance value. Therefore, the values collected by the same sampling circuit may vary on different fields. In order to improve the adaptability and stability of the vehicle body on different tracks, a normalization method can be adopted for processing, and the collected inductance values can be uniformly mapped to a fixed range. After these treatments, the deviation from the center of the track can be obtained by comparing the differences and calculating the fitting deviation.

The inductance layout plays a very important role in the tracking of the car. If the inductance is placed in a straight line, the maximum inductance value can be obtained, but when the line is bent at a right angle, there will be a situation where the ratio of left and right inductance differences is 0; If the inductor is placed vertically, the inductance value obtained on the straight path is almost 0, and it is even more difficult to follow the path normally. Therefore, in order to make the electromagnetic car suitable for various tracks, a combination of horizontal and vertical inductors was adopted, and the difference between the vector sum of the left and right horizontal and vertical inductors was compared and calculated[6].

$$ad_{left}=\sqrt{ad\_left\_x^2+ad\_left\_y^2} \tag{2}$$

$$ad_{right}=\sqrt{ad\_right\_x^2+ad\_right\_y^2} \tag{3}$$

$$Error = \frac{ad_{left} - ad_{right}}{ad_{left} + ad_{right}} \tag{4}$$

The calculated difference ratio and value, i.e. the left and right deviation, reflect the direction of the car's offset, and its magnitude reflects the degree of car's offset, as shown in Fig 2.

Figure 2: Inductance Layout Scheme

3.2 Cascade control

Compared to single stage control, cascade control has higher control accuracy, better robustness, and stronger anti-interference ability, which can improve the performance of the system. By finely adjusting control parameters and increasing control levels, cascade control can enable the system to respond more quickly to input changes, reduce system overshoot and steady-state errors, and thus improve the dynamic performance and control accuracy of the system[7].

In single loop PID control, only one PID controller is responsible for controlling the entire system. This PID controller calculates the control output based on the system's error (deviation) and adjusts the output signal based on three terms: proportional, integral, and derivative. Single loop PID control is suitable for simple systems, where only one main control objective needs to be adjusted. Its advantages are simple and easy to use, easy to adjust, and can achieve good results for systems with small steady-state errors and low dynamic response requirements. The tracking process of an electromagnetic car is a complex system that requires cascade control for processing. Different control algorithms can be used for the inner and outer loops to meet the different needs of the system[8]. Through the series connection of the inner and outer loops, the system can more effectively resist the influence of external interference and noise, thereby improving the stability and reliability of the system, enabling the car to track the center of the track more accurately and achieve smooth turning movements.

The three wheeled vehicle model used in this article cannot use a servo for steering, so it can only rely on the difference in speed between the two rear wheels to achieve steering. If the output speed of the left wheel is greater than that of the right wheel[9], a right turn is achieved; otherwise, a left turn is achieved. The cascade controller consists of an outer loop and an inner loop, with the outer loop being the direction loop and the inner loop being the angular velocity loop. The outer loop outputs the target angular velocity as input to the inner loop, which then outputs differential acceleration and deceleration to the left and right motors. The specific implementation is as follows: taking the difference ratio and value of the car's inductance as the input of the outer loop, and then obtaining the output of the inner loop to adjust the speed of the left and right wheels to make a difference in speed, realizing the turning or adjustment of the vehicle, and then obtaining the current state information of the car for loop feedback to adjust the control signal, achieving more accurate control.

$$speed_L = speed - K\_diff \tag{5}$$

$$speed_R = speed + K\_diff \tag{6}$$

$speed_L$ is the left wheel target speed, $speed_R$ is the right wheel target speed, and K_diff is the output of the cascade controller - differential speed,as shown in Fig 3.

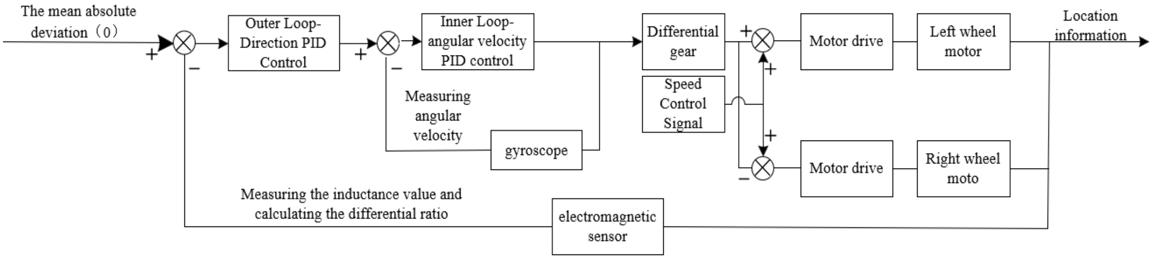

Figure 3: Cascade Control Block Diagram

3.3 Fuzzy algorithm

On the basis of cascade control, this article further combines fuzzy algorithm to achieve control of the small car. Fuzzy algorithm is a calculation method based on fuzzy logic, used to deal with problems of fuzziness or uncertainty. It converts fuzzy input data into fuzzy sets and infers them based on a series of fuzzy rules, ultimately obtaining fuzzy outputs. This output can be converted into a determined value through deblurring methods, which can be used to solve practical problems in various fields, such as control systems, pattern recognition, decision support, etc. Fuzzy algorithms can effectively handle the fuzziness and uncertainty of input data, making the system more flexible in dealing with complex situations[10].

The formulation of fuzzy rules is a process that relies on both theoretical knowledge and practical experience, which needs to be determined through expert experience and continuous testing during the shunting process. Fuzzy rules are the basis for reasoning in fuzzy controllers. Usually, the "if so" form is used, which describes the relationship between the fuzzy set of input variables and the fuzzy set of output variables. When the input of the system is fuzzified, the fuzzy rule matches the input fuzzy value with the rules in the predefined rule library, and then generates the output fuzzy value through fuzzy inference. This process allows the fuzzy controller to perform fuzzy inference based on the fuzzy inputs of the system, in order to determine appropriate control actions.

This article presents a fuzzy rule-based PID parameter self-tuning design for electromagnetic vehicles. The driving of the car is a time-varying nonlinear system, while the traditional PID algorithm is a linear control algorithm. For different degrees of bends on the track, a unified set of PID parameters cannot adapt to all bends, and cannot meet the control requirements of the car when encountering sudden disturbances or sudden changes, resulting in poor performance. The fuzzy control algorithm considers the influence of the deviation and deviation rate of the vehicle body and track center on the parameters of the PD controller. By adjusting the control output based on real-time sensor data, it can minimize static errors and improve the response speed of the system. By considering the fuzzy information of deviation and deviation change rate, the fuzzy control algorithm can dynamically adjust the parameters of the outer loop PD of the cascade controller according to the actual situation to adapt to the steering requirements of different degrees of bends. This can make the control system more flexible, better adapt to changes on the track, and improve the control performance and stability of the car[11].

The specific implementation of the entire process is as follows: the car first collects track information through electromagnetic sensors to determine the current deviation from the centerline of the track, as well as the changes in the current deviation and the previous deviation ec, as well as the domain of the output Kp, Ki, Kd. Then, and are used as inputs for the PID parameter self-tuning designer to fuzzify the input values. Based on fuzzy rules, fuzzy inference and de fuzzification are performed on the output values to obtain the corresponding PID parameters for different and, namely Kp, Ki, Kd. Therefore, on the track, the car can modify parameters in real-time according to changes in the path,as shown in Fig 4.

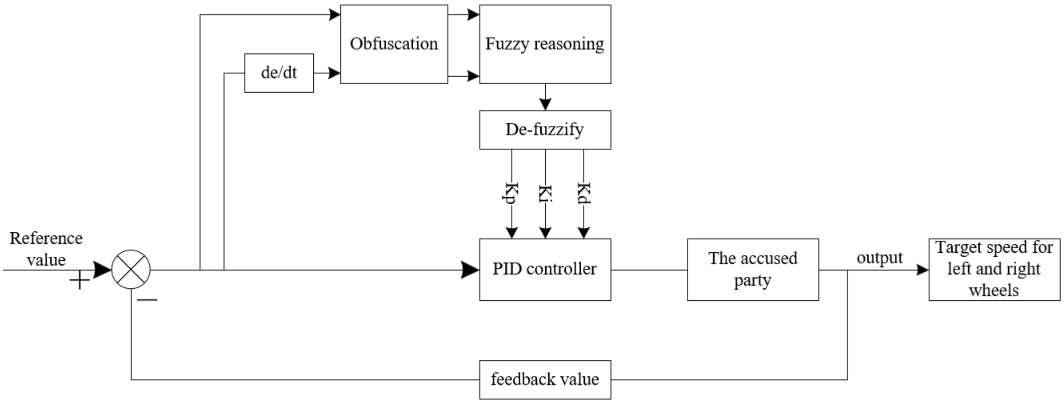

Figure 4: Fuzzy Algorithm Block Diagram

4. Conclusions

This article introduces the overall design scheme of the electromagnetic car, studies the motion control system of the electromagnetic car, and proposes a fuzzy algorithm based cascade control method to cope with complex environmental changes and road conditions on the track. The system utilizes electromagnetic sensors to collect the position information of the track center, and combines fuzzy control algorithms to achieve direction adjustment and speed control of the car. By optimizing and improving the control algorithm of the electromagnetic car, it can autonomously navigate on different tracks, achieve precise steering and stable motion, which has certain practical value and promotional significance.

References

[1] Lu Xiao. Intelligent Vehicle Lateral Control Based on Fuzzy Sliding Mode Adaptation [D]. Shenyang University of Technology, 2022
[2] Qi Xiaohua. Application of Three wheeled Intelligent Vehicles Based on Fuzzy PID Algorithm [J]. Changjiang Information and Communication, 2024,37 (02): 141-144
[3] Xiong Zhonghua. Design of an upright vehicle based on electromagnetic tracking [J]. Electronic Manufacturing, 2022, 30 (14): 6-8+26
[4] Kang Huaguang. Basic Simulation of Electronic Technology [M]. 5th Edition. Beijing: Higher Education Press, 2006
[5] Xiao Yumeng, Cheng Dengliang, Yang Wenjun. Design of Electromagnetic Tracking Intelligent Car [J]. Journal of Hubei University of Automotive Industry, 2021,35 (01): 75-80
[6] Zhan Hanbin, Wang Jing, Fan Haoran, et al. Design of Autonomous Tracking Intelligent Vehicles Based on Electromagnetic Induction [J]. Automation and Instrumentation, 2023,38 (10): 16-19+23
[7] Liu Yueting, Meng Weihua, Ding Jianzhong. Design and Performance Analysis of a PID-PID Cascade Control System [J]. Journal of Yanbian University (Natural Science Edition), 2023,49 (04): 358-365
[8] Chang Zhe, Chen Pengyun, Li Jiacheng, et al. Quadrotor attitude control method based on cascade linear self disturbance rejection [J]. Telemetry and Remote Control, 2024,45 (01): 38-46
[9] Song Nianyun, Song Yuanbin, Liu Kangwen. Tracking Design of Electromagnetic Three wheeled Intelligent Car [J]. Computer Knowledge and Technology, 2019,15 (18): 206-208
[10] Ma Shiren. Research on Intelligent Vehicle Motion Control Technology Based on Fuzzy Control Algorithm [D]. Shenyang University of Aeronautics and Astronautics, 2022.
[11] Wang Yinwen. Research on Fuzzy PID Intelligent Vehicle Control Algorithm Based on Simulink Simulation [J]. Information Technology and Informatization, 2020, (11): 229-232