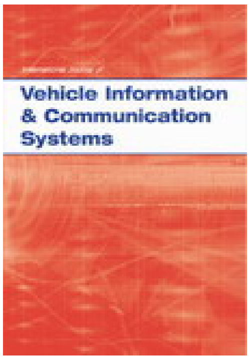

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Automatic control method of automobile steering-by-wire based on fuzzy PID

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Abstract: Automatic driving is gradually being popularised, and automatic control of automobile steering by wire has also become a topic worthy of research. The research combines the fuzzy control algorithm and PID to construct a fuzzy PID control strategy, and integrates the genetic algorithm into the basic fuzzy rules to form an improved new algorithm. The algorithm mainly focuses on multiple changes in the steering-by-wire of the car, including angular momentum, angular velocity, linear velocity and linear acceleration, to build more complex fuzzy rules and then use the three most basic parameters of PID. The results show that the average accuracy rate, average recall rate and average precision rate of the improved algorithm are 91.27%, 73.67% and 80.94%, which are significantly higher than the other two algorithms for comparison, indicating that the improved algorithm has better performance.

Keywords: fuzzy control strategy; PID controller; genetic algorithm; vehicle control-by-wire; autonomous driving.

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Caifeng Sun graduated with a Master's degree in 2016. Her research interests include new energy vehicles and digital design. Since graduation, she has presided over or participated in a number of municipal or above natural science research projects and an industry-university-research project. She has published 5 papers and granted 4 patents. In addition, he has won provincial and higher honours in teaching and innovation and entrepreneurship competitions for many times.

1 Introduction

With the continuous development of science and technology, human beings have enjoyed the convenience brought by many intelligent times, including the intelligent automatic driving of cars (Sarhadi et al., 2017). In the problem of intelligent automatic driving of automobiles, it is particularly important for the automobile to realise automatic control of steering-by-wire. Precise automatic steering-by-wire can not only ensure the normal operation of the car, but also ensure the safety of the driver's life and property (Gao et al., 2020). Although there are many self-driving cars on the market, there is still room for improvement in their performance. More improvements can still be made in the intelligent algorithm of automatic control of car-by-wire steering. At present, it is not uncommon for smart cars to have accidents in autonomous driving, which also shows that certain improvements need to be made in automatic steering control (Coban, 2019). In view of this, on the basis of the achievements of many other researchers, a method based on fuzzy control PID and integrated with genetic algorithm is proposed to be used in the research and experiment of automatic control method of steering-by-wire in automobiles. The method used in the research is based on fuzzy control strategy and PID algorithm, which is combined to form a fuzzy PID strategy. At the same time, according to the fuzzy control rules, the genetic algorithm is improved to expand the population diversity in the later calculation process and it is applied to fuzzy control. PID, in order to obtain a better algorithm, and the algorithm can be applied to the automatic control of automobile steering by wire.

2 Related work

Lot of researches have been done on the automatic steering control of automobiles. Hua et al. (2018) designed a proportional integrated control valve for the actual needs of the auto steering hydraulic system, and established the corresponding model and state equation using the non-linearity of the hydraulic system. The results show that the hydraulic system designed by this model has better performance in automatic steering control (Hua et al., 2018). Ye et al. (2019) proposed a new compensation control strategy to compensate the instability limit of the automatic steering system controller under non-linear disturbance conditions, and deduced the disturbance torque model of the automatic steering system at different vehicle speeds through the tire structure mechanism. Simulation results on the road show that the controller has better accuracy in automatic steering (Ye et al., 2019). Bai et al. (2020) proposed a man-machine steering torque superposition robust steering control method based on a linear matrix inequality algorithm, which is suitable for automatic control and steering in the presence of a driver. The research introduces the steering system and steering resistance torque model using Lyapunov stability theory and Schur's complement property to transform the regional pole configuration and robust control constraints into a convex optimisation problem of linear matrix inequality, and solves the steering superposition control law. Simulation results show that the method solves the model uncertainty and robustness decay caused by human intervention, ensuring good tracking performance and system stability (Bai et al., 2020). Wang et al. (2018) analysed the influence of the disturbance torque, time delay and noise of the automatic steering system on the tracking accuracy of the intelligent vehicle, in order to further study the coupling mechanism between the automatic steering control system and the intelligent vehicle trajectory tracking control system. Based on the non-linear automatic steering system and the intelligent vehicle dynamic model, the related controller model was established. By simulating various forms of non-linear factors of the automatic steering system, the influence of the automatic steering system on the trajectory tracking of the intelligent vehicle was verified (Wang et al., 2018). Parmar developed an easy-to-understand computer program in Visual Basic Studio to determine the manoeuvring parameters of an automatic steering system. The results show that the developed software can be used for guided control of automatic steering (Parmar et al., 2017).

In the fuzzy control strategy and genetic algorithm, scholars at home and abroad have also done a lot of research. Dong et al. (2017) used fuzzy control algorithm to quantitatively evaluate various values of fault sealing in oil and gas reservoirs when studying fault sealing. The results show that the results of using fuzzy control to evaluate oil and gas reservoir faults are more accurate (Dong et al., 2017). Liu et al. (2020) used fuzzy control to give the allocation of factors affecting the final productivity of a basin, and established a productivity prediction model based on it. Jiang et al. (2017) used rough sets and fuzzy control to construct a sub-health auxiliary diagnosis model, and found that its application in the auxiliary diagnosis of sub-health has a positive effect (Jiang et al., 2017). In the process of studying the image classification of convolutional neural network, Sun et al. (2020) used genetic algorithm to design the automatic structure of convolutional neural network to effectively solve the problem of image classification. Yokose (2020) used the genetic algorithm to solve the problem of minimising the energy consumption of non-linear friction robot joints when studying the problem of fossil energy consumption, and combined the genetic algorithm with the gradient method to quickly find the global optimum in a large range. solution. Mahoney and his team used genetic algorithms to study the genetics and environment of plants during the restoration process, and finally obtained an effective way to analyse the results (Mahoney et al., 2019). When Bhola et al. (2020) studied the optimisation of wireless sensor networks, they introduced an optimised genetic algorithm and used its fitness function to find the optimal path. The results show that the wireless sensor propagation path is better than the usual path, indicating that its search function is superior (Bhola et al., 2020). Abbasi et al. (2020) introduced the multi-objective genetic algorithm into the propagation delay between fog devices and cloud space in the Internet of Things, and found that the load distribution algorithm in the fog device and cloud space scene improved the energy consumption and delay of the Internet of Things system.

It can be seen from the above research results that the research on automatic steering-by-wire and automatic driving of automobiles is relatively common, and the application of fuzzy PID and genetic algorithm is also widely distributed in various fields, but the combination of fuzzy PID and genetic algorithm forms There are relatively few researches on the new model and the use of this model in the automatic control of automobile steering by wire. In view of this, the research starts with fuzzy control strategy, PID algorithm and genetic algorithm, constructs a model based on fuzzy PID and genetic algorithm as an auxiliary improvement measure and applies the model to the specific automatic control of steering-by-wire vehicles, in order to get better control.

2 Application of improved fuzzy PID based on genetic algorithm in auto steer-by-wire auto control

2.1 Fuzzy control and construction of fuzzy PID in auto steering-by-wire automatic control

Fuzzy PID is a control strategy model that combines fuzzy control and PID algorithm. In the fuzzy PID model, the fuzzy control strategy is the basis for constructing the whole model. According to the principle of information incompatibility, when the complexity of the whole system is very large, the clarity and complexity of the system will be repelled, that is, anti-correlation will occur. Therefore, in the problems of complex systems, it is impossible to carry out relatively clear control, and fuzzy control is used at this time. The characteristic of fuzzy control is that it does not need to know the specific mathematical model of the control object, the control rules are derived from a large amount of actual operation data and the control strategy is expressed through induction and natural language (Baroud et al., 2017). For the automatic control problem of steering-by-wire, the traditional clear control effect is not applicable due to its non-linear, time-varying and strong coupling characteristics, so the fuzzy control method is adopted. In the fuzzy control strategy, the basic mathematical theory is the fuzzy set, that is, a set of corresponding mapping elements is selected from the fuzzy universe, as shown in equation (1).

$$\begin{cases} I : U \rightarrow [0,1] \\ x \rightarrow \mu_I(x) \end{cases} \tag{1}$$

In formula (1), U is the fuzzy universe, and the set I is the fuzzy set on the corresponding universe, $\mu_I(x)$ indicating U the degree to x which each element x belongs to the set, that is, I the membership function of the element belonging to the set *I*. The range of the membership function is between [0, 1]. The closer the value is to 0, the lower the degree of membership, and the closer to 1, the higher the degree of membership. The common membership functions are mainly sigmoid and Gaussian functions, followed by triangles and trapezoids. The basic membership functions can be freely combined to form new functions. The triangular function membership function used in the research foundation is shown in equation (2).

$$f(x,a,b,c) = \begin{cases} 0, x < a \\ \dfrac{x-a}{b-a}, a \le x \le b \\ \dfrac{c-x}{c-b}, b \le x \le c \\ 0, x > c \end{cases} \tag{2}$$

Equation (2) is b the vertex coordinate value, a and the sum c is the corresponding bottom-edge intersection coordinate value. In the membership function, the fuzzy relation is shown in equation (3). The fuzzy set in equation (3) is the fuzzy relationship X to the Y above, that is, the binary fuzzy relationship. When the number of sets in the universe of discourse is more, it is the fuzzy relationship of the corresponding number.

$$X \otimes Y = \left\{ (x, y) \middle| x \in X, y \in Y \right\} \tag{3}$$

In the domain of discourse, if the $X \otimes Y$ described if -- A then B rule has a fuzzy implication relation, then for a given one $A_1 \in X, B_1 \in Y$, there is always the synthetic operation relation of equation (4)

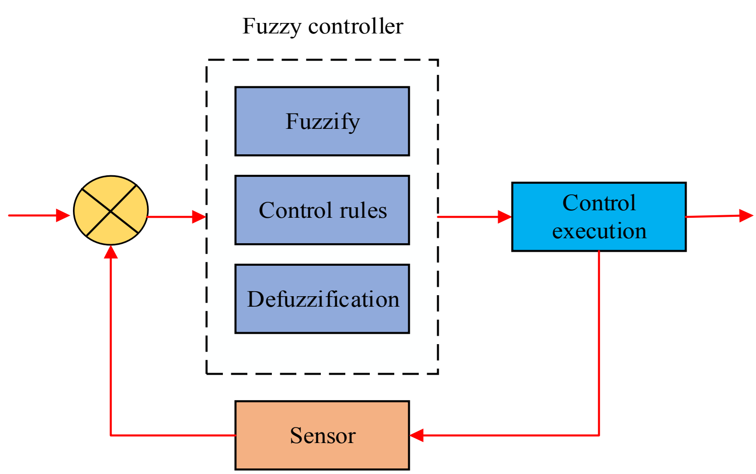
$$B_1 = A_1 \otimes I \tag{4}$$

After the fuzzy rules are set, the fuzzification operation is completed, that is, the clear amount is converted into a fuzzy amount, as shown in equation (5). Equation (5) is n the value of the fuzzy set of one of the fuzzy universes, j is the number and y is the value of the corresponding component of the physical theory domain, which k represents the transformation coefficient.

$$k_j = \frac{n_j}{y_j} \tag{5}$$

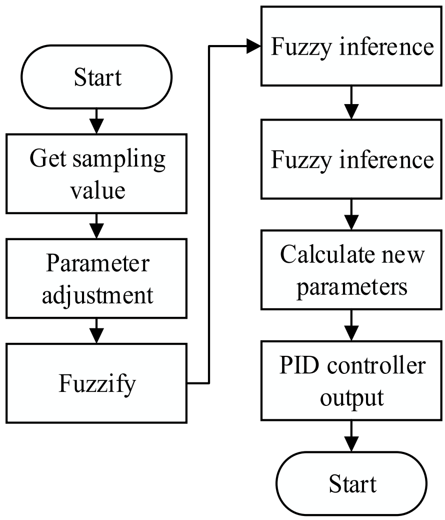
After the fuzzification is completed, the corresponding fuzzy control strategy control system is established according to the rules and its structural frame is shown in Figure 1.

Figure 1 Basic structure of fuzzy control system



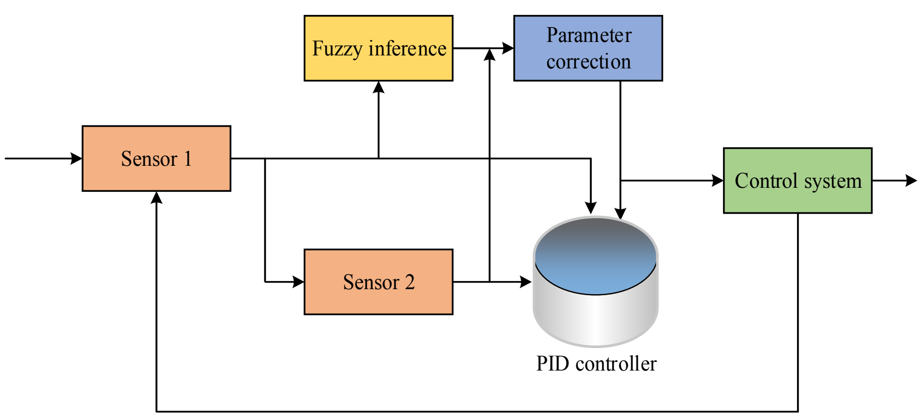
The key elements of the PID controller are the proportional (Proportion), integral (Integral) and differential (Differential) of the deviation. Because of its good robustness, high reliability and complexity of parameter setting, PID algorithm is usually combined with fuzzy control strategy to form fuzzy PID controller (Liu and Wang, 2017). On the basis of traditional PID, fuzzy PID takes the deviation and deviation change rate of the control system as input and combines the three adjustment parameters of PID itself with the input of fuzzy control to obtain a new output and compensate the error. The steps are as follows: first, the actual motion state value of the control object at a specific moment is obtained by detecting, that is, the speed and acceleration of the vehicle motion, etc., and the obtained actual value is compared with the command value, and the value of the deviation ratio can be obtained; The value of, is measured and calculated continuously through the feedback system, and the factors corresponding to all three parameters of the PID are obtained, and then these factors are added to the original three parameters to obtain the new three parameters. Finally, the new parameters are automatically adjusted according to the requirements of fuzzy PID control to calculate the output at the corresponding moment (Zuo et al., 2017). The workflow of fuzzy PID is shown in Figure 2.

Figure 2 Simple flow chart of fuzzy PID



The specific method of the two-dimensional fuzzy PID used in the study is to bind the corresponding sensor to the car target, obtain the specific values of the car's steering angle, angular velocity, linear velocity and linear acceleration and form a closed-loop loop with the controller according to the numerical results. Then, the deviation of the steering angle and the discretisation of the deviation change rate are used as the input of the fuzzy control. When the various values of the car keep the corresponding time and position unchanged, the automatic steering control is completed. The controller structure of the integrated fuzzy PID is shown in Figure 3.

Figure 3 Overall control structure of fuzzy PID



Then, adjust the three parameters of the PID according to the fuzzy rules. According to the existing design scheme of the control system, the relationship between the three parameters and the deviation and the deviation change rate can be obtained and the fuzzy rule table of the fuzzy PID can be obtained. Its corresponding fuzzy rule table controls the corresponding parameters. Finally, on the basis of the membership function, the transfer function of each motion is set (Ramasamy et al., 2017). The engine transfer function and the system transfer function are shown in equations (6) and (7), respectively. In equation (6), s the linear velocity of the shaft is expressed, which K_e is the time constant T_e of the engine and the amplification factor of the engine. In equation (7), n is the engine speed, K_T is the linearisation time constant of the engine, and ρ_s is the propeller transfer constant under different conditions.

$$K_{em}(s) = \frac{K_e}{T_e s + 1} \tag{6}$$

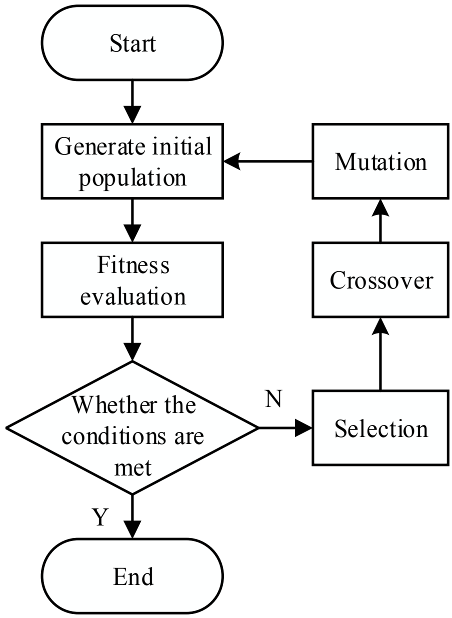
$$H(s) = 2K_T \rho_s D^4 n \tag{7}$$

2.2 The role of improved genetic algorithm in fuzzy PID automatic steering-by-wire control

Because fuzzy PID usually not only uses the PID algorithm, but also combines other algorithms to perform operations at the same time as the basis of fuzzy control, and the Genetic Algorithm (GA) itself is a probabilistic search algorithm for global optimisation, which is more suitable for fuzzy PID control. Therefore, the research uses GA in the control strategy of fuzzy PID.

GA mainly includes seven elements, which are used to constitute the whole process, namely coding chromosome, fitness evaluation, initial population setting, selection, mutation, crossover and termination principle (Dawid and Kopel, 2019). The main function of encoding chromosomes is to encode the data parameters that need to be mined and calculated. Encoding chromosomes symbolises the problem, using strings to define it in contiguous space. The initial population setting is to use the algorithm to define the initial population, select the appropriate initial population and the number must be appropriate. The fitness evaluation is to use the objective function to evaluate the result of the solution, and use the fitness value to compare the good or bad value of the solution, which is the main basis for the selection mechanism. Selection, crossover and mutation are all algorithm steps that imitate the changes of genes in biology. Selection is mainly to judge the goodness of the individual, that is, to compare the fitness value of the individual with the entire population, and screen out the relatively partial optimal solution. Crossover is mainly to exchange the information of coding chromosomes at will, and constantly generate new individuals to improve the search ability of the algorithm. The role of intersection in the algorithm is crucial. After the intersection is repeated to the end, the search ability of the entire algorithm will change significantly (Volkanovski et al., 2017). Mutation is to randomly change the chromosomal information of the population to form new chromosomes according to a certain probability. Mutation can ensure the global search ability, and the global search effect can be guaranteed by maintaining the global population diversity. The termination principle is to output and terminate the algorithm after the results obtained by the algorithm meet certain principle requirements. The basic flow of GA is shown in Figure 4.

Figure 4 Basic flow chart of genetic algorithm



In the genetic algorithm solution, a suitable fitness function needs to be selected and solved. According to the actual needs of production, a weighted multi-objective fitness function is designed, as shown in equation (8).

$$fit = 1 \Big/ \omega_1\lambda_1 f_1 \cdot \omega_2\lambda_2 f_2 \cdot \omega_3\lambda_3 f_3 \cdot \omega_4\lambda_4 f_4 \tag{8}$$

In equation (8), it f represents the objective function, the set number of the multi-objective function is 4, which ω is the weight and the sum of the four weights is 1, which λ is an adjustable parameter. In order to enhance the intuition of the initial population size, the research adopts the method of natural number coding for chromosome coding, the initial population size is set to 100 and the maximum number of iterations is set to 200. After the population enters the selection operator link, the chromosomes with the fitness in the top 30% are entered into the final generation by the sorting selection method, and the remaining individuals are selected by the spinning wheel method. The combination of the sorting selection method and the spinning wheel method can ensure the smooth inheritance of excellent individuals while ensuring the diversity of the population. The probability of remaining individuals being selected is shown in equation (9).

$$P_i = \frac{f(a_i)}{\sum_{i-1}^{K} f(a_i)} \tag{9}$$

In equation (9), P_i represents the selection probability of the *i*-th individual, *K* represents the population size and $f(a_i)$ represents the individual fitness. In the crossover operation, the parent chromosomes are cross-exchanged. According to the characteristics of FJSP, the Laplacian crossover operator is used in the study to perform crossover operation on the x_a sum of a certain generation and x_b the next generation obtained is shown in equation (10).

$$\begin{cases} x_a` = x_a + \eta\left|x_a - x_b\right| \\ x_b` = x_b + \eta\left|x_a - x_b\right| \end{cases} \tag{10}$$

Equation (10) is η the core of the Laplace distribution, and the calculation method of the core parameters is shown in equation (4). In equation (11), μ the position parameter and v the scale parameter can be obtained by inverse calculation through the distribution of the Shang function.

$$\eta = \begin{cases} \mu - v\ln(u), u \geq \frac{1}{2} \\ \mu + v\ln(u), u < \frac{1}{2} \end{cases} \tag{11}$$

Because GA has problems such as poor local search ability, low efficiency in the later stage of search and low-convergence maturity, in order to make GA more compatible with fuzzy PID and enhance the performance of the algorithm, the improved genetic algorithm is applied to the control strategy in middle. The improved genetic algorithm is mainly to increase the diversity of the population without losing the better individuals in the population. According to the Euclidean distance, k assuming that the individuals in the first-generation population are x_k^i composed m of genes, k the average number of individuals in the first-generation population is shown in formula (12).

$$\overline{x}_k = \frac{1}{m}\sum_{i=1}^{m} x_k^{i(l)} \tag{12}$$

In formula (12), it is l an arbitrary positive integer between 1 and m. At this time, the average individual distance from k the individuals x_k^i in the first k generation group to the first-generation group is shown in formula (13). Equation (13) is j any i possible value within the range.

$$dist\left(x_k^i, \overline{x}_k\right) = \sqrt{\sum_{j=1}^{m}\left(x_k^{i(j)} - \overline{x}_k^{(j)}\right)^2} \tag{13}$$

According to formula (13), the average value of the sum of distances from chromosomes to the average individual in the population is obtained as shown in equation (14). Equation (14) is t the algebra of the population.

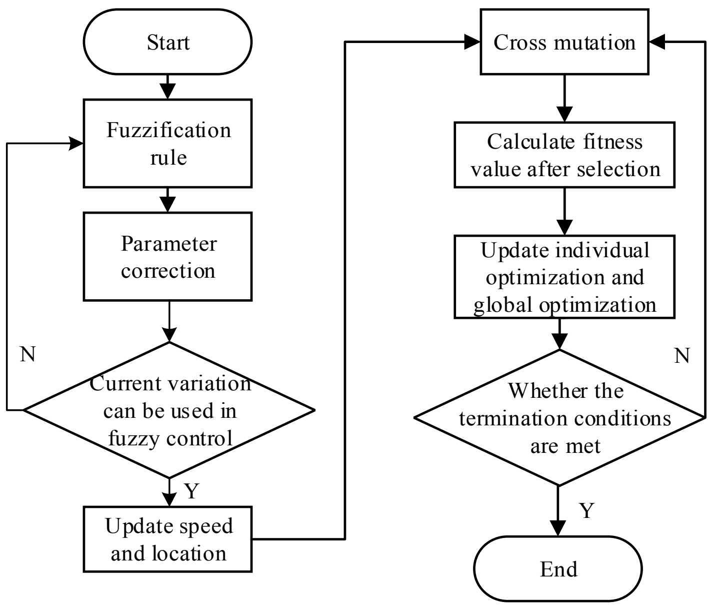
$$V_t = \frac{1}{m}\sum_{i=1}^{m} dist\left(x_k^i, \overline{x}_k\right) \tag{14}$$

The degree of diversity of the population at this time is ω shown in equation (15). Since ω the value range is [0, 1], ω the closer to 1, the greater the population diversity.

$$\begin{cases} \omega = \dfrac{V_t}{V_{\max}} \\ V_{\max} = \max\left(V_j, j = 1, 2, ..., t\right) \end{cases} \tag{15}$$

Owing to the late evolution, the value of ω will gradually shrink and approach 0, so the improved algorithm is to adjust the size through the membership function and fuzzy rules of the fuzzy PID ω, so that it can be close to 1 even in the late evolution. Then, the improved genetic algorithm is integrated into the basic fuzzy rules to form the Fuzyy-PID-GA algorithm. The algorithm flow of the fuzzy PID control of the improved genetic algorithm is shown in Figure 5.

Figure 5 General flow chart of fuzzy PID control

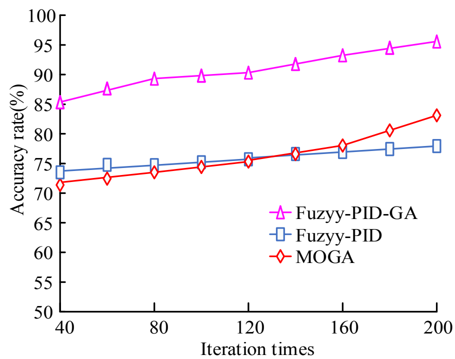


In the simulation experiment, 60% of the sample data is the training set and the remaining samples are equally divided into the test set and the validation set. In order to make the results more referential, two other algorithms were selected for comparison, namely, Fuzzy-PID and Multiple Objects Genetic Algorithm (MOGA).

3 Simulation results and analysis under the comparison of three algorithms

The hardware environment of the performance test is I7-8750 processor, 16 G memory, 2T hard disk and the programming environment is Python. The performance test of the algorithm mainly includes the accuracy rate, recall rate, precision rate, ROC and PR curves and the result value of the harmonic function F1 of the comprehensive evaluation. The accuracy results of the three algorithms are shown in Figure 6 when the number of iterations increases.

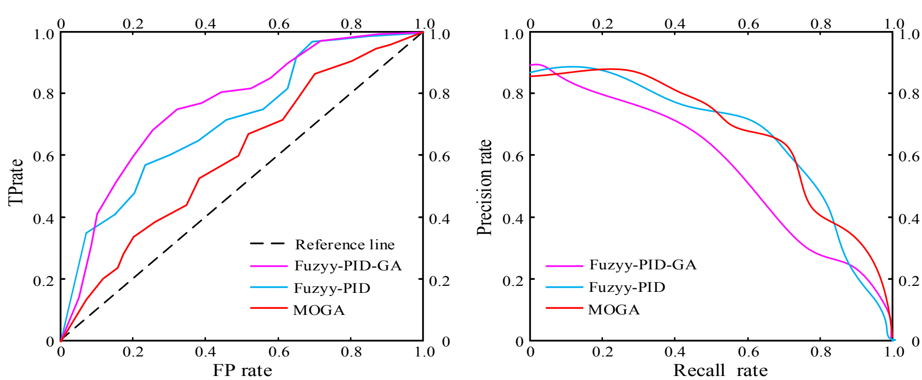
Figure 6 Accuracy rate results of three algorithms along with iteration times



(a)Testing set (b)Verify set

It can be seen from Figure 6 that when the number of iterations increases, the accuracy of each algorithm shows a clear upward trend. The accuracy of Fuzyy-PID-GA algorithm is higher than the other two algorithms in both test set and validation set. In the average results obtained, the average accuracies of Fuzyy-PID-GA, Fuzyy-PID and MOGA are 91.27% 75.29% and 78.13%, respectively. Using the significance analysis to judge the three average values, it is concluded that the average value of Fuzyy-PID-GA is significant with the other three algorithms, indicating that the accuracy of the algorithm is significantly higher than the other two algorithms. Accuracy has a clear performance advantage. Among the three algorithms, the ROC curve and PR curve results of the comprehensive test set and validation set are shown in Figure 7.

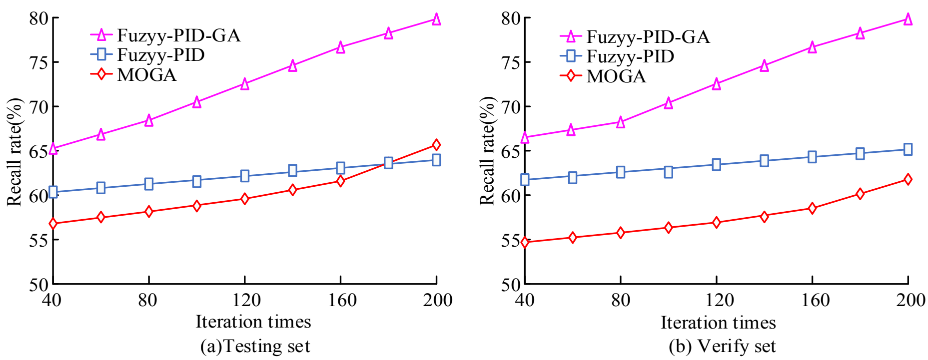
Figure 7 ROC curve and PR curve of three algorithms



(a)ROC curve (b)PR curve

As can be seen from Figure 7, in the results of the ROC curve, the area under the curve of Fuzyy-PID-GA is significantly higher than that of the other two algorithms and the area under the curve of the ROC curve represents the comprehensive performance of the test accuracy of positive and negative cases. In the results of the PR curve, the area under the curve of Fuzyy-PID-GA is smaller than the other two algorithms and the area under the curve of the PR curve represents the possible offset of the prediction. According to the actual calculated area under the curve, the area under the curve of the ROC curve of the three algorithms Fuzyy-PID-GA, Fuzyy-PID and MOGA is 0.821, 0.746 and 0.589, respectively; the area under the curve of the PR curve of the three algorithms were 0.475, 0.579 and 0.556, respectively. Combining the results of the ROC curve and the PR curve, Fuzyy-PID-GA has a significant comprehensive performance advantage in the prediction and solution of data. In the simulation results, the recall rates of the three algorithms vary with the number of iterations as shown in Figure 8.

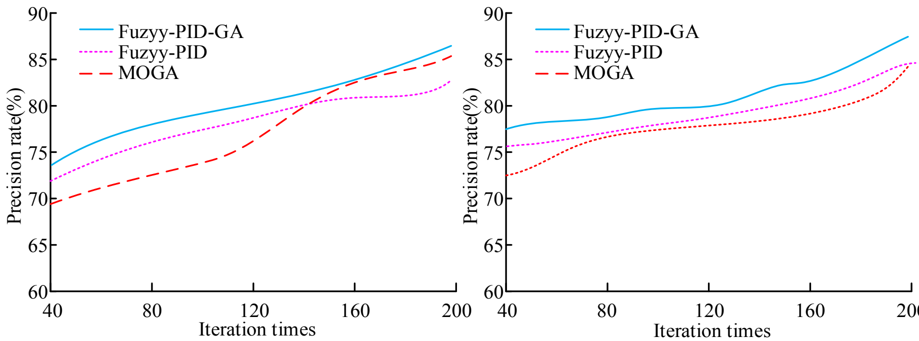
Figure 8 Recall rate results of three algorithms along with iteration times



It can be seen from Figure 8 that when the number of iterations increases, the recall rate of each algorithm also shows an obvious upward trend. The recall rate of Fuzyy-PID-GA is significantly higher than the other two algorithms in both the test set and the validation set. From the average results, the average recall rates of Fuzyy-PID-GA, Fuzyy-PID and MOGA are 73.67%, 67.59% and 66.92%, respectively. Using the significance analysis to judge the three average numerical results, it is concluded that the average value of Fuzyy-PID-GA is significant compared with the other two algorithms, indicating that Fuzyy-PID-GA is more conventional than the conventional algorithm. It has a significant performance advantage in the numerical judgment of negative examples. As the number of iterations increases, the accuracy of each algorithm is shown in Figure 9.

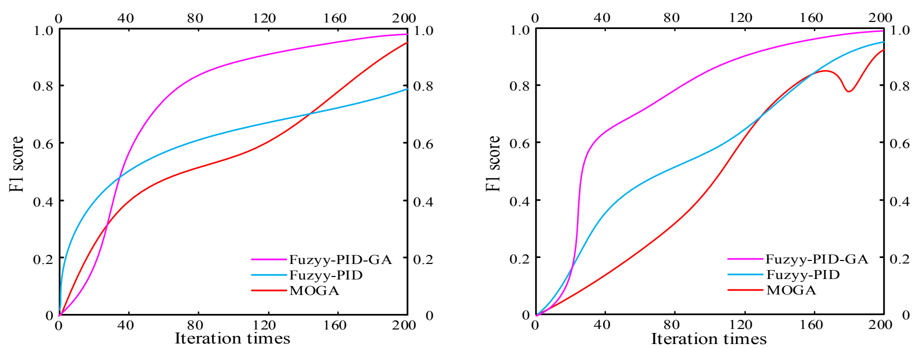
It can be seen from Figure 9 that the curves of Fuzyy-PID-GA in the three algorithms are always at the top, indicating that the accuracy of this algorithm is always higher than the other two algorithms. In the average results obtained, the average accuracies of Fuzyy-PID-GA, Fuzyy-PID and MOGA are 80.94%, 72.25% and 69.45%, respectively. Using the significance analysis to judge the three average values, it is concluded that the average value of Fuzyy-PID-GA is significant with the other three algorithms, indicating that the accuracy of the algorithm is significantly higher than that of the other two algorithms. The granularity of the overall verification of the example has a clear performance advantage. In the simulation results, the results of the four algorithms are synthesised respectively, and the results of the obtained harmonic function F1 value changing with the number of iterations are shown in Figure 10.

Figure 9 Precision rate results of three algorithms along with iteration times



(a)Testing set (b)Verify set

Figure 10 F1 score results of three algorithms along with iteration times



(a)Testing set (b)Testing set

As can be seen from Figure 10, the F1 score of Fuzyy-PID-GA in both the test set and the validation set is always above 80, which is significantly higher than the F1 score of the other two algorithms. In the average results obtained, the average F1 scores of Fuzyy-PID-GA, Fuzyy-PID and MOGA algorithms are 88.52, 69.91 and 75.32, respectively. Significance analysis was used to compare the average results of the three algorithms, and it was concluded that the average F1 score of Fuzyy-PID-GA was significantly different from the average F1 score of the other two algorithms. In balance, Fuzyy-PID-GA has significant advantages over the other two algorithms.

4 Conclusion

In order to solve the problem of automatic control of automobiles, complete the automatic steering of automobiles and ensure the normal operation of automatic control of automobile steering-by-wire, the combination of fuzzy control algorithm and PID algorithm is studied to construct a fuzzy PID strategy. At the same time, the improved genetic algorithm is integrated into the basic fuzzy control rules to form an improved Fuzyy-PID-GA algorithm, and the algorithm and the other two algorithms, namely Fuzyy-PID and MOGA, are tested and compared using the same data at the same time. Test Results. The results of the simulation experiments show that the improved Fuzyy-PID-GA algorithm achieves 91.27%, 73.67%, 80.94% and 88.52 in average accuracy, average recall, average precision and average F1 value, respectively, which are not only significantly higher than the other Both algorithms are at a high-level relative to the norm. The area under the curve of the Fuzyy-PID-GA algorithm is larger than that of the other two algorithms, while the area under the curve of the PR curve is smaller than the other two algorithms, which further verifies the performance results of the improved algorithm. The experimental results show that the improved Fuzyy-PID-GA algorithm has significant performance advantages in many performances, and it can be applied to the automatic control of automobile steer-by-wire. Although the research has achieved certain results, the experimental sample data of the research is small and lacks a certain degree of representativeness, and the improvement of the genetic algorithm is generally less, focusing more on the integration of the genetic algorithm into the fuzzy rules, while the genetic algorithm The improvement of the algorithm has great potential, which is also the main direction of further research in the future.

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