DOI: 10.13434/j.cnki.1007-4546.2017.0304

Motion Control of Omnidirectional Mobile Platform based on Fuzzy PID

PENG Jiang-tao[1], GAO Peng-fei[2], YANG Dong[1], AKBOTA Kalizhanova[2], MENG Hua-lin[1]

([1] Avic Chengdu Aircraft Industral (Group) Co.Ltd, Chengdu 610091, P. R. China
[2] Northwestern Polytechnical University, Xi'an 710072, P. R. China)

Abstract: The omnidirectional mobile platform has three degrees of freedom that make it widely applicable to all areas of industry, while the Mecanum wheel has the disadvantages of large vibration, the trajectory precision of Mecanum wheel omnidirectional mobile platform is always difficult in the omnidirectional mobile platform. To control the trajectory of the omnidirectional mobile platform better, this paper proposes a fuzzy self-tuning PID control model, through establishing the motion model of omnidirectional mobile platform in Adams software, then combined with Simulink simulation, analysis of fuzzy PID controller to improve the accuracy of the speed control of omnidirectional mobile platform, improve the control method of a precise trajectory of the omnidirectional mobile platform motion.

Keywords: omnidirectional mobile platform; fuzzy self-tuning PID; control model

1 Introduction

The omnidirectional mobile technology is a new technology from mobile robots development, omnidirectional mobile platform is the application results of the omnidirectional mobile technology, omnidirectional mobile platform can be achieved and rotated three degrees of freedom motion. Because a translational and rotary motion is independent of each other, so it can be more convenient to adjust the robot motion, to solve the traditional mobile platform in a narrow space within the radius, not accurate positioning and difficult to adjust the pose problem[1]. Because of its good motion characteristics, omnidirectional mobile platform has been widely used in production and processing as well as people's daily life[2]. However, the positioning accuracy of the existing omnidirectional mobile platform is not very satisfactory, increase of the freedom of the omnidirectional mobile platform also leads to the deviation of the speed and direction of movement[3-5]. In this paper, according to the deviation of omnidirectional mobile platform movement speed and direction of motion, it shows fuzzy self-tuning PID control model, controller to eliminate the deviation of the platform motion, reduce the fluctuation of the steady-state speed, improve the stability of motion. The motion error of omnidirectional mobile platform is inevitable. Therefore, it is very important to know how to improve the motion accuracy and reduce the error of trajectory tracking. The speed control is a key link in the control system of the omnidirectional mobile platform, and the speed control includes the control of the servo motor and the speed control of the mobile platform. Only by improving the precision of the mobile platform speed control, we can control the trajectory of the platform.

Received 16 March 2017

2 Overall speed control design of omnidirectional mobile platform

Proportional, integral and differential control is one of the most widely used control methods in engineering, referred to as PID control[6]. PID controller has the advantages of the simple structure, easy realization of hardware and software, good stability, high reliability and good robustness to model an error[7], which is widely used in industrial process controlling. Fuzzy control is a method, based on rules, it directly uses language control rules and expert control phenomenon in engineering related experience as the starting point, it is a method of artificial control, strong adaptability, and certain degree of intelligence[8]. The fuzzy controller needs to establish the relevant reasoning mechanism, and does not need to know the exact mathematical model of the controlled system. The omnidirectional mobile platform is a multi-input and multi-output nonlinear system, showing influence of wheel slippage, uneven load distribution, motor control deviation and other factors in the process of movement, so fuzzy control algorithm is adopted.

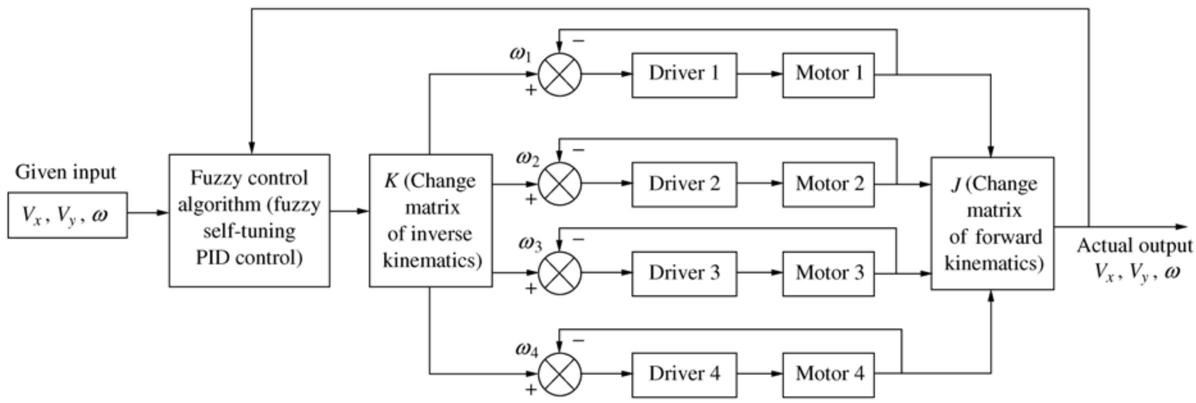

Figure 1 The mobile platform speed control overall structure diagram

As shown in Figure 1, the speed control of omnidirectional mobile platform adopts the idea of fuzzy PID control to improve the motion accuracy of the system. First of all, the difference between the actual platform speed from the external sensor detects the initial velocity, and the amount of output as the input of fuzzy controller, fuzzy controller with the corresponding mobile platform after processing, the speed sensor gets the input speed of each motor through the inverse kinematics transformation matrix of the system. At the end, the kinematics matrix obtained the theory of output speed which is for omnidirectional mobile platform by each wheel speed.

3 Outer loop fuzzy PID control of omnidirectional mobile platform

Fuzzy self-tuning PID [9] is based on the PID controller, according to the input error e and error rate of change e_c, the application of two-dimensional fuzzy control method for the PID with the three parameters in real-time setting[10]. The controller combines the advantages of fuzzy control and conventional PID, when the input error faster response speed, and when a small error can improve the stability of the system, the controller structure is shown in Figure 2.

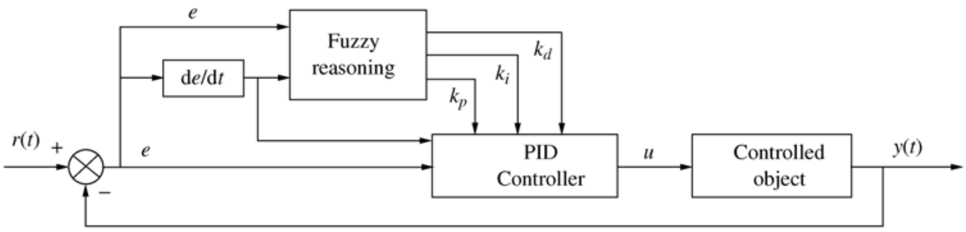

Figure 2 Structure of fuzzy self-tuning PID controller

3.1 Design of fuzzy self-tuning PID controller

When the platform moves longitudinally, speed steady-state error and speed fluctuation of mean achive minimum; during the horizontal movement, there is a certain bias speed steady state mean and the theoretical value, the speed fluctuation is small; with the platform along the 45 degree oblique motion, longitudinal and transverse velocity fluctuation, the motion precision is low[10]. Due to the relatively large error of V_y, the longitudinal velocity of V_x is relatively large. It has been shown, the fuzzy self-tuning PID controller is used to improve the speed control accuracy.

1) Fuzzy variable

Signal input device for the fuzzy input velocity deviation of delta V_y, e_c variation of transverse velocity deviation rate; the output parameters of the fuzzy PID controller are k_p, k_i and k_d. The total output of the fuzzy self-tuning PID controller is u, which provides the adjusted speed control signal for the mobile platform.

The error e of the value space is [−20,20], the error e of the fuzzy language for {NB, NS, ZE, PS, PB}, the value of the error is quantified to [−2,2], the quantization factor k_e is 10. Steady state velocity fluctuations around the mean, the data sampling period is smaller, the slope velocity curve (error rate e_c) greater value space position, error rate of e_c is [−12 001 200], the value space of fuzzy language is {NB, NS, ZE, PS, PB}, the value of error rate is also quantified to quantify [−2,2] factor k_{e_c} is 600. Input error e and the input error rate of e_c membership functions are shown in Figure 2 and Figure 4, the membership function of the common triangle function, convenient and relatively simple calculation.

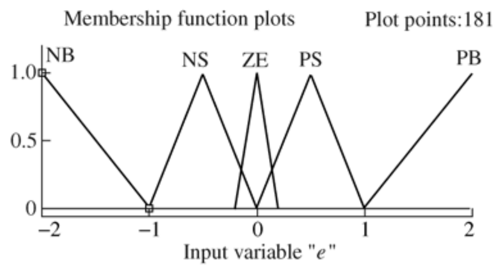

Figure 3 Membership chart of input deviation e

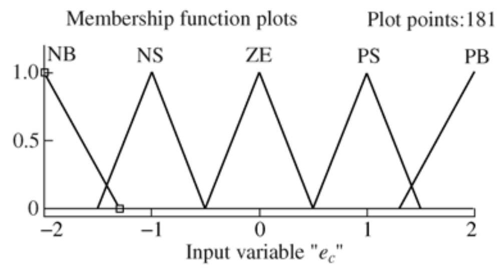

Figure 4 Membership degree of input deviation rate e_c

The value space proportional coefficient k_p is [0, 3], fuzzy language value space for {PS, PM, PB}; interval integral parameter k_i is [0, 15], the value space of fuzzy language is {ZE, PS, PB}; interval differential parameter k_d is [0, 0.01], the value space of fuzzy language is {ZE, PS, PB}. k_p, k_i and k_d three output variables of the membership function is also taken as a triangular function, as shown in Figure 5, Figure 6 and Figure 7.

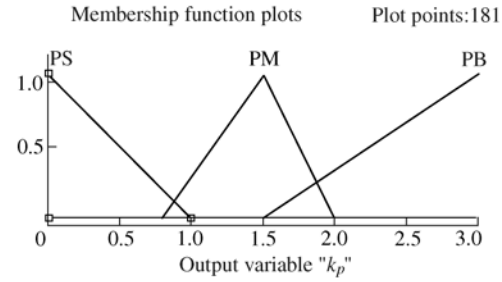

Figure 5 Membership coefficient of scale factor k_p

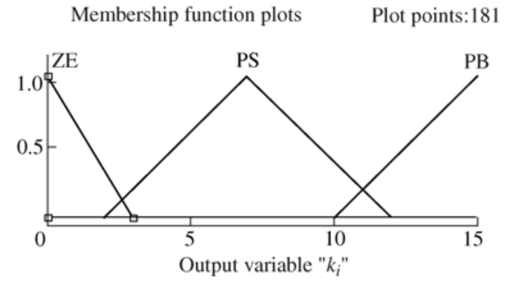

Figure 6 Membership coefficient of integral coefficient of k_i

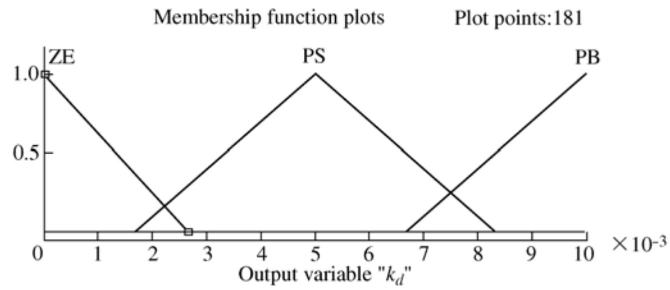

Figure 7 Membership degree of differential coefficient of k_d

2) Fuzzy control rule base design

The parameter adjustment model of PID is usually based on the step response characteristics of the two order system. In order to make the longitudinal motion of the omnidirectional mobile platform more rapid and sTable, combined with the practical experience of setting PID parameters and the step response characteristics of the two order system, the following control rules are proposed under:

Rule 1: in the initial state, the error e is larger, can take a larger proportion of k_p; in order to shorten the response time, reduce the steady-state error, can take the appropriate integral coefficient k_i;

Rule 2: when the error e is of moderate size, in order to reduce overshoot, smaller k_p and k_i coefficients can be obtained;

Rule 3: when the error e is small, in order to increase the stability of the system, the k_p coefficient of moderate size and the k_d coefficient of moderate size can be taken into account;

Rule 4: when the error e is small, k_d is also based on the error rate of change in the size of e_c to be adjusted, the larger the e_c takes a smaller k_d, the smaller the e_c takes a larger k_d.

According to the above rules, select the "if e e_c then u" form, the establishment of the output variables k_p, k_i and k_d 25 control rules, and the establishment of the corresponding query table. k_p, k_i and k_d parameters corresponding to the fuzzy output space are shown in Table 1, Table 2 and Table 3.

Table 1 k_p on e and e_c fuzzy control rule table

k_p		e_c				
		NB	NS	ZE	PS	PB
e	NB	PM	PB	PB	PB	PB
	NS	PS	PS	PM	PM	PB
	ZE	PM	PM	PS	PM	PM
	PS	PB	PB	PM	PM	PS
	PB	PB	PB	PB	PB	PM

Table 2 k_i on e and e_c fuzzy control rule table

k_i		e_c				
		NB	NS	ZE	PS	PB
e	NB	ZE	ZE	ZE	ZE	ZE
	NS	PS	PS	ZE	ZE	ZE
	ZE	ZE	PS	PB	PS	ZE
	PS	PB	PB	PS	ZE	ZE
	PB	PB	PB	PB	PB	PB

Table 3 fuzzy control rule table of k_d about e and e_c

k_d		e_c				
		NB	NS	ZE	PS	PB
e	NB	PD	PB	PB	ZE	ZE
	NS	PS	PB	PS	ZE	ZE
	ZE	PS	PB	PB	PB	PS
	PS	ZE	ZE	PS	PB	PS
	PB	ZE	ZE	ZE	PB	PB

3) Defuzzification method

In this paper, the weighted average method (discrete centroid method) is used to solve the fuzzy sets of output parameters k_p, k_i and k_d. The output of u can be expressed as:

$$u = \frac{\sum \mu_i(u_i)u_i}{\sum \mu_i(u_i)} \tag{1}$$

In the formula, a point in the fuzzy space of the output variable, which is the membership degree of the point.

According to the formula(1), the real time parameters of k_p, k_i and k_d of the PID controller can be calculated at different time.

3.2 Simulation of fuzzy self-tuning PID control for omnidirectional mobile platform

This paper adopts mechanical model of omnidirectional mobile platform in the ADAMS as shown in Figure 8, the model is added to the fuzzy self-tuning Simulink to create PID control diagram, simulation diagram as shown in Figure 9, in which the input signal for the V_y lateral velocity step signal, velocity for 300 mm/s, the input angular velocity and longitudinal velocity V_x around its center of rotation were 0. Speed mobile platform input through the inverse kinematics equation module into the motor speed of the four wheels; motor and reducer module can be simplified into a typical K_m/order system (T_m, $s+1$), according to the motion characteristics of common servo motor, and the time coefficient Tm is 0.01, the driving signal is input to the last mechanical model of the wheel. The measurement module in ADAMS can be used as a sensor module, the output platform of the longitudinal velocity and lateral velocity of V_y and V_x around its center of rotation angular velocity, the transverse velocity feedback V_y and the ideal combination of input speed as the input signal of fuzzy controller.

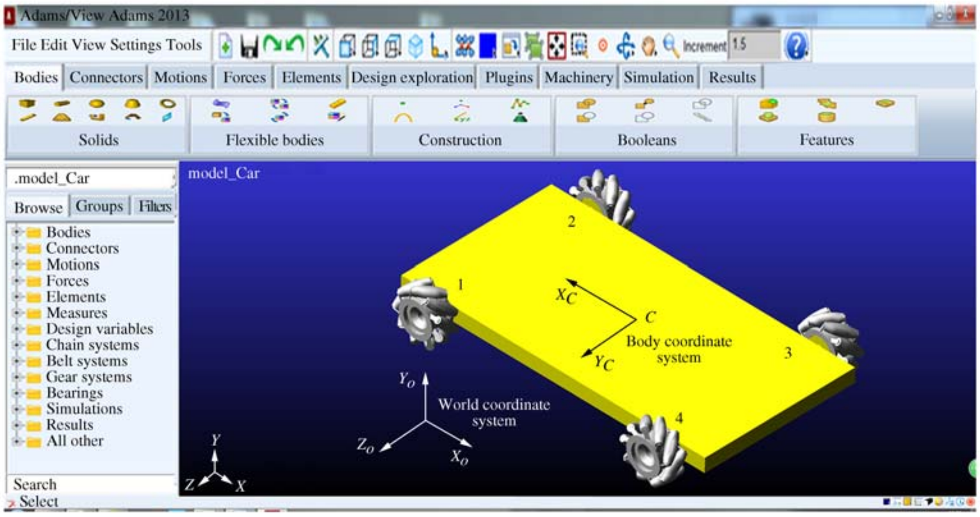

Figure 8 Virtual prototype of mobile platform

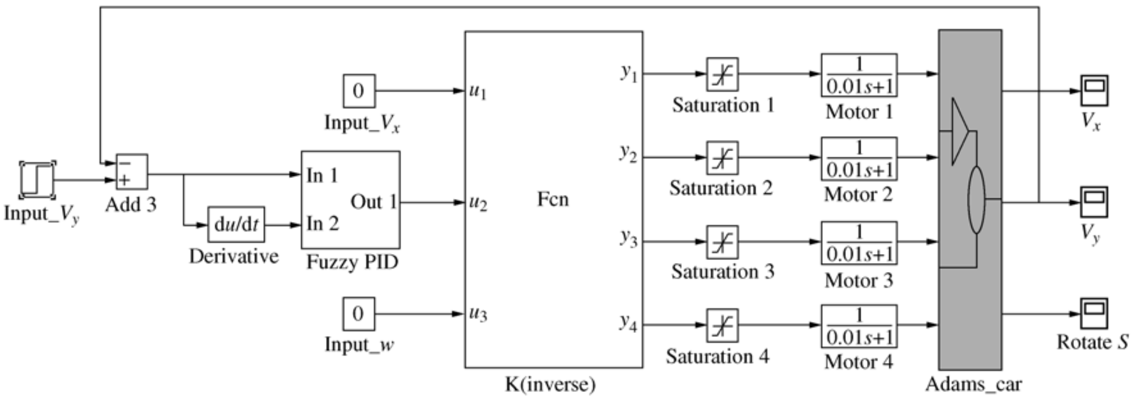

Figure 9 Block diagram of fuzzy self-tuning PID controller for mobile platform

From Figure 10 and Figure 11 following results can be obtained, when the speed of order of omnidirectional mobile platform lateral input 300 mm/s step signal, the steady-state mean open loop curve is 293. 3 mm, and 2. 2% of the error value, and the speed fluctuation is 5. 7%, and the previous simulation results in ADAMS are introduced; PID method that can eliminate the steady-state error. The steady-state mean conventional PID algorithm is 300. 03 mm/s, and the relative error between the theoretical values is 0. 01%, the steady-state maximum speed of V_{max} = 306. 53 mm/s, minimum speed V_{min} = 294. 84 mm/s, small fluctuation rate about 3. 90%; fuzzy self tuning PID algorithm of the steady-state mean was 300. 02 mm/s, and the relative error between the theoretical values is 0. 007% at steady state, the maximum speed V_{max} = 304. 87 mm/s, minimum speed V_{min} = 295. 22 mm/s, small fluctuation rate about 3. 22%. The steady-state error of the two control algorithms is very small, no more than 0. 2%, and the fluctuation amplitude of both the control algorithms is less than 5%. Therefore, after adding PID and fuzzy self-tuning PID algorithm, the moving speed of the mobile platform can reach a higher precision standard

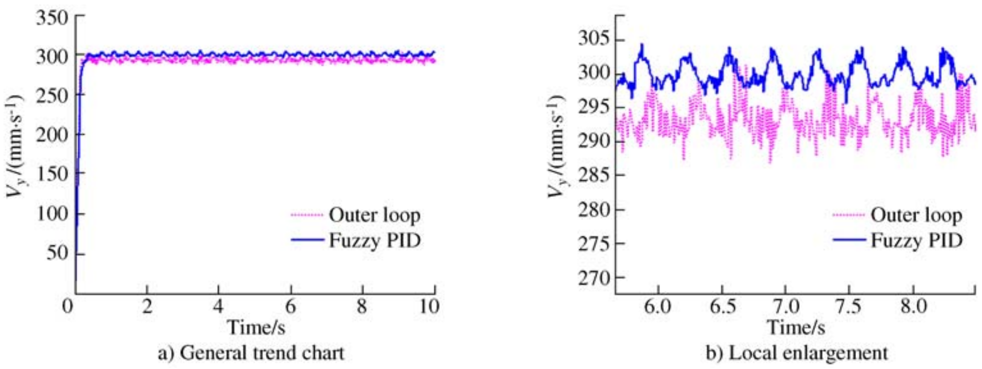

Figure 10 Fuzzy self-tuning PID step response curve

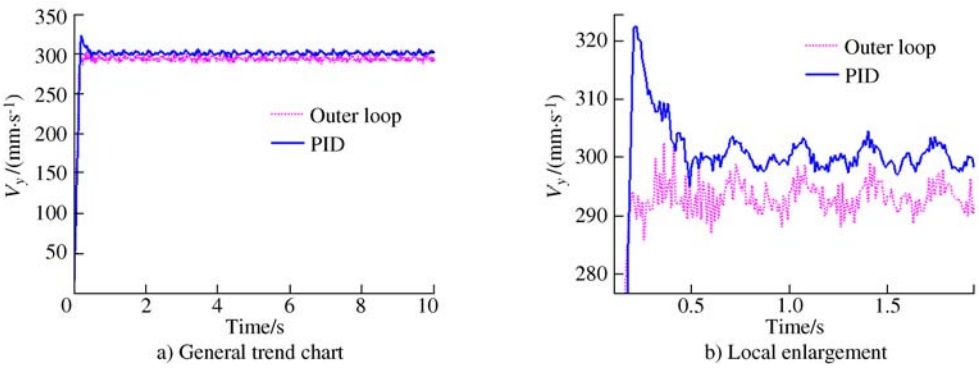

Figure 11 Normal PID step response curve

In the beginning of the conventional PID control, there is an overshoot process, the overshoot is about 7. 3%, and the fuzzy self-tuning PID controller adjusts the proportion and integral coefficients of the PID to avoid the overshoot phenomenon. Under the influence of motor performance and mobile platform of mechanical system inertia and other factors, the fuzzy self-tuning PID control time is about 0. 2 s; due to the overshoot, the conventional PID control system reaches the steady state in long periods of time, the adjustment time is about 0. 4 s. Finally, the speed response characteristic of the fuzzy self-tuning PID controller is better than that of the conventional PID controller, which reduces the response time of the platform while eliminating the lateral motion error of the moving platform.

In summary, in this paper the fuzzy self tuning PID controller designed to control the overall performance is good, the design requirements of precision mobile platform lateral movement, the deviation between the mean and minimum steady-state speed, the theoretical value is less than 0. 2%, and the speed fluctuation can be controlled within 5%.

4 Conclusions

This paper proposes a fuzzy self-tuning PID control model, through the establishment of omnidirectional mobile platform and the speed of fuzzy self-tuning PID controller, and the combination of ADAMS and MATLAB simulation experiments to verify the performance of the controller. After adding the controller, can eliminate the speed deviation of lateral movement, and control the speed fluctuation in steady state within 5%, solve the precision control problem of motion velocity of the omnidirectional mobile platform, using a method of precise trajectory control of omnidirectional mobile Mecanum wheel, which is based on the reference and help for the accurate logistics application of omnidirectional mobile platform in the industry.

References

[1] How T V. Development of an anti-collision and navigation system for powered wheelchairs[D]. University of Toronto(Canada), 2010

[2] Du Z. The ten emphasis on the development of robot in the next five years, robot industry development plan (2016 - 2020)[J]. China's Strategic Emerging Industries, 2016,(11):44-45 (in Chinese)

[3] Ishigami G, Pineda E, Overholt J, et al. Design, development, and mobility test of an omnidirectional mobile robot for rough Terrain[C]// Field and Service Robotics. Springer Berlin Heidelberg, 2014: 599-611

[4] Cao F, Wang X, Li X. Fuzzy adaptive PID control of a mobile assistive robot platform[C]// Dependable, Autonomic and Secure Computing (DASC), 2014 IEEE 12th International Conference on. IEEE, 2014: 502-506

[5] Xie L, Herberger W, Xu W, et al. Experimental validation of energy consumption model for the four-wheeled omnidirectional Mecanum robots for energy-optimal motion control[C]// Advanced Motion Control (AMC), 2016 IEEE 14th International Workshop on. IEEE, 2016: 565-572

[6] Bai M, Wang H, Rui X, et al. Optimization design for PID parameter of mobile robot based on genetic algorithm[J]. Journal of Northeast Forestry University, 2008, 4(2):80-82 (in Chinese)

[7] Kuo T C, Huang Y J. A sliding mode PID-controller design for robot manipulators[C]// Computational Intelligence in Robotics and Automation, 2005. CIRA 2005. Proceedings. 2005 IEEE International Symposium on. IEEE, 2005: 625-629

[8] Jiang X, Motai Y, Zhu X. Predictive fuzzy logic controller for trajectory tracking of a mobile robot[C]// Soft Computing in Industrial Applications, 2005. SMCia/05. Proceedings of the 2005 IEEE Mid-Summer Workshop on. IEEE, 2005: 29-32

[9] Lai X, Zhu S, Wu W. Research on driving wheel control of cleaning robot based on fuzzy adaptive tuning PID[C]// Mechatronics and Automation, 2009. ICMA 2009. International Conference on. IEEE, 2009: 535-540

[10] Chen W, Gao Y, Chen Z, et al. Application of fuzzy-PID controller in electic chassis featured by mecanum wheel[J]. Journal of Mechanical Engineering, 2014, 50(6):129-134 (in Chinese)

Brief Biographies

PENG Jiang-tao is a senior engineer in AVIC Chengdu Aircraftt Industral (Group) Co. Ltd. His research interest is digital assembly of aircraft. pengjt2008@ sina.com

GAO Peng-fei is a master candidate in School of Mecanical Engineering, Northwestern Polytechnical University. His research interest is integrated development and application of omnidirectional mobile platform. gpf@ mail.nwpu.edu.cn

YANG Dong is an assistant engineer in AVIC Chengdu Aircraftt Industral(Group) Co. Ltd. His research is the design of digital assembly control system . 2356193354@ qq.com

AKBOTA Kalizhanova is a master candidate in School of Mecanical Engineering, Northwestern Polytechnical University. Her research interest is integration of electromechanical systems. 3102837898@ qq.com

MENG Hua-lin is a senior engineer in AVIC Chengdu Aircraftt Industral(Group) Co. Ltd. His research is the design of production line system. menghualin78614@ 126.com