Researchand Simulation of Boarding Bridge Wheel Trajectoty Tracking Based on Fuzzy Control

Fang Ding, Ming Yang

College of Electronic Information and Automation, Civil Aviation University of China, Tianjin 300300, China

Abstract

A new path tracking control method is proposed for uncertain mobile environment and high nonlinear dynamic of differential Boarding Bridge Wheel Frame. The method applies fuzzy control theory to obtain the appropriate velocity and angular velocity by selecting optimal parameter of fuzzy logic controller. In order to obtain the optimal planning path of Boarding Bridge Wheel Frame, the dynamic model of differential Boarding Bridge Wheel Frameis presented to expand the suitable range of geometric parameter derived from fuzzy controller. The trajectory tracking of Boarding Bridge Wheel Frame is a nonlinear system. The traditional control methods such as PID are difficult to meet the control requirements of stability and accuracy. However, the fuzzy control system can effectively improve the situation and thus can better meet the practical application needs.

Keywords

Boarding Bridge Wheel Frame, trajectory tracking, fuzzy control.

1. INTRODUCTION

The control of boarding bridge wheel frame mainly lies in the control of linear speed and angular speed.According to the information provided by the perception system, the trajectory planner can plan a real-time path that conforms to the rules, avoids obstacles and optimizes from the current position to the target position[1].The main task of trajectory tracking is to accurately track a predefined (real-time or off-line) path when considering the actual position and motion state of boarding bridge wheel frame.Because of the high nonlinearity of boarding bridge wheel frame dynamics and the uncertainty of working environment, trajectory tracking has become one of the most complex and difficult tasks in boarding bridge wheel frame control.Linear proportional control is proposed in literature [2] and [3], PI control is proposed in literature [4], predictive control is proposed in literature [5], and genetic algorithm control is proposed in literature [6].Aiming at the high complexity and non-linearity of boarding bridge wheel frame dynamics model, this paper adopts fuzzy logic to realize trajectory tracking control.In uncertain working environment, it is difficult to accurately model the contact between wheel and ground, and the fuzzy controller is good at solving the interaction between these non-linear subsystems with non-integrity and uncertainty.In addition, the fuzzy controller is especially suitable for direct application of human experience to the driving control of boarding bridge wheelframe in the absence of an accurate and complete model.

2. KINEMATICS MODEL OF BOARDING BRIDGE WHEEL FRAME

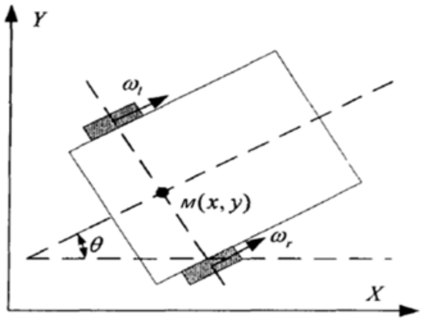

Figure 1. Kinematics Model of Wheel Frame of Two-wheel Differential Boarding Bridge

Considering the simplified kinematics model of typical two-wheel differential boarding bridge wheel frame shown in Figure 1.It has two coaxial driving wheels, each driven by a separate motor. Taking the midpoint M of the central connection of the left and right wheels as the reference point, let ω_l and ω_r be the angular velocities of the left and right

Driving wheels respectively, that is:

$$\begin{cases} \dot{x} = \cos\theta \\ \dot{y} = \sin\theta \\ \theta = \omega \end{cases}$$

Linear and angular velocities of the central motion of the wheelframe:

$$v = \frac{r}{2}(\omega_l + \omega_r)$$

$$\omega = \frac{r}{w}(\omega_r - \omega_l)$$

As shown in Figure 2, the position and posture of the boarding bridge wheel frame are represented by the coordinates and navigation angles of the axle midpoint M of its two driving wheels in the global coordinate system and the navigation angle θ.That is, the current position and posture of boarding bridge wheel frame is $P = [x, y, \theta]^T$, v and ω are thelinear and angular velocities of the wheel frame, and are the inputs of the model.

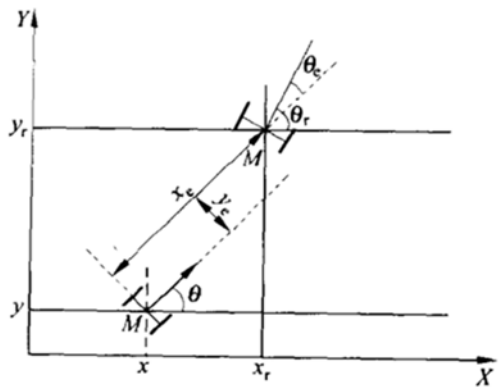

Figure 2. Schematic diagram of wheel frame position and posture coordinates of boarding bridge

The kinematics equation of the wheelframe is:

$$\dot{P} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} v \\ \omega \end{bmatrix}$$

Assuming the desired trajectory $q_r = [x_r, y_r, \theta_r]^T$, The desired state is $[v_r, \omega_r]$, The boarding bridge wheel frame model satisfies nonholonomic constraints:

$$\dot{x}_r \sin\theta_r - \dot{y}_r \cos\theta_r = 0$$

According to coordinate transformation, the error equation of the system can be obtained as follows:

$$p_e = \begin{bmatrix} x_e \\ y_e \\ \theta_e \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} x_r - x \\ y_r - y \\ \theta_r - \theta \end{bmatrix}$$

The differential equation of pose error can be obtained by deriving its error equation [8]:

$$\dot{p}_e = \begin{bmatrix} \dot{x}_e \\ \dot{y}_e \\ \dot{\theta}_e \end{bmatrix} = \begin{bmatrix} y_e\omega - v - v_r\cos\theta_e \\ -x_e\omega + v_r\sin\theta_e \\ \omega_r - \omega \end{bmatrix}$$

The goal of trajectory tracking of boarding bridge wheelframe is to find control law $[v, \omega]^T$,The error equation of the system can converge to 0 for any error, Namely $\lim_{t\to\infty} \| p_e \| = 0$.

3. DESIGN OF TRAJECTORY TRACKING CONTROL LAW FOR WHEEL FRAME

According to the differential equation of the boarding bridge wheel frame's position and attitude error, a reasonable Lyapunov function is designed by using the idea of inversion controller design. According to the stability condition of Lyapunov function [9], the trajectory tracking control law of boarding bridge wheel frame can be obtained. The Lyapunov function is selected as follows:

$$V = \frac{1}{2}(x_e{}^2 + y_e{}^2) + \frac{1}{k_2}(1 - \cos\theta_e) \tag{1}$$

The Lyapunov function of Formula (1) can be obtained by finding the first derivative of time (2):

$$\dot{V} = x_e(-v + v_r\cos\theta_e) + \frac{\sin\theta_e}{k_2}(\omega_r - \omega + k_2 v_r y_e) \tag{2}$$

Assuming that the selected control law is:

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \begin{bmatrix} v_r \cos\theta_e + k_1 x_e \\ w_r + k_2 v_r y_e + k_3 \sin\theta_e \end{bmatrix} \tag{3}$$

Substituting Formula (3) into Formula (2) Obtainable:

$$\dot{V} = -(k_1 x_e{}^2 + \frac{k_3}{k_2}\sin^2\theta_e) \tag{4}$$

When k_1, k_2, k_3 are greater than zero, From Formula (2) and Formula (4) $V \geq 0$, $\dot{V} \leq 0$, In order to satisfy Lyapunov's condition of asymptotic stability, the control law of type (3) is selected to satisfy the condition of trajectory tracking of boarding bridge wheelframe. Determine k_1, k_2, k_3 parameters. Traditional methods need to be identified by system identification, and the algorithm is complex and the robustness is poor.Therefore, this paper designs a fuzzy controller based on the distance and angle deviation between the actual position and the expected position of the boarding bridge wheel frame, and adjusts the parameters in real time, so that the system has better robustness and stability.The design system model is shown in Figure 3.:

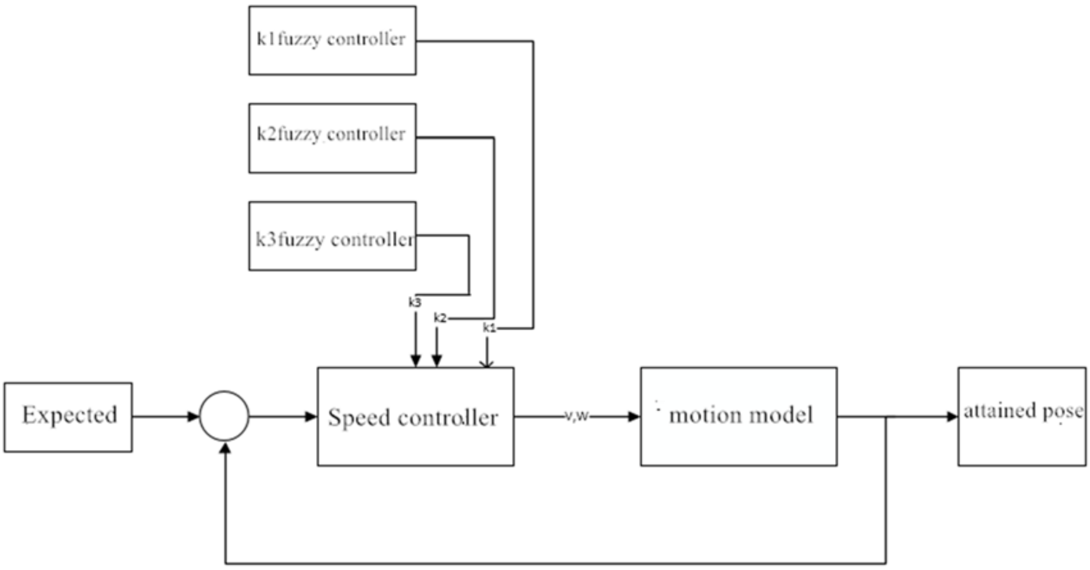

Figure 3. Control Chart of Track Tracking System for Boarding Bridge Wheel Frame

4. DESIGN OF FUZZY CONTROLLER

There are k_1 k_2 and k_3 3 parameters in Control Law $[v, \omega]^T$, So three fuzzy controllers need to be designed. All three fuzzy controllers use distance deviation D and angle deviation a as input and output, the output is determined to be k_1 k_2 and k_3 respectively.

4.1. Fuzzy input and output variables

Assuming that the range of distance deviation D is [0, 5], The range of angular deviation A is [0, pi]. D and a are divided into seven fuzzy sets: SB (super-large), HB (large), B (large), M (medium), S (small), HS (small), SS (super-small), and the universe is [-6,6].

Assume that the range of k_1 is[1,10], The range of k_2 is[1,8], The range of k_3 is[1,8]. k_1 k_2 and k_3 are divided into seven fuzzy sets: SB (super large), HB (large), B (large), M (medium), S (small), HS (small), SS (super small), and the universe is [-6,6].

Distance deviation d, angle deviation A and k_1 k_2 k_3 The domain and linguistic variables of the parameters are the same, so the five variables are all triangular membership functions. As shown in Figure 4.

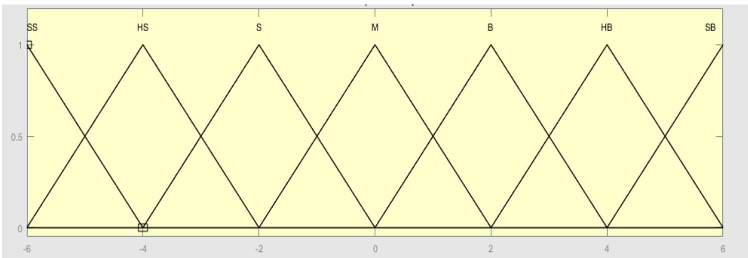

Figure 4. d, a, k_1 k_2 and k_3 membership function

4.2. Establishing fuzzy rules

Formula (7) shows that k_1 affects the linear velocity v of the wheel frame. k_2 and k_3 Influence the angular velocity of wheel frame ω .Therefore, when the distance deviation d is small k_1 Should be increased, To maintain the motion line speed v of the wheel frame. Keep it in a larger range so that it converges faster. When angle deviation is small k_2 and k_3 Should be increased,To maintain speed ω . Keep it on a wide range. Simultaneous turning radius $r = v / w$, In order to smooth the transition of the turning radius, attention should be paid to adjusting the parameters v And ω To coordinate with each other.To sum up, the establishment of fuzzy rules is shown in Table 1, and the fuzzy rule parameters are shown in Figure 5.

Table 1. k_1 Fuzzy rule table

k_1		Distance deviation d						
		SS	HS	S	M	B	HB	SB
a	SS	HB	HB	B	M	S	HS	SS
	HS	HB	HB	B	B	M	S	HS
	S	HB	HB	B	B	B	S	S
	M	HB	HB	B	B	B	S	M
	B	SB	HB	HB	B	B	S	M
	HB	SB	SB	HB	HB	B	M	M
	SB	SB	SB	HB	HB	B	B	B

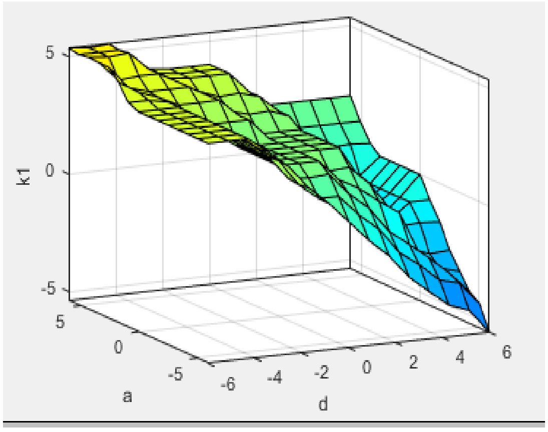

Figure 5. Fuzzy relationship diagram of d, a and k_1

4.3. Unblurring

In this paper, the centroid method is used to solve the ambiguity. Compared with the maximum membership method, the barycenter method has a smoother output inference control [10].For discrete fields with m output quantized series.

$$v_o = \frac{\sum_{k=1}^{m} v_k \mu_v(v_k)}{\sum_{k=1}^{m} \mu_v(v_k)}$$

5. SYSTEM SIMULATION AND RESULT ANALYSIS

5.1. Fuzzy controller simulation

The Fuzzy logic toolbox in Matlab provides a set of functional functions for establishing fuzzy logic systems. Therefore, based on the toolbox, this paper sets up a new tool box k_1 k_2 and k_3 fuzzy controller.Now An example of k_1 Fuzzy Controller introduces the Establishment of Fuzzy Controller. First, the distance deviation d and angle deviation a are established based on the membership function of section 3.1. Membership function of k_1, Then the fuzzy inference rules are set, and then the fuzzy reasoning operation and the fuzzy solving method are set up.Finally, fuzzy interface and clear interface of fuzzy control are established.

5.2. Simulink model building

Building a system model in a simulink environment is shown in figure 6.The system is mainly generated by the desired trajectory [12] [13]. k_1 k_2 and k_3 fuzzy controller,Speed controller module,Kinematic module of wheel frame, etc.

ISSN: 2472-3703
Volume 5 Issue 6, 2019

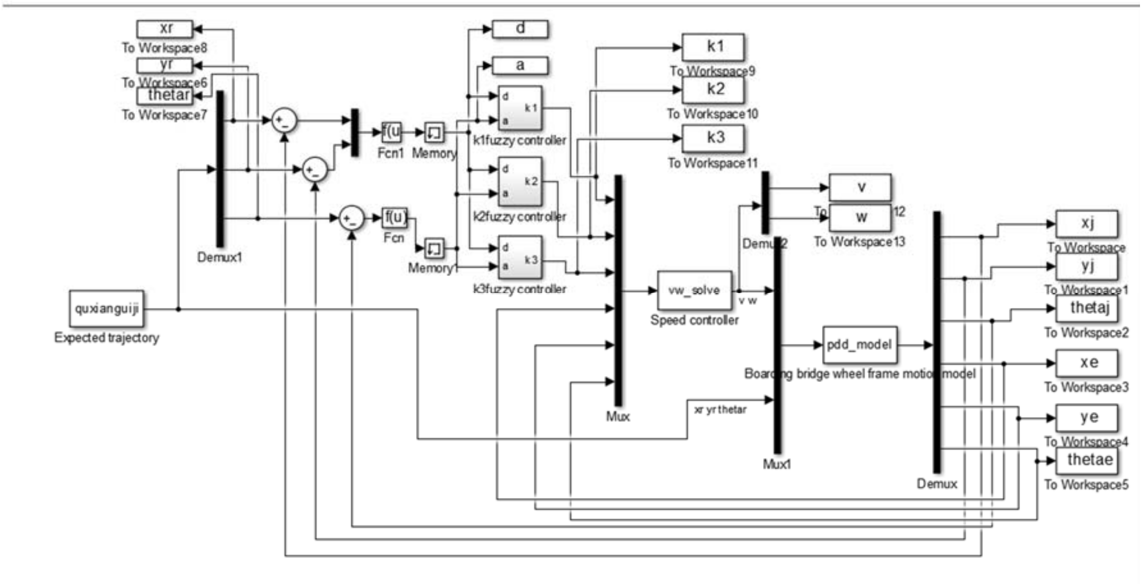

Fig 6. Simulation model of wheel frame trajectory tracking system for boarding bridge

5.3. Simulation results and analysis

The simulation results are shown in figure 7:

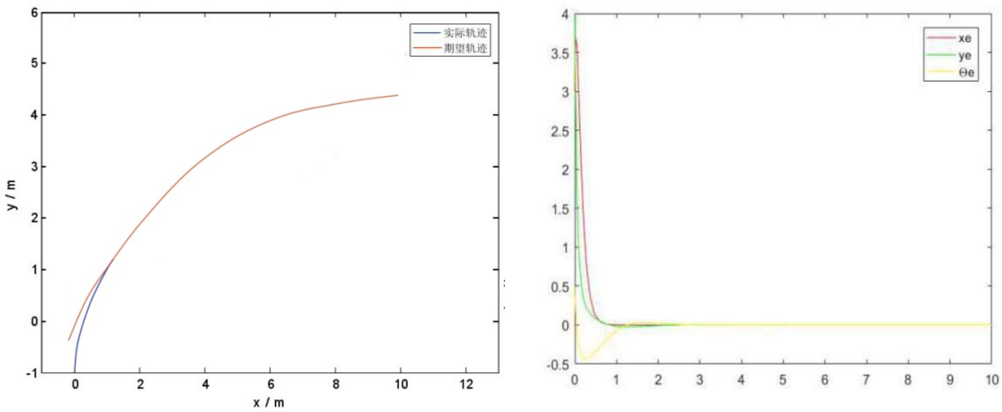

Fig 7. Curve track tracking results and pose deviation curve

In the docking process, the coordinates of the boarding bridge are (0, 0) and the aircraft door is (10, 5).In theory, the linear distance between the two points from the starting point to the target point is the shortest, but because the boarding bridge belongs to the large bridge-borne equipment, it has certain inertia. If the boarding bridge docks directly from the starting point along a straight path and the plane hatch, it will lead to an accident in which the boarding bridge encounters an aircraft engine hatch. There is a certain angle between the speed direction of the boarding bridge at the beginning and the relative position between the boarding bridge and the aircraft, so it is necessary to adjust the movement direction of the boarding bridge to gradually deflect the boarding bridge until it is docked with the front of the cabin door. From figure 7, you can see that the boarding bridge is a smooth orange curve in the path from the starting point to the docking hatch. In order to improve the safety of docking, the target point can be set to 0.5 meters in front of the boarding bridge. Preventing the boarding bridge from colliding with the aircraft and then docking the aircraft vertically can greatly improve the feasibility of the path planning. Figure 7 shows that there is a certain deviation between the actual trajectory and the expected trajectory, but it can track the desired trajectory accurately and quickly, which shows the feasibility of the desired path. The attitude deviation curve shows that the actual trajectory can converge to the desired trajectory quickly, and the stability is good. The fuzzy controller does not need to accurately calculate the control law of the boarding bridge wheel frame, but adjusts the parameters in real time according to the deviation in the running process to achieve stability.

6. CONCLUSION

In this paper, the fuzzy control principle is used to control the path tracking of the boarding bridge wheel frame. The simulation results show that the system can track any reasonable trajectory well, and can converge the pose error to 0 quickly, and the stability is good.The fuzzy controller does not need to accurately calculate the control law of the boarding bridge wheel frame, but adjusts the parameters in real time according to the deviation in the running process to achieve stabilityThe simulation results show that the fuzzy controller has good convergence and stability and can meet the requirements of actual trajectory tracking.The system still has strong stability and robustness in uncertain environment.The selection of more accurate membership function and the improvement of fuzzy rule function library are the next research directions.

REFERENCE DOCUMENTATION

[1] Yue Zhangfu, Cui Pingyuan, Cui Hutao. Path Planning Technology of Planet Detection Robot Based on Improved Ant Colony Algorithm[J]. Control and Decision, 2006, 21(12):14371440. KANAYAMA I, YUTA S. Vehicle path specification by a sequence of straight lines[J]. IEEE Journal of Robotic and Automation, 1988, 4(3): 265-276.

[2] AMIDI O.Integer mobile robot control[R]. Pittsburgh:Carnegie Mello University Robotics Institute Technical Report CMU-RI-TR- 90-17. 1990: 27-31.

[3] KANAYAMA I, MIYAKE N. Trajectory generation for mobile robots[J]. Robotic Research, 1986, 3: 333-340.

[4] CROWLEY J. Asynchronous control of orientation and displacement in a robotic vehicle[C]//Proc IEEEConference on Robotics and Automation. [S.l.]: IEEE Press, 1989: 1277-1282.

[5] Wu Jinfei, Qin Dongxing, Liu Jun. Nonholonomic motion control of four-wheeled mobile robot [J]. Journal of University of Electronic Science and Technology, 2007,36 (2): 302 / 304.SINGH S, SHIN D H. Position based path tracking for wheeled mobile robots[C]//Proc IEEE International Workshop on Intelligent Robots and Systems. [S.l.]: IEEE Press, 1989: 386-391.

[6] Zhou Xing, Wu Hongming. Design of adaptive fuzzy controller for AGV trajectory tracking [J]. Lifting and Transportation Machinery, 2017 (7): 19 / 22.Koo J,Choi S,Won S.Observe-based trajectory tracking control for a wheel mobile robot[J].Asian Control Conference,2009(7).

[7] Liu Jinkun. Intelligent control [M]. Beijing: electronic Industry Press, 2015. Li Guoyong. Intelligent control and its MATLAB implementation [M]. Beijing: electronic Industry Press, 2005.

[8] Liao Hua, Zhou Xiang, Dong Feng, etc. AGV tracking algorithm based on fuzzy control [J]. Journal of Harbin University of Technology, 2005, 37 (7): 896 / 898.

[9] Chen Hao. Trajectory tracking control of nonholonomic wheeled mobile robot based onadaptive fuzzy sliding mode controller [D]. Shaanxi: Changan University, 2013.