# INTELLIGENT CONTROL TECHNOLOGY OF AGRICULTURAL GREENHOUSE OPERATION ROBOT BASED ON FUZZY PID PATH TRACKING ALGORITHM /

## *基于模糊 PID 路径跟踪算法的农业温室作业机器人智能控制技术*

**Ren Qun** [1]
Bozhou University, Department of Electronic and Information Engineering, Bozhou, Anhui, 236800 / China
**Tel: 13006396137; E-mail: gtukhx35@sina.com*
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## ABSTRACT

*With the development of agricultural automation, applying intelligent algorithms to the navigation control of agricultural work vehicles has important practical significance for improving vehicle navigation accuracy and operation efficiency. In view of the complexity of the agricultural greenhouse environment, this study proposed a fuzzy PID path tracking algorithm based on the traditional vehicle PID control system. This algorithm uses a fuzzy controller to improve the PID control system, thereby realizing the online setting of PID control parameters. In order to verify the effectiveness of the fuzzy PID path tracking algorithm, the improved control system was applied to the tracked vehicle robot of Beijing Forestry University, and the operation performance of the vehicle robot was tested. The research results show that the absolute error rate of vehicle robot distance measurement is less than 1%; the error of the man-machine follow-up test is between 4 and 7 cm, and the measured follow-up distance is slightly less than the safe follow-up distance; the maximum error of the vehicle's fixed-point parking is 0.3 cm; The linear position tracking control has a lateral position deviation of ±3cm, and the vehicle's linear driving control and steering effects are better. The fuzzy PID path tracking algorithm designed this time shows good control performance, which has reference significance for the practical application of agricultural robots.*

## 摘要

*随着农业自动化的发展，将智能算法应用于农业作业车辆的导航控制，对于提高车辆导航精度和作业效率具有重要的现实意义。针对农业温室环境的复杂性，本文在传统车辆 PID 控制系统的基础上，提出了一种模糊 PID 路径跟踪算法。该算法采用模糊控制器对 PID 控制系统进行改进，从而实现 PID 控制参数的在线整定。为了验证模糊 PID 路径跟踪算法的有效性，将改进后的控制系统应用于 S 大学履带式车辆机器人，并对其运行性能进行了测试。研究结果表明，车载机器人测距的绝对误差率小于 1%；人机跟踪试验的误差在 4～7cm 之间，实测跟踪距离略小于安全跟踪距离；车辆定点停车最大误差为 0.3cm；直线位置跟踪控制具有±3cm 的横向位置偏差，车辆的线性驾驶控制和转向效果较好。本次设计的模糊 PID 路径跟踪算法具有良好的控制性能，对农业机器人的实际应用具有参考意义。*

## INTRODUCTION

The in-depth research and development of modern science and technology and control theory have guided the intelligent transformation of agricultural production technology. The traditional agricultural production method mainly relies on manpower. This method has low production efficiency and is greatly affected by the environment and weather. The application of automation technology has fundamentally liberated the agricultural labour force. *Blake T.* discussed the impact of the development of automation, robotics, and the Internet of Things on the transformation of agricultural production technology, and proposed to apply modern factory control experience to agricultural technology to improve agricultural productivity *(Blake T., 2016). Auat Cheein F.* proposed an intelligent sampling technology for automatic vehicle tracking path. The probability frame was used to predict and avoid obstacles. Finally, the working performance of the controller was tested on agricultural machinery.

[1] *Ren Qun, As. PhD. Eng.*

The results show that this technology significantly improves agricultural machinery, control performance and work efficiency *(Auat C.F., 2016)*. Facility agriculture is the current mainstream modern agricultural production method. This technology is to carry out agricultural production activities, such as agricultural greenhouse production, in an artificially constructed facility environment. Facility agriculture is a labour-intensive industry. If a high level of equipment and technical automation cannot be achieved, the production efficiency of this method will be greatly limited. Agricultural vehicles are important cooperative operation equipment in facility agriculture. Improving the intelligent control technology of agricultural vehicles can effectively improve agricultural production's efficiency. Electromagnetic navigation is currently the main method of agricultural vehicle navigation, but the stability of electromagnetic sensors is poor, and it is susceptible to electromagnetic interference from other equipment. Path tracking is currently an important research direction in the navigation control of agricultural vehicles, but in facility agriculture, traditional control technology is greatly affected by the environment, and the navigation effect is unstable. This study uses intelligent algorithms to improve traditional control techniques in order to improve the stability and accuracy of agricultural vehicle navigation.

This study proposed the use of fuzzy PID control algorithm to improve the navigation performance of agricultural vehicles. This algorithm contains two aspects, namely fuzzy logic and PID control. PID control is a classic industrial control method, but this method has poor control performance for nonlinear and uncertain objects. Fuzzy control is the use of fuzzy rules for fuzzy reasoning, and the online setting of control parameters is achieved through the fuzzy control rule table. Combining fuzzy control with PID control can make up for the limitations of PID control technology.

For the optimization of the navigation technology of agricultural work vehicles, there are two innovations in this study. One is to use the weighted fusion algorithm to process the sensor distance value. This method assigns weights to the ranging information of different sensors to ensure full monitoring of the operating environment information. The second is to use fuzzy controller to improve the PID control technology. The fuzzy controller adjusts the PID control parameters and improves the accuracy of the control algorithm.

This research is mainly carried out from four parts. The first part analyses the relevant literature at home and abroad, and expounds the research status from the three perspectives of automated agriculture, PID control technology and fuzzy logic. The second part designs the navigation control algorithm of agricultural vehicles from two aspects: distance weighted fusion algorithm and fuzzy PID control technology. In the third part, the control algorithm designed above is used for field test application, and the performance of the fuzzy PID path tracking control algorithm is analysed according to the test results. Finally, the fourth part summarizes the method and results of this research, and reflects and explains the shortcomings of the research process.

*Paul M*. studied the relationship between sustainable agriculture and a fair economy in the United States, proposed the reconstruction of food sheds to create sustainable and safe local food systems, and discussed the feasibility of rebuilding food sheds from the perspective of mass participation (*Paul M. and Philip A. L., 2016*). According to the current situation of agricultural automation in India, *Patel. A et al*. proposed adaptive intelligent systems for the development of agriculture based on the complexity and nonlinear characteristics of biological systems, and analysed the role of various intelligent technologies in the transformation of agricultural technology *(Patel A, Kadam P., 2016)*. *Li J.* applied intelligent robot technology to the cycle management of agriculture, and proposed key technologies such as robot vision modelling, pattern recognition, and human-computer interaction decision *(Li J., Wei X. and Zhang G., 2017)*. *Ishii K. and others* discussed the application status and application prospects of robot technology in the primary industry, and gave a detailed introduction to the current research on advanced robot technology in order to improve the production and management efficiency of agriculture, forestry, fishery and the primary industry. *(Ishii K., Hayashi E., Misron N.B., 2018)*

*Hamidi K E* and others designed an adaptive control strategy. By combining PID fuzzy logic and particle swarm optimization algorithm, the stability and trajectory tracking problems of the aircraft system were solved, and the control was proved by robustness *(Hamidi K. E. et al., 2019). Maurya S et al*. proposed a neutral fuzzy PID controller and analysed the position tracking control performance of the neutral fuzzy PID controller through simulation experiments, proving that this method has better robustness *(Maurya S., Jain V. K., 2016). Yan H*. and others designed a processing system based on fuzzy logic and PID control, and analysed its processing performance in a single-axis solar tracking system.

The results show that this system can effectively reduce the influence of uncertain factors on system control *(Yan H., Deng S. and Chan M., 2016)*. *Peng L. et al.* proposed a fuzzy PID control strategy based on variable domain in view of the characteristics of large inertia and large lag in the main steam temperature control system of thermal power plants, and proved the effectiveness and superiority of this strategy through simulation experiments. *(Peng L, Zheng S. and Chai X., 2018)*.

*Sabir M.M. and others* designed an optimal PID controller and used a swarm intelligence algorithm to optimize the PID controller. The research shows that the Cuckoo search algorithm has the best optimization effect on the controller *(Sabir M. M. and Ali. T., 2016)*. *Kurniasih D. et al.* used fuzzy logic method to study the potential development direction of the village of Bullejo based on the indicators of agricultural potential, large cattle farms, small livestock and poultry farms, and proved that this method is used to calculate the potential development direction of the village. *(Kurniasih D, Jasmi K. A. and Basiron B., 2018). Morais P.* has a good application effect *(Morais P., Alberto Marchi, 2017)*. *Yan H. et al*. proposed an automatic control method for farmland irrigation based on sensor network technology, and used fuzzy logic technology to select the best cluster head to achieve the lowest energy consumption of sensor nodes. Research shows that this control strategy effectively extends the entire longevity of the network *(Yan H., Xia Y. and Deng S., 2017)*. *Rodriguez E. et al.* used fuzzy logic to establish an agricultural soil dynamic quality index, and proved the response performance of the index by verification experiments *(Rodriguez E., Peche R. and Garbisu C., 2016)*.

In summary, intelligent technology and robot technology have a huge impact on the sustainable development of agriculture; PID control technology has a lot of research and application in path tracking; the advantage of fuzzy logic lies in handling uncertainty, inaccuracy and Subjective question. Here, fuzzy PID control technology is applied to the operation of vehicle robots in agricultural greenhouses, in order to achieve intelligent control of vehicle robots in path tracking.

## MATERIALS AND METHODS

### Design of weighted fusion algorithm for target distance information processing

Agricultural greenhouses have a complex and changeable open production environment, so it is difficult to obtain complex environmental information with only a single sensor. *(Na Y, Qing W and Shicao C., 2020)* Due to the difference in working principle and equipment performance, the measurement range and accuracy of different sensors are different. Ultrasonic technology and infrared technology are currently commonly used sensor technology for agricultural greenhouses. Ultrasonic sensors have better measurement accuracy, but their measurement efficiency is lower, and multiple sets of measurements will reduce the real-time detection of equipment. Although the infrared sensor has a slightly lower measurement accuracy, it has a digital-to-analogue conversion function, which can ensure the real-time and efficiency of the device detection *(LingXin B, ChengKun C, GuangRui H, Adilet S and Jun C., 2020).* With the development of intelligent technology, multi-sensor fusion algorithms fuse the measurement information of different sensors to make up for the shortcomings of a single sensor *(Yibo L., Hang L and Xiaonan G., 2020).* The core idea of this technology is to use the measurement information of different sensors in accordance with the established time sequence and rules, so as to realize the comprehensive detection of environmental characteristic information. The current sensor information fusion technology mainly includes weighted average method, artificial neural network method, Bayesian estimation, etc. This research will use weighted fusion algorithm to process the sensor measurement information of infrared technology and ultrasonic technology.

$X_u$, $X_r$ represents the ultrasonic and infrared sensor measurement values; $X$ represents the true value; e represents the random detection error, and $e_i \sim N(0, \sigma_i^2)$. Then there is the following relationship.

$$\begin{cases} X_u = X + e_u \\ X_r = X + e_r \end{cases} \tag{1}$$

Based on the measured values and adaptive methods of the two sensors, the weights of the two sensors can be calculated. Combining weights and measurement values, the optimal value of the fusion detection system can be obtained. It is assumed that the optimal value is an unbiased estimate of the true value, and it has a linear relationship with the measured value. Let $X$ represent the optimal value, and its function expression is as follows, where $W$ is the weight of the corresponding sensor.

$$\hat{X} = W_u X_u + W_r X_r \tag{2}$$

The difference between the true value and the optimal value represents the estimated error value of the sensor, then the total mean square error $E[X^2]$ of the ranging module is shown below.

$$E\left[\tilde{X}^2\right] = E\left[\left(X - \hat{X}\right)^2\right] \tag{3}$$

The optimal value $X$ is an unbiased estimate of the true value $X$, and $W_u+W_r=1$ Combining equations (1), (2), and (3), the following relational expression can be calculated.

$$E\left[\tilde{X}^2\right] = W_u^2 e_u^2 + W_r^2 e_r^2 \tag{4}$$

According to the theory of seeking extremum of multivariate function, under the condition that the total mean square error $E[X^2]$ is the smallest, the function expression of the weighting weights of the two sensors is shown in formula (5). By combining formula (2) and formula (5), the optimal value $X$ after weighted fusion can be obtained.

$$\begin{cases} W_u = \sigma_u^2 \left( \dfrac{1}{\sigma_u^2} + \dfrac{1}{\sigma_r^2} \right)^{-1} \\ W_r = \sigma_r^2 \left( \dfrac{1}{\sigma_u^2} + \dfrac{1}{\sigma_r^2} \right)^{-1} \end{cases} \tag{5}$$

**Design of vehicle robot control system based on fuzzy PID**

The vehicle operating state is easily affected by the vehicle's own structural characteristics and external road conditions, so the vehicle's operating system exhibits characteristics of nonlinearity and inaccuracy. PID control is also called proportional integral differential control. Because of its simple algorithm and good robust performance, it is widely used in industrial process control. In the vehicle operation control system, the traditional PID control technology mainly adjusts the movement state of the vehicle through the position, speed, and heading angle of the vehicle. However, in practical applications, this control strategy reflects some limitations, such as the difficulty of setting control parameters and the lack of flexibility in control. Considering the complexity of the ground environment of agricultural greenhouses and the inaccuracy of environmental information, fuzzy control technology is used here to set the PID control parameters online, thereby improving the stability and control accuracy of the traditional PID control technology.

The core design of the fuzzy PID controller has three main parts, namely, determining the model structure, determining the membership function, and establishing the fuzzy control rule table. The key to determining the model structure of the fuzzy PID controller is to determine the structure of the fuzzy controller. The commonly used fuzzy controller is a dual-input single-output structure, but in this study, the three control parameters of the PID controller need to be jointly tuned, so the dual-input three-output model structure is selected here. After the input variables are fuzzified, the membership of the corresponding fuzzy subset will be obtained. Commonly used membership functions are triangle, trapezoidal, Gaussian and other types; the specific membership function selection needs to be considered in conjunction with practical problems. Fuzzy control rules are the basis for fuzzy inference and the core of fuzzy control algorithms. There are two forms of fuzzy rule control, one is a computer language form, such as "if...then..."; the other is a table form, the advantage of this form is that it is easy to read.

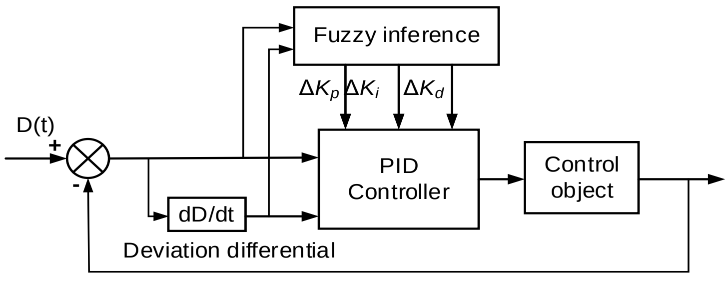


**Fig. 1 - Structure diagram of fuzzy PID controller**

Figure 1 shows the structure of the fuzzy PID controller. There are two important parameters in the running process of the vehicle. The lateral position deviation e refers to the deviation between the sensor centre and the preset path. The lateral deviation change rate $e_c$ can be calculated from the lateral position deviation and the measured value. In the actual operation process, the greenhouse operation vehicle achieves the purpose of turning control by changing the speed of the left and right track wheels.

The fuzzy PID controller uses a two-dimensional fuzzy controller before the traditional PID controller, so as to realize the online tuning of PID control parameters. The control method of fuzzy PID controller is incremental PID control. The characteristic of this method is to discretely sample the deviation to obtain discrete deviation data.

Under incremental PID control, the system only needs to calculate based on this and the previous two deviations, which greatly improves computational efficiency. The function expression of the incremental PID is as follows, where $k$ represents the number of discrete samplings, $k=1,2,\ldots$, and $k_i = \frac{k_i T}{T_i}, k_d = \frac{k_d T}{T_d}$; $T$ is the sampling period; $e(k)$ represents the system deviation of the $k^{th}$ order.

$$\begin{aligned} u &= u(k) - u(k-1) \\ &= k_p\left(e(k) - e(k-1)\right) + k_i e(k) + k_d\left(e(k) - 2e(k-1)\right) + e(k-2) \end{aligned} \tag{6}$$

The input of fuzzy PID controller is $e_c$, $e$, and the output parameter adjustment is $\Delta K_p$, $\Delta K_i$, $\Delta K_d$. When adjusting PID control parameters, three adjustment principles need to be followed. When the deviation value is a large value in the domain, in order to ensure the system response speed and avoid differential oversaturation, it is necessary to take a smaller value for $K_p$, $K_d$; when the deviation value is an intermediate value, in the case of satisfying the system response speed, the value of $K_p$ needs to be reduced; when the deviation value is a smaller value in the domain, in order to control the steady-state performance of the system, the value of $K_p$, $K_i$ needs to be increased appropriately.

The greenhouse operation vehicle designed by this research is to use the magnetic navigation system to detect the degree of position deviation. There are 7 kinds of position deviation output, which are left large deviation *(NB)*, left centre deviation *(NM)*, left micro deviation *(NS)*, Zero offset *(ZR)*, right micro offset *(PS)*, right centre offset *(PM)*, right large offset *(PB)*. Therefore, the fuzzy definition of the position deviation can be defined as follows.

$$e = \{NB, NM, NS, ZR, PS, PM, PB\} \tag{7}$$

The deviation change rate is a measure of the change in the lateral position offset distance at different moments, so the function expression of the deviation change rate and the definition of fuzzy subset are as follows.

$$e_c = e_{i+1} - e_i \tag{8}$$

$$e_c = \{NB, NM, NS, ZR, PS, PM, PB\} \tag{9}$$

According to the correction range of the parameters, the change range of the position deviation and deviation change rate of the fuzzy PID control system is set, and the basic domain of the parameter adjustment amount $\Delta K_p$, $\Delta K_i$, $\Delta K_d$ *is* [-0.3, 0.3], [-0.06. 0.06], [-3, 3] to define the fuzzy subset of each output. In this study, the description of fuzzy subsets will use a Gaussian membership function. The image of this function is shown in Figure 2. Among them, the abscissa represents the fuzzy universe, and the ordinate represents the degree of membership.

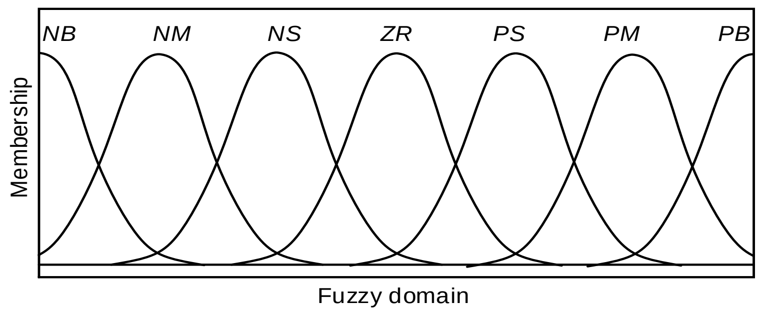


**Fig. 2 - Gaussian membership function**

Establishing a fuzzy control rule table is the key to fuzzy control. This process not only needs to consider the position deviation and deviation change rate, but also needs to comprehensively consider the role and correlation of the three parameter adjustments. Based on engineering design experience and vehicle operating conditions, this study established the fuzzy control rule table shown in Table 1 for the three output control parameter adjustments. Here, the fuzzy rule control table is described in computer language, and the general description form "if...then..." is used. Among them, the part of if describes the state of position deviation and deviation change rate, and the part of then describes the state of output in the control rule table. Therefore, under this method, 49 control rules can be obtained for each output control parameter adjustment.

**Table 1**

**Fuzzy control rules of $\Delta K_P$**

| Output | EC | E | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | NB | NM | NS | ZR | PS | PM | PB |
| $\Delta K_p$ | NB | PB | PB | PM | PM | PS | PS | ZR |
| | NM | PB | PB | PM | PM | PS | ZR | ZR |
| | NS | PM | PM | PM | PS | ZR | NS | NM |
| | ZR | PM | PS | PS | ZR | NS | NM | NM |
| | PS | PS | PS | ZR | NS | NS | NM | NM |
| | PM | ZR | ZR | NS | NM | NM | NM | NB |
| | PB | ZR | NS | NS | NM | NM | NB | NB |
| $\Delta K_i$ | NB | NB | NB | NB | NM | NM | ZR | ZR |
| | NM | NB | NB | NM | NM | NS | ZR | ZR |
| | NS | NM | NM | NS | NS | ZR | PS | PS |
| | ZR | NM | NS | NS | ZR | PS | PS | PM |
| | PS | NS | NS | ZR | PS | PS | PM | PM |
| | PM | ZR | ZR | PS | PM | PM | PB | PB |
| | PB | ZR | ZR | PS | PM | PB | PB | PB |
| $\Delta K_d$ | NB | PS | PS | ZR | ZR | ZR | PB | PB |
| | NM | NS | NS | NS | NS | ZR | NS | PM |
| | NS | NB | NB | NM | NS | ZR | PS | PM |
| | ZR | NB | NM | NM | NS | ZR | PS | PM |
| | PS | NB | NM | NS | NS | ZR | PS | PS |
| | PM | NM | NS | NS | NS | ZR | PS | PS |
| | PB | PS | ZR | ZR | ZR | ZR | PB | PB |

The process of solving the fuzzy control parameter adjustment according to the control rule table is to defuzzify. Deblurring not only needs to consider the prerequisites of approximate reasoning, but also needs to consider the inherent relationship between fuzzy rules. The output of defuzzification is a fuzzy set, which is generally segmented and irregular. In order to ensure the rationality of the output value, it is necessary to clarify the output fuzzy set and scale the processed value according to the scale factor. In this study, the weighted average method is used as the method of clarification, and the scale factor is calculated according to the physical range of the controlled object.

## RESULTS

### Vehicle robot path tracking experiment based on distance information

In order to verify the effectiveness of the target tracking control system for agricultural greenhouse work vehicles proposed in this research, here is a field test in the agricultural greenhouse with the crawler vehicle robot of Beijing Forestry University as the platform. Fig. 3 shows the shed operation of the tracked vehicle robot. The test is mainly divided into two parts, one is the path tracking test of the vehicle robot based on the ranging information, and the other is the fixed-point parking and linear tracking control test of the vehicle robot.

**Fig. 3 - Crawler-type greenhouse working vehicle robot**

The first part of the test is based on the sensor's ranging information, so here the ultrasonic sensor and infrared sensor's ranging information is first collected and weighted. The test equipment includes work vehicle, 1m precision steel tape measure, 1.2m × 0.45m foam board, and navigation magnetic stripe. Before the test starts, you need to select the preset route for vehicle operation and lay a navigation magnetic strip on the preset route. Place the foam board vertically on the preset route to calibrate the distance measured by the sensor.

**Table 2**

**Statistics of distance measurement after weighted fusion**

| Statistics | Statistical results | | | | |
|---|---|---|---|---|---|
| Actual value | 100 | 90 | 80 | 70 | 60 |
| Weighted fusion value (cm) | 100 | 89.9 | 79.8 | 70 | 59.8 |
| Absolute error rate | 0.00% | 0.11% | 0.25% | 0.00% | 0.33% |
| Actual value | 50 | 40 | 30 | 25 | 20 |
| Weighted fusion value (cm) | 49.9 | 39.9 | 30 | 24.8 | 19.9 |
| Absolute error rate | 0.20% | 0.25% | 0.00% | 0.80% | 0.50% |

During the test, it was found that between 10 and 20 cm, the measurement error of the ultrasonic sensor is relatively large, while the infrared sensor cannot measure. Between 20 and 100 cm, the absolute error of both sensors is relatively stable. Therefore, the experiment takes the distance measurement results between 20 and 100 cm as the effective information of weighted fusion. Table 2 shows the statistical results of the distance measurement information after weighted fusion. According to the statistical results in Table 2, it can be found that the absolute error rate of ranging between 30 and 100 cm is within 0.33%; the absolute error rate of ranging between 20 and 25 cm is controlled between 0.50% and 0.80%. Overall, the absolute error rate of the measured value after weighted fusion is less than 1%. Therefore, the ranging performance of the ranging sensor between 30 and 100 cm is relatively stable, and the weighted fusion algorithm has a better processing effect on the ranging information.

**Table 3**

**Statistical results of human-machine following test**

| Statistics | Statistical results | | | | |
|---|---|---|---|---|---|
| Initial distance (cm) | 200 | 190 | 180 | 170 | 160 |
| Set following distance (cm) | 100 | 100 | 100 | 100 | 100 |
| Measured following distance (cm) | 94 | 95 | 95 | 94 | 95 |
| Initial distance (cm) | 150 | 140 | 130 | 120 | 110 |
| Set following distance (cm) | 100 | 100 | 100 | 100 | 100 |
| Measured following distance (cm) | 94 | 93 | 95 | 96 | 93 |

In order to test the human-machine following ability of the vehicle robot, on the basis of the above test, the following distance of the vehicle robot is tested. Set the safe following distance to 100 cm and the vehicle speed to 1 m/s. Table 3 shows the statistical results of the man-machine following test. It can be seen from the statistical results in Table 3 that the error between the measured follow distance and the safe follow distance is between 4 and 7 cm, and the measured follow distance is slightly smaller than the safe follow distance. Combined with the vehicle operating state and the analysis of the results, it may be because of the inertia effect of the vehicle operation and the motor response characteristics, which causes the actual following distance of the vehicle robot to be slightly smaller than the safety distance. On the whole, under the fuzzy PID control system, the operating robot can basically meet the functional requirements of human-machine following and realizing the target tracking of the greenhouse operation.

**Vehicle robot's fixed-point docking performance and linear path tracking performance**

The vehicle robot mainly realizes the detection of the surrounding environment and the fixed-point cruising of the vehicle through the induction of the magnetic block around the magnetic navigation. The magnetic blocks of different magnetic poles are laid on the preset route and the guide path respectively, so that the vehicle robot travels at different speeds, and the parking distance of the vehicle at different speeds is tested.

**Table 4**

**Statistical results of vehicle robot parking distance at different speeds**

| **Speed (m/s)** | **1.0** | **0.8** | **0.7** | **0.6** | **0.5** | **0.4** |
|---|---|---|---|---|---|---|
| Distance between vehicle and magnetic landmark (cm) | 4.8 | 5.7 | 6.3 | 6.6 | 6.9 | 7.4 |
| Distance error between vehicle and detection point (cm) | 0.2 | 0.1 | 0.2 | 0.3 | 0.2 | 0.2 |

Table 4 shows the parking distance of vehicle robots at different speeds. Observing the statistical results in Table 4, it can be found that when the vehicle is traveling at a speed of 0.4 to 1.0 m/s, the distance error between the vehicle and the detection point does not exceed 0.3 cm. Therefore, the fixed-point parking performance of the vehicle robot can meet the parking needs.

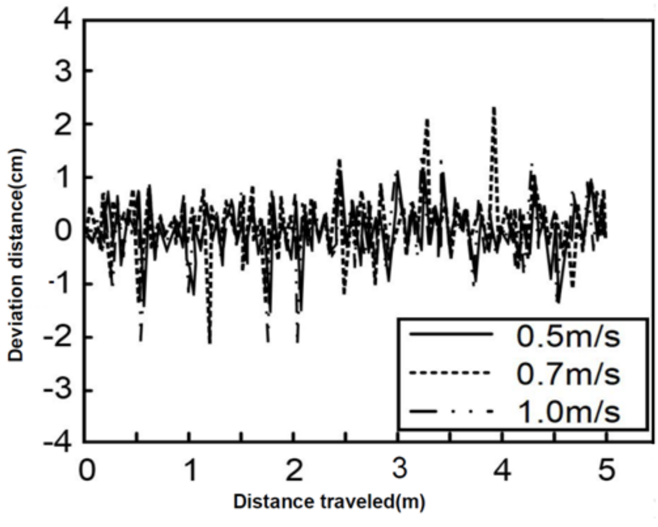


**Fig. 4 - Lateral deviation of vehicle running in straight line at different speeds**

Under the same test conditions, the linear path tracking performance of the vehicle robot is tested. In order to better record the running trajectory of the vehicle robot, an ink bottle is placed at the rear of the test vehicle, and the ink bottle is allowed to drip ink at a certain speed. Travel at 0.5 m/s, 0.7 m/s, 1.0 m/s to detect the position deviation of the vehicle in straight line tracking, and define the left deviation of the vehicle as positive and the right deviation as negative. Figure 4 shows the lateral deviation of the vehicle traveling straight at different speeds.

Observing Fig. 5, it can be found that the maximum lateral position deviation during the straight-line driving of the vehicle is ±2.5 cm, which indicates that the straight-line path tracking stability of the vehicle is good.

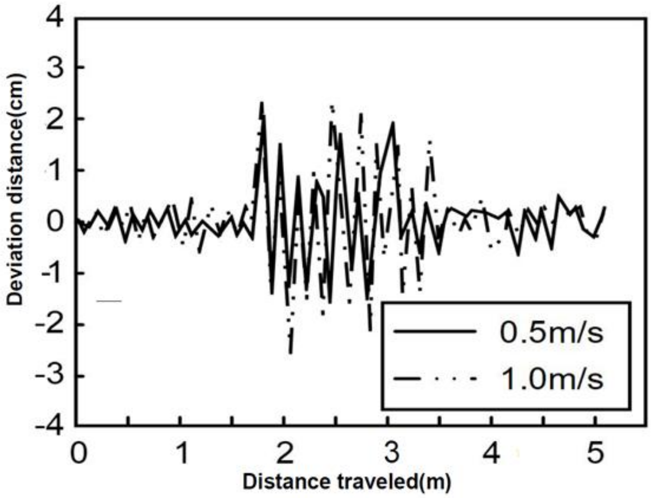


**Fig. 5 - Lateral deviation of vehicle circle curve line running at different speeds**

With reference to the experimental design of the linear path tracking performance, the circular curve path tracking performance of the vehicle is tested. Drive at a speed of 0.2 m/s and 0.3 m/s, and measure the lateral position deviation of the vehicle on a preset circular curve path. Figure 4 shows the results of the lateral deviation of the vehicle traveling on a circular curve at different speeds. Observing Figure 5, we can find that when the vehicle travel speed is 0.2 m/s, the lateral deviation of the circular curve path tracking is ±2.3 cm; when the vehicle travel speed is 0.3 m/s, the lateral deviation of the circular curve path tracking is ±2.9 cm; overall, the lateral deviation of the work vehicle is controlled within ±3 cm, and the steering effect of the vehicle is better. Therefore, the vehicle's circular curve path tracking performance is good, which can meet the needs of agricultural greenhouse operations.

## CONCLUSIONS

The environmental information of agricultural greenhouses is uncertain and variable, so in the application of automation technology in agricultural greenhouses, traditional control strategies reflect poor control accuracy and efficiency. In view of the limitations of traditional PID control technology, this study proposed a fuzzy PID path tracking algorithm.

This algorithm uses a fuzzy controller to adjust the PID control parameters to improve the control accuracy and flexibility of the control system. Based on the crawler vehicle robot system of Beijing Forestry University as a platform, the fuzzy PID path tracking algorithm is tested.

The research results show that under the weighted fusion algorithm, the ranging error rate of the vehicle robot is less than 1%; in the man-machine follow-up test, the measured distance is slightly less than the safety distance, and the following error is up to 7 cm; in the fixed-point parking performance test of the vehicle, the maximum parking error is 0.3 cm; in the linear path tracking performance test, the lateral position deviation of the vehicle is ±3 cm.

The fuzzy PID path tracking algorithm proposed in this research not only has good target tracking effect, but also reflects good linear driving and steering control performance. It is hoped that this research result can provide some data reference for path tracking research, and at the same time make a positive contribution to the development of agricultural intelligent technology. The research still has deficiencies, and in the future, the control algorithm will be further improved based on the actual operating environment of the agricultural greenhouse.

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