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Research Article

Research on the Steering Control System of Rice Transplanter based on Fuzzy Immunity PID

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Abstract: In order to realize the automatic driving of the machinery working in the paddy field, using the stepping motor as the driving power and taking 2ZG630A high speed rice transplanter as the study platform, the steering mechanism of the rice transplanter was improved in this study. The controller with the fuzzy immunity PID control algorithm was designed and applied in the navigation control system of the rice transplanter as well. The test result indicated that the course deviation can be controlled within 0.5° and 1.1° and its control can be realized in 4 and 6 sec separately when the rice transplanter was driven in the cement floor or the paddy field by the speed of 0.7 m/sec. It also indicated that the steering control system of rice transplanter based on fuzzy immunity PID can satisfy the automatic navigation request of the vehicles used in the agriculture.

Keywords: Fuzzy control, fuzzy immunity PID, rice transplanter, steering control

INTRODUCTION

The vehicles' steering control is the foundation of the agriculture machinery automatic navigation control. At present, the two kind of common methods are the electro-hydraulic control and the motor control (Hu *et al*., 2009). Yoshisada Nagasaka from Japan took the PH-6 rice transplanter as the platform, used the direct current motor and the synchronizing gear to drive the rotation column, measured the vehicle's steering angle by the absolute encoder installed on the rotation column and controlled the DC motor to carry out the steering action by PLC controller (Yoshisada *et al*., 2004). Wu Xiaopeng from South of China Agricultural University took the Dongfanghong X804 tractor as the platform, realized the tractor's automatic steering control by using the electro-hydraulic proportion hydraulic valve and with PID control algorithm (Wu and Zhao, 2009). Lian Shijiang from Northwest A and F University took the Foton Leoford type-4040 tractor as the study object. And the vehicle's steering fuzzy controller was designed to realize the tractor's automatic steering through all kinds of sensors to obtain the vehicles' position (Lian and Chen, 2009).

Objecting 2ZG630A high speed rice transplanter, the rice transplanter mechanism was improved, the tractor steering controller was designed by the theory of fuzzy immunity PID control, the course determiner of the tractor was designed by the fuzzy control theory in this study. Through the simulation and test, the steering and tracking control of the tractor has been studied, which can achieve its accuracy requirement of the steering and tracking control.

MATERIALS AND METHODS

The composition of rice transplanter steering control system: On the basis of the original hydraulic steering system, the steering driving mechanism, the steering operation controller, the steering deviation angle sensors, the course angle sensors, the velocity sensors are added into it. The information checked by the sensors was input into the computer on the truck after it processed by the steering operation controller. Then the computer made decision how to drive according the various real-time information from the sensors and sent the information into the steering operation controller. The steering control of the tractor was achieved through the steering driving mechanism. The composition structure of the rice transplanter steering control system is shown in Fig. 1.

The improvement of the rice transplanter operation mechanism: The driver controlled the steering, running and the velocity of the tractor by the steering mechanism, the main changing speed handle and the throttle. In order to achieve the control of the tractor's navigation, 2ZG630A high speed rice transplanter has been carried out an essential improvement on the electrical control. The steering mechanism was driven by the stepping motor, a pair of the synchronizing gear

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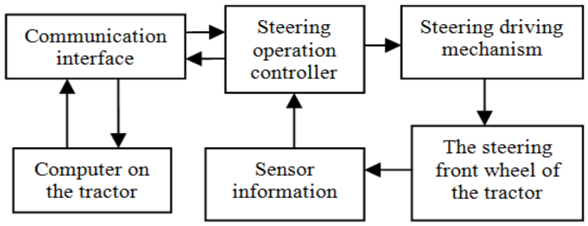

Fig. 1: The structure diagram of the rice transplanter steering control system composition

and belt. The main variable handle and throttle were controlled by the electrical rod of the feedback system.

Principle of steering and tracking control:

Principle of controlling the steering and tracking: Vehicle's steering control system is the important part of the vehicle's automatic driving. This system adapted the fuzzy immunity PID algorithm to control vehicle's steering. The fuzzy immunity PID controller figured out the proportion, the integral, the differential parameter of PID online depending on the deviation change and its rate between the rotation angle expectancy and the front wheel rotation angle of the tractor. Then the controller calculated the proper PWM signals which were sent into the motor's driver. The steering wheel would be deflected by the steering driving mechanism. The steering controller, which adapted the closed loop PID according to the front wheel deflection angle feedback, achieved the front wheel deflection angle's tracking control with its constantly change.

Design of controller based on fuzzy immunity PID: Using the fuzzy control principle, the fuzzy immunity PID controller figured out the integral online, the differential parameter of PID according to the deviation and its changing rate of the controlled object, the proportion parameter can be figured out through the output change and its rate of the fuzzy immunity PID, which make the controlled object with the good dynamic performance and the controller with the strong adaptability and robustness.

In the analogy regulating system, the general expression of the fuzzy immunity PID control algorithm is (Liu, 2004; Vatau *et al*., 2010):

$$u(k)=u(k-1)+K_{P1}\left(\left(e(k)-e(k-1)\right)+K_I e(k)+K_D\left(e(k)-2e(k-1)+e(k-2)\right)\right) \tag{1}$$

In the formula:

$$K_{P1}=K\left(1-\eta f\left(u(k),\Delta u(k)\right)\right), \tag{2}$$

Which is the proportional control coefficient, K_I is the integral coefficient, K_D is the differentiating time constant, u (k) is the control signal, e (k) is deviation signal. In this research, u (k) is the stepping motor control signal, e (k) is the angle deviation.

Table 1: The fuzzy controlling rule table for f (.)

	Δu (t)	
u (t)	P	N
P	N	Z
N	Z	P

Table 2: Fuzzy controlling rules of ΔK_I

	e						
ec	NB	NM	NS	ZE	PS	PM	PB
PB	ZE	ZE	NM	NM	PB	PB	PB
PM	PS	ZE	NS	NS	PM	PB	PB
PS	PM	PS	ZE	ZE	PS	PM	PB
ZE	PB	PM	PS	ZE	PS	PM	PB
NS	PB	PB	PS	ZE	ZE	PS	PB
NM	PB	PB	PM	NS	NS	ZE	PS
NB	PB	PB	PB	NM	NM	ZE	ZE

Table 3: Fuzzy controlling rules of ΔK_D

	e						
ec	NB	NM	NS	ZE	PS	PM	PB
PB	NB	ZE	PB	PB	PB	PM	PB
PM	NB	NS	PM	PM	PM	PS	PM
PS	NB	NB	PS	PS	PS	ZE	PS
ZE	ZE	NB	NB	NS	NS	NS	ZE
NS	PS	ZE	PS	PS	PS	NM	NB
NM	PM	PS	PM	PM	PM	NS	NB
NB	PB	PM	PB	PB	PB	ZE	NB

Using the fuzzy controller to fit f (u (k), Δu (k)) and adopting two-dimensional fuzzy controller to realize f (u (k), Δu (k)), controller's fuzzy reason rule was reasoned by the Lyapunov stability theorem, the fuzzy control rule of the nonlinear function f (·) = f (u (t), Δu (t)) was obtained (Maeda and Assilian, 1992), as shown in Table 1. Where, Positive (P) and Negative (N) are the immunity PID controller's output and the change quantity of output separately, universe is (-1, 1), the output is the fuzzy quantity of the nonlinear function f (·), which are Positive (P), zero (N) and Negative (N) separately, universe is (-1, 1).

The angle deviation and its change rate can be taken as the input of setting the fuzzy controller by the PID integral, differential, while the coefficient of the integral and differential were taken as the output. According to the setting principle from the reference (Xie, 2009), the two parameters ΔK_I, ΔK_D setting fuzzy control table as shown in Table 2 and 3. PB (Positive Big), PM (Positive Middle), PS (Positive Small), ZE (Zero) and NS (Negative Small), NM (Negative Middle), NB (Negative Big) are the seven input and output expressed by language commonly used in the fuzzy control algorithm. The actual universe of "e" is e (-1°, 1°), while the actual universe of "ec" is ec (-0.1°, 0.1°).

The membership function selects the triangle, while the fuzzy reasoning uses Mamdani. The fuzzy quantity output by control would be obtained after being fuzzy reasoning according to the control rule. Then the fuzzy quantities would be transferred into the

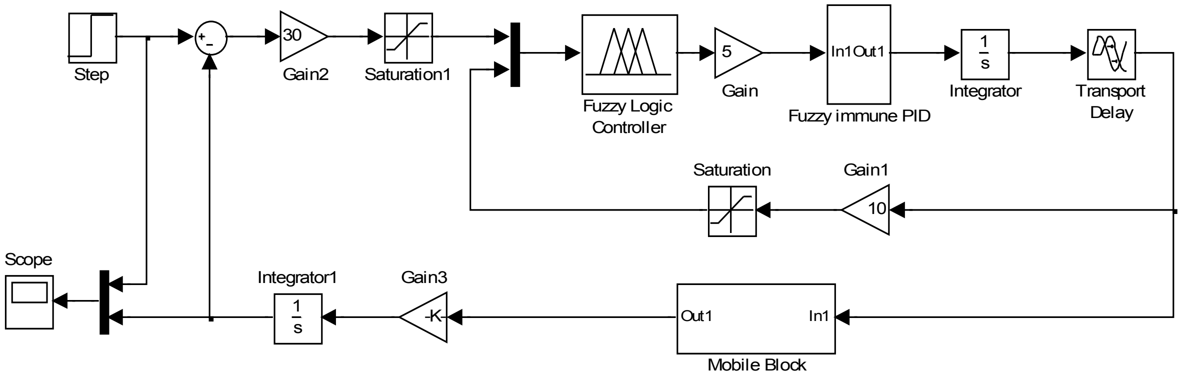

Fig. 2: The simulation scheme of course tracking controlling system

clear quantities by the common anti-blurring weighted average method. The data in the above control table would be stored in the computer. While the working machinery carried out the operation, the steering mechanism could be modified on PID parameters online after checking out the output from the table according to the input.

RESULTS AND DISCUSSION

Simulation of course tracking control:

The transfer function model of the steering driving mechanism and the rice transplanter's kinematics model: Based on the basic composition principle of the steering driving mechanism, adjusting the stepping motor frequency f (s) was defined as the input, the steering angle of the actual steering wheel was taken as the output, the transfer function model of the steering driving mechanism can be obtained:

$$\omega_l(s) \big/ f(s) = \frac{0.14}{0.4s^2 + s} \tag{3}$$

The rice transplanter is one kind of wheeled agriculture machinery which the front wheel steers, the rear wheels drive. Suppose that the road is smooth, the speed is constant, the tractor tire is not leaned, with no skidding in the direction of vertical and sideways, according to vehicle's kinematics relations, tractor's kinematics equation can be obtained as follows (Chen *et al*., 2006):

$$\begin{aligned} \dot{x} &= v\cos\theta \\ \dot{y} &= v\sin\theta \\ \dot{\theta} &= \frac{v}{L}\tan\alpha \end{aligned} \tag{4}$$

where,

x, y = The central coordinate of the tractor rear wheels, the unit: m
v = The vehicles' driving velocity, unit: m/sec
θ = Tractor's course angle, the unit: rad

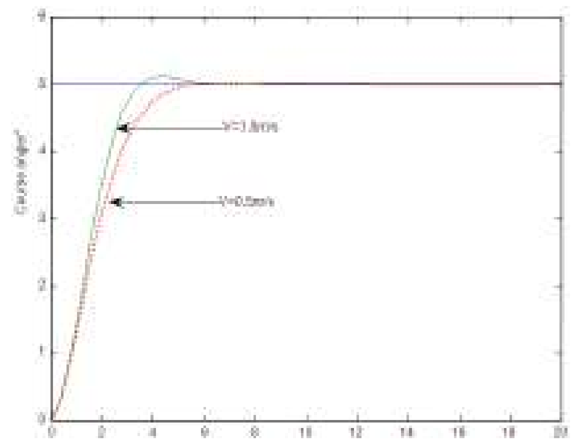

Fig. 3: Simulink result of 5° step wave orientation

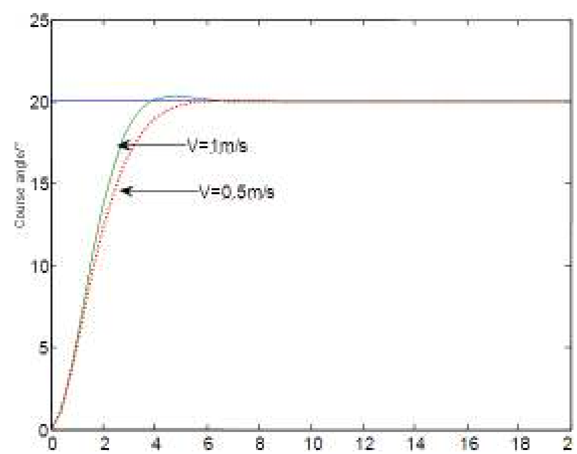

Fig. 4: Simulink result of 20° step wave orientation

α = Vehicles' front wheel rotation, the unit: rad
L = The distance between the front wheel axis and the rear wheel of the tractor, the unit: m

Simulation research: Using the simplified model as well as the fore-mentioned fuzzy immunity PID controller, the course control system simulation chart has been established under the MATLAB/SIMULINK circumstance, as shown in Fig. 2.

The distance between the front wheel axis and rear wheel axis of the rice transplanter was 1.1 m, the running velocity of the rice transplanter selected 0.5 and 1.0 m/sec separately when the simulation was carried out. The step response curve that the course angle changes with the increasing time when the rice transplanter tracked the course angle 5° and 20°, as shown in Fig. 3 and 4. From the chart, when the running velocity of the rice transplanter was quick, the rising time reduced, which resulted in 4% overshoot. When the course angle increases, the system's track time is almost consistent. It can be seen that this control system has the very good self-adapted ability and good tracking capacity, which provided the theory base for the following path-tracking and the course-controlling.

Test:

The tracking test of the steering controller on the cement floor: To further test the performance of the steering control system of rice transplanter, the head of rice transplanter was controlled by remote controller to the front ground of the eighth teaching building in Hunan Agricultural University, which make the front and rear wheel become a straight line as well as the front axis and rear axis. Take the axis center line and the red line on the ground as the reference, then the deviation was formed by 5° from the line of the front and rear axis, which is supposed to initial course deviation. The horizontal deviation is 0 m and the aim course is 0°. Start the rice transplanter, set the speed of it as 0.7 m/sec and go automatically.

Using the locate mode of double laser source and the technology of electronic compass fused to measure the course, the current real-time angle can be obtained and saved in the computer. Compare the real-time angle to the target course, the real-time course drift would be figured out.

From Fig. 5, a conclusion can be drawn that the steering controller has the good capacity to control the course deviation of the rice transplanter within 0.5° in 4 sec. With the increasing time, the course deviation would be convergent gradually.

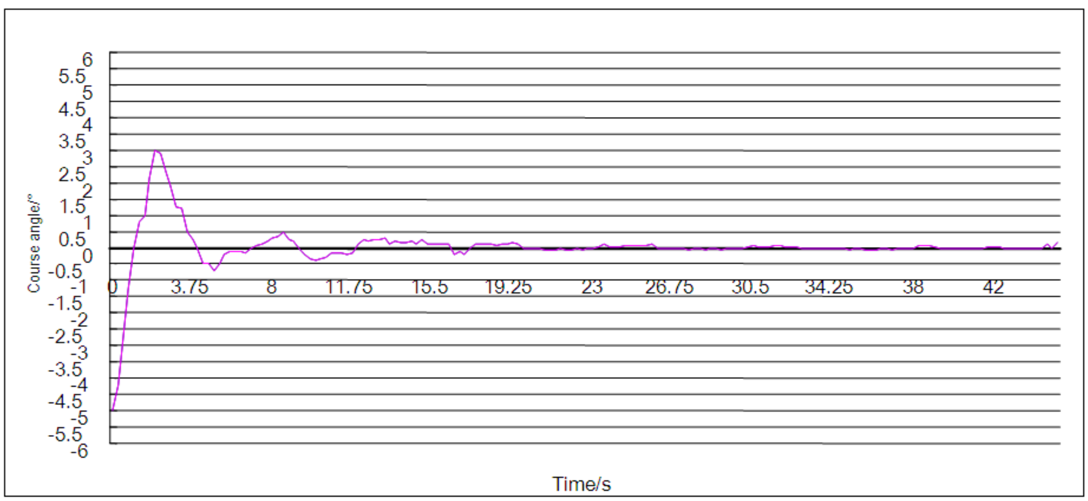

Fig. 5: The curve of course deviation shifting

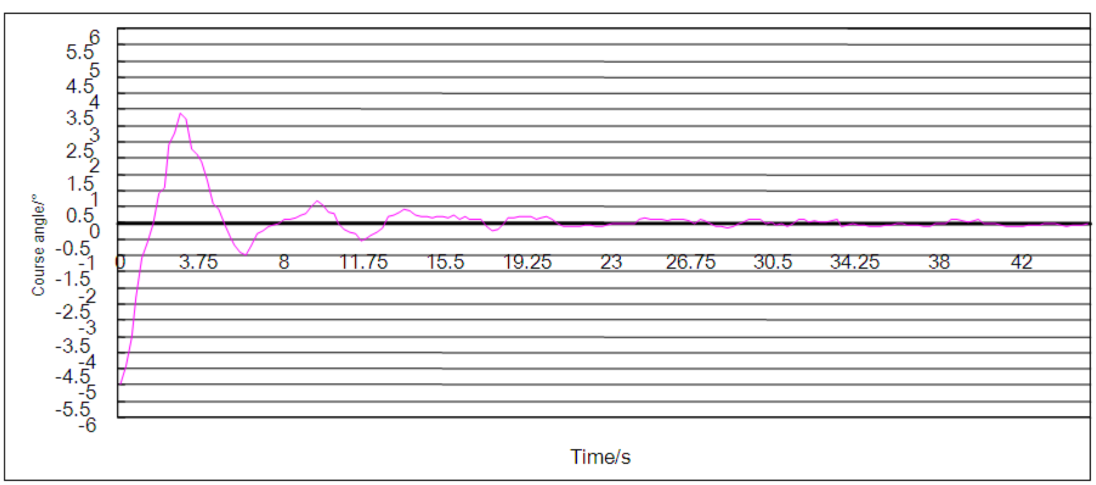

Fig. 6: The curve of course deviation shifting

Steering and tracking test in the field: Test to check the path-tracking capacity of the steering controller was carried out in the field. Suppose that the experimental condition is on the cement floor and the data sampling way was same with it. The curves diagram of the course deviation as shown in Fig. 6. The steering control system based on the fuzzy immunity PID control has a good ability of tracking the course and the course deviation is within 1.1° in 6 sec. The track tendency is convergent gradually.

The cement floor and the paddy field experiment indicated that the steering control system response performance is good, the fuzzy immunity PID control algorithm has good auto-adapted, robustness. But the corresponding time is not good, which the reason is mainly the rotation gear response is slowly. Therefore, improving the steering control system structure and reducing the delay time are must.

CONCLUSION

In order to achieve automatic navigation of the machinery worked in the paddy field, the steering mechanism, main transmission lever and throttle of the high-speed rice transplanter have been improved in this study. Take the stepping motor as the drive power, the controller based on fuzzy immunity PID was designed as well. From the simulation and test results, the conclusion can be drawn-fuzzy immuninty PID algorithm applied to machinery worked in the paddy field has a good real-time adjustment function about steering control of it, which also can satisfy the request of the control accuracy when the machinery worked in the paddy field.

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