Simulation and implementation of Bicycle Robot Control without Mechanical Auxiliary structure

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Abstract: Bicycle is an efficient and environmentally friendly means of transportation. However, the dynamic characteristics of bicycle are more complex, from the point of view of control, it is an under driven unstable system. In order to realize the steady and straight driving of the bicycle robot, it demonstrated that the dynamic modeling and system simulation of the rear drive bicycle robot, which does not have the mechanical auxiliary structure and only depends on adjusting the handlebar to maintain the self-balance. In order to solve the problem that it is difficult to realize equilibrium control for bicycle robot systems with typical symmetry under driven nonholonomic constraints, the mechanical mechanism of the system analyzed based on LaGrange method, and a simplified dynamic model is established. The simulation and experimental results show that, the bicycle effectively realized. The linear motion self-balance control of robot lays the theoretical foundation for further carrying out the balance motion control of bicycle robot and other under-drive system.

1. Introduction

Bicycle is an efficient and environmentally friendly means of transportation. Since German Deles (Baron Karivon Drais) invented a wooden two-wheeled bike with a handlebar in Paris, France, bicycles have brought great convenience to human life. At the same time, People are also making continuous improvements to it [1]. In 2006, the famous Japanese robot “Murata recalcitrant” showed people walking ramps and S-shaped balance beams, walking backwards, detecting obstacles, and entering the garage. Mobile phone remote control operation, voice, plays music and other functions. In recent years, as the economy turns, with the development of high-tech industry, robots, artificial intelligence and other emerging fields, the application demand of all kinds of mobile robots is becoming more and more urgent. Most mobile robot system chassis is multi-wheel or even crawler structure. At rest, it has strong static stability, but because of its large turning radius, it needs a large workspace, is not flexible enough, and has a complex structure. The limitation of power consumption is large. Bicycle robot and ordinary multi-wheeled machinery have potential application prospect and market value in security inspection, resource exploration, logistics industry, and entertainment display and science popularization. As a nonholonomic and under driven system with typical symmetry characteristics, the robot arranged longitudinally before and after two wheels and has no direct drive at lateral inclination. How to realize the balanced nonlinear control of the whole system through handlebars or other mechanical auxiliary structures is a recognized problem in academic circles. From the point of view of design structure, at present, there are two main ways for bicycle robots to maintain the balance of the car body: mechanical auxiliary devices and no mechanical auxiliary devices. Obviously, the connector without mechanical assistance is simply connected. The connectors with mechanical structure can be distinguished in connection stability and reliability, connection quality efficiency, connection speed and so on.

2. Research and Development of Bicycle Robot in Foreign countries

The analysis of bicycle balance in foreign countries started early. The first qualitative analysis

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was in 1869. In 1899 and 1900, Whipple and Cavalla carried out a strict analysis of the dynamics of an inverted pendulum model. The linear equation of motion of the bicycle model around the vertical grounding equilibrium point derived. The dynamic model points out that the two wheels and the inverted pendulum are in a similar static unsTable state, but in the appropriate speed range. The system balances itself as it rolls forward, a phenomenon known as self-stability. F. Klein, Sommerfeld and Me Tenuous and other scholars established the dynamic model of bicycle in 1941 and 1948, but regarded people as a rigid body fixed in the seat, and its model is too tedious, so the derived results are quite different from the actual results. With regard to the idea that only the bicycle robot handle without mechanical auxiliary structure can control the balance, GETZ [2] thinks that the balance control of the car body can realized only through the rotation of the handle and the drive of the rear wheel. The designed model is simple and easy to calculate. The torque of the handlebar motor to the front fork system and the driving torque of the rear wheel motor selected as the balance control of the car body. A reduced dynamic model of bicycle robot derived and the control strategy of tracking the transverse roll angle trajectory of the car body is studied. In the 21st century, GAVIN and other scholars [3] have made certain contributions to the field of unmanned bicycles. After a lot of careful and serious research work on bicycle structure, they have laid the foundation for the research work of future generations. Through the innovation of the mechanical structure of the bicycle, he changed the position of the center of mass of the bicycle, and realized the motion control of the bicycle by turning the rod and adjusting the flywheel. At the same time, the concept of using Lagrangian equation to establish dynamic model and path planning put forward.

3. Research and Development of Cycling Robots in China

In recent years, China has also begun to pay attention to the research of bicycle robots, and the national investment in related scientific research projects has increased. Guo Lei, Yu Xiu li and others of Beijing University of posts and Telecommunications have put forward a variety of excellent control methods and bicycle models. At first, Professor Liu Yan zhu of Shanghai Jiao tong University proposed in 1995 to consider the influence of human control on bicycles, and to take the strength of human waist as the factor affecting dynamics. It proposed that the stability of the bicycle can controlled only by adjusting the steering angle of the handlebar [34], and the corresponding conditions satisfying the stability are obtained through the research. On this basis, Dr. Guo Lei established The SISO nonlinear dynamic model with the rotation angle of the vehicle as the input and the rolling angle of the vehicle balance as the output taken as the input. The nonlinear model locally linear zed by the approximate linearization method, and the controller based on the classical control theory designed. The bicycle system transformed into the standard form of Isadora-Byres nonlinear system, and the linear subsystem stabilized by using the exact feedback linearization theory, because the established system is a non-minimum phase system. Therefore, the unsTable zero dynamics of the system stabilized by using the central manifolds theorem and a fuzzy sliding mode controller is designed for this system to minimize the instability caused by sliding mode control. Shake the earthquake to realize the sTable control of the bicycle robot. After that, the MIMO affine nonlinear system designed respectively, and the exact linearization of the system and the decoupling of the multi-input control quantity realized. The bicycle robot platform is also built to realize the straight line riding of the robot at uniform speed .In 2001, some scholars studied the stability and mobility of bicycles in driving. In 2008, Wang Lu bin used fuzzy control method to design the ST model of the system with speed as the control variable. The balance of bicycle in variable speed motion realized. After that, some scholars put forward a new bicycle mechanism to adjust the horizontal stability of bicycles. This structure based on RHR2 redundant drive parallel mechanism model, and Lagrange models the model. In recent years, the domestic research in the field of intelligent control has gradually increased, which the global environment also affects. In 2005, UAV and unmanned vehicle began to appear in people's field of vision, and achieved a good application prospect. In China, it can say that bicycle robots have more space. They can imagine their applications in many fields, such as transportation, public welfare, commercial logistics, health and environmental protection, with the increase of people's demand. It can help people with mobility difficulties travel, deliver their own cargo letters, act as "running partners" and even as travel aids. The attention of unmanned bicycles has increased again, which is a means of transportation that is more in line with China's national conditions. Bicycles owned in China than cars. Compared with unmanned cars, no one owns their own bicycles. Driving is cheaper and safer. As a result, some companies have also been involved in the research and development of bicycle robots.

4. Dynamic model of bicycle robot system.

A bicycle robot with a body length within 400 mm and a height within 300 mm designed. The motor that controls the balance installed in the front handle and the driving motor installed in the middle and back of the bicycle frame. A front wheel has driven by a belt drive, corresponding to the tooth disk driven by the pedal when the person is riding a bicycle. The motor power drives the rear wheel disk and the axle through the belt drive, and the power supply and control circuit installed on the upper side of the car body frame. In order to assist the early balance and debugging of the car body, auxiliary wheels installed on both sides of the rear wheel to prevent the body from falling under the condition of overturning. The bicycle robot only relies on the handle motor to control the rotation of the handlebar. Balance, drive the motor installed in the middle and rear of the bicycle frame, drive a front wheel through belt drive, and drive the rear wheel disk and axle through belt drive. The bicycle robot must balance the handle at all times while keeping the bike in a straight line. Among them, the contact point between the rear wheel and the ground is the origin of the reference coordinate system. The coordinate system with the center of the rear wheel as the origin of the coordinate system is e (1), and the coordinate system with the center point of the shaft as the origin of the coordinate system is e (2). The radius of the front and rear wheels of the car body is R, the lateral roll angle of the rear wheel of the bicycle is a, the linear speed of the forward rotation of the rear wheel of the bicycle is v, and the turning angle of the handle of the front wheel of the bicycle is w. When the bicycle body tilted sideways for curved motion, the straight line of the front and rear wheel shafts is a spatial hetero-plane straight line. In order to facilitate the adjustment of the turning radius of the car body in the straight-line turning handle or the curve motion, Analyze and analyze the turning attitude of the car body by using the top view of the bicycle robot. For the convenience of calculation, the position of point C regarded as the straight line where the contact point of the front and rear wheels is located. The turning radius of the front and rear wheels when the bicycle body turns is:

$$\rho_1 = \lambda \cot\theta$$
$$\rho_1 = \lambda \csc\theta$$

The turning radius of the center of mass at point C is:

$$p = \sqrt{\lambda_1^2 + \rho_1^2} = \sqrt{\lambda_1^2 + \lambda^2 \cot^2\theta}$$

The general form of Lagrangian dynamic equation is as follows:

$$F_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} \quad i = 1,2,3,...,n$$

Among them, F: broad force can be a force; can also be a moment;

q_i : The generalized coordinates selected by the system;

$\dot{q}_i$: The generalized coordinates calculate the first derivative of time, that is, the velocity;

L: Lagrangian function can also be called Lagrangian operator. The Lagrangian equation of motion also expressed as follows:

L=K-P

Where K is kinetic energy and P is potential energy. The Lagrangian dynamic equation generally established according to the following steps:

(1) The complete and independent generalized coordinates selected. $q_i = q_1, q_2, q_3, ..., q_n$;

(2) Select the general force; $F_i = F_1, F_2, F_3, ..., F_n$;

(3) The total kinetic energy K of the system is calculated respectively, and then the total potential energy P is obtained, and the two are brought into the construction of the corresponding Lagrangian function.L=K-P. When the obtained results brought into the Lagrangian equation, the dynamic equations of the corresponding system can obtain.

The dynamic equations of the bicycle robot system are as follows:
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) - \frac{\partial L}{\partial \varphi} = \tau_\varphi$$
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right) - \frac{\partial L}{\partial \theta} = \tau_\theta$$

5. Handlebar twist angle controller

Professor Liu Yan zhu of Shanghai Jiao tong University proposed in 1995 that the influence of human control factors on dynamics should taken into account, and that the stability control of bicycles can be realized by relying solely on the handlebars, and the stability conditions can be obtained at the same time [4]. As can be seen from the content, the inclination angle θ And tensional angle φ There is an association. Referring to the handlebar controller designed by Yoshiro Tanaka et al., the desired inclination angle is set to be θ_d ,Set tensional angle $\varphi = (k_i\theta_d - \theta) - k_2\dot{\theta}$;

The transfer function can expressed as follows: $\frac{\theta}{\theta_d} = \frac{K(s+\tau)}{S^2 + Ms + N}$ 11

6. Simulation of Fuzzy Adaptive Control algorithm for Bicycle Robot

According to the experience of daily cycling, it is necessary to rotate the handlebar at a larger speed when you feel that the body tilted largely. The balance control of the car body has realized by making the center of gravity of the car body move laterally and the concentric force of the car body curve by turning the handle. The torque output of the motor actually has a complex nonlinear relationship with the transverse roll angle. In order to improve the control effect, In order to strengthen the robustness of the system, the optimal state maintained under the extreme conditions such as large tilt angle and fast dumping speed of the car body. In this paper, fuzzy adaptive control proposed to adjust the parameters online according to the fuzzy rules to realize the optimal control. Considering that while maintaining the balance of the body through the rotation of the handlebar, the handlebar can return to make the body travel in a straight line, and the balance control of the system is superior to other controls. In this system, PID double closed loop control adopted for bicycle machine object. PD control used to control the speed loop of the rotating motor of the handlebar in the system balance and the inner ring of the outer ring. Figure 1 and figure 2 reflect the variation of the torsional angle with the inclination angle. Through the torsional angle controller, both the inclination angle and the torsional angle converge at 0 °.

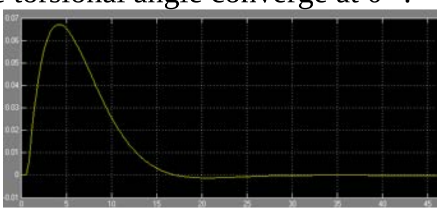

Fig. 1 variation of inclination (Radian)

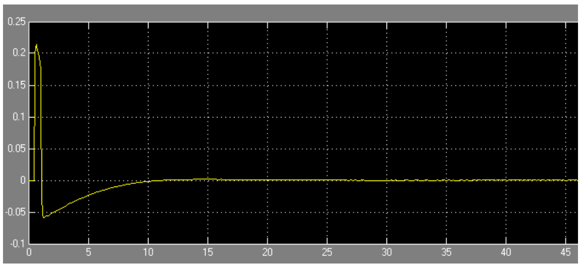

Fig. 2 variation of torsional angle (Radian)

The simulation results show that the control strategy designed in this paper can effectively achieve the expected goal for the special complex nonlinear system of bicycle robot, in which the fuzzy adaptive controller has better control effect under the same disturbance state. It can better adapt to the demand of bicycle robot for balanced motion.

Table 1 car body and controller parameters

name	parameter	numerical value
damping parameter	η	0.7
angular frequency	ω_n	10
proportional gain	k_1	0.523
proportional gain	k_2	1.562
Body mass	m	14.02(kg)
The distance from the rear wheel to the center of mass of the car body	b	0,93(m)
The distance between the front and rear wheels	a	1.21(m)

7. Summary

In this paper, based on the structural modeling and control analysis of a special driving nonholonomic system of bicycle robot, a fuzzy adaptive control strategy for bicycle robot designed. The simulation results show that the fuzzy adaptive controller can adjust the control parameters in real time according to the input deviation and deviation change rate, and realize the balance of bicycle more quickly and smoothly. The experimental results show that the fuzzy adaptive controller can achieve a good effect on the balance control of bicycle robot by processing the detected data in the actual control environment, and promotes the typical example of bicycle and unicycle. The further research on balance control of nonholonomic drive system has certain reference significance for the further research and market-oriented application of bicycle robot in the future.

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