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A Method Based On Self-Adaptive Fuzzy Control For Agricultural Vehicles Tracking Straight Paths

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Abstract:- In precision agriculture,straight path tracking, on large fields, is the main task of agricultural vehicle navigation systems.A path tracking method based on self-adaptive fuzzy control is proposed in this study. Firstly, a kinematic model of agricultural vehicles was derived, on the basises of some assumptions.Combining with the self-adaptive fuzzy control path tracking method ,the navigation control task was decomposed into two control tasks,the target point determine task and the steering control task.Then,a series of field experiments were conducted to verify the feasibility and effectiveness of the proposed method.Our experimental vehicle is a farm machinery model car,on which RTK-GNSS sensors were installed.Results of the experimental data analysis show that the maxinum lateral offset of straight path tracking was less than 5cm,which proves that the proposed method could meet the requirements of the straight path tracking of agricultural vehicles.

Keywords:- straight path tracking, agricultural vehicles,navigation control, kinematic model,self-adaptive fuzzy control

I. INTRODUCTION

Precision agriculture is an important way to achieve efficiency, low consumption, high quality and safety of agricultural working. Agricultural automatic navigation control as one of the key technologies of precision agriculture,which can make the job of agricultural machinery in accordance with the optimized path, reduce duplication and missing area of farming, improve the field operation quality and efficiency of agricultural machinery and reduce the labor intensity of the farm tractor drivers. As early as 1924,Willrodt[1] invented a tractor driving attachment and obtained US patent, which is a mechanical device mounted on the front axle of the tractor.The tractor driving attachment can guide the tractor travel along a route parallel to a furrow.Into the 1990s, with the development of computer technology, network technology, information acquisition and processing technology, the high precision automatic navigation control of agricultural vehicles becomes possible.

Over the past decade, the research on automatic navigation control of agricultural vehicles is becoming increasingly popular.The agricultural vehicles automatic navigation control methods can be divided into two categories: model-based control methods and model-free control methods. Model-based control methods can be divided into methods based on kinematic model of agricultural vehicles and methods based on the dynamic model of agricultural vehicles, and optimal control, optimal estimation, adaptive control, artificial neural network, fuzzy control and robust control of modern control theory and methods are widely used. O'Connor et al.[2] applied the high precision RTK-GPS into agricultural vehicles navigation, the first to have the practical value of the research and exploration. Chen et al.[3] studied on the method of tractor automatic guidance and walking based on the vehicle kinematic model by using the optimal control theory. Li et al.[4] established a agricultural vehicle relative kinematics model with lateral deviation and the heading deviation as state variables, developed a linear quadratic optimal controller, which improved the accuracy and stability of the navigation control.

Since the kinematic model based control method did not consider the effect of the dynamic parameters, some researchers also developed the dynamic model-based methods.Bevly et al.[5] put forward a kind of model of course rate dynamic model on the basis of a large number of identification tests, and designed a LQR path tracking control method based on the model, which solves the problem of navigation control during the high speed driving. Bao et al.[6] constructed a two wheel tractor dynamic model, filtered out the noises and eliminated the effect of repeated measures effectively by using Kalman filter, realized the estimation of tractor running state.

Model-free control methods can avoid the negative effects caused by the inaccurate modeling or the change of model parameters. H.Qiu et al.[7] developed a fuzzy steering controller for wheel-type agricultural vehicles with an electrohydraulic (E/H) steering system. The fuzzy controller, which consisted of a variable fuzzifier an inference engine with a steering control rulebase, and a control signal defuzzifier, was developed based on a common-sense model of agricultural vehicle steering. The controller implemented steering corrections based upon the desired steering rate and the error between the desired and the actual wheel angles. The test results indicated that the controller could be used on vehicles with similar steering actuating mechanisms. Zhang et al.[8] developed a new type of three-dimensional vehicle guidance simulation system and designed a fuzzy-adaptive control method. The system could achieve the simulation of vehicle navigation and control successfully and provide the help to the design of the real navigation systems, and the designed fuzzy-adaptive control method could effectively weaken the control process overshoot.

For straight path tracking is the major oprating mode of agricultural vehicles in large-scale farms, model-free control methods require extensive experience and complex training processes, describing all tractor features leads to very large models and most of the dynamic parameters of agricultural vehicles are badly known, and difficult to obtain experimentally. A kinematic model is considered.In this paper,a method based on self-adaptive fuzzy control for agricultural vehicles tracking straight paths was proposed on the basis of existing state of experiment,which is introduced below.

II. CONTROLLER DESIGN BASED ON AGRICULTURAL VEHICLE KINEMATIC MODEL

2.1 Agricultural Vehicle Modelling

The kinematic agricultural vehicle model is deduced according to the following assumptions:

A. The agricultural vehicle moves on a horizontal plane,

B. The agricultural vehicle moves through the rolling of the wheels, and the wheels rolling without slipping,

C. The four-wheel agricultural vehicle is simplified into a two-wheel kinematic model,

D. The speed of the agricultural vehicle and the steering wheel steering angle are the variables that need to be controlled,

E. The agricultural vehicle is a rigid body as well as its components.

A kinematic model of agricultural vehicle is derived as is shown in Fig.1:

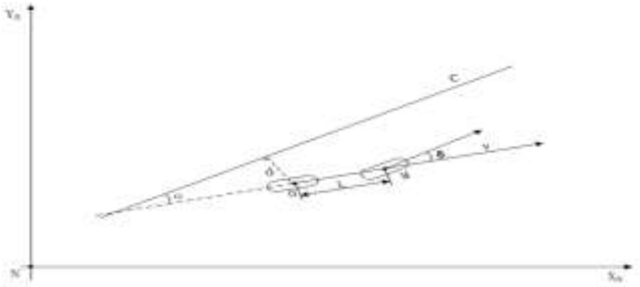


FIG 1. The kinematic model of agricultural vehicle.

On Fig.1, $(X_N - N - Y_N)$ is the navigation frame; C is the expected travel path, a straight path; L is the wheelbase of the agricultural vehicle; M is the center of agricultural vehicle front axle; O is the center of agricultural vehicle rear axle; d is the lateral deviation, the shortest distance from O to C; α is the heading deviation,the angular deviation of the orientation of agricultural vehicle centerline with respect to path C; v is the agricultural vehicle linear velocity at point O along the centrerline of the vehicle; δ is the steering wheel steering angle with repect to vehicle centerline.

According to assumption E ,the position and course of the agricultural vehicle can be uniquely determined in the navigation coordinate system, so the state vector of the agricultural vehicle can be expressed as :

$$X = (v, d, \alpha)^T \qquad (1)$$

2.2 Path Tracking Control Method

2.2.1 Path Tracking Kinematic Model

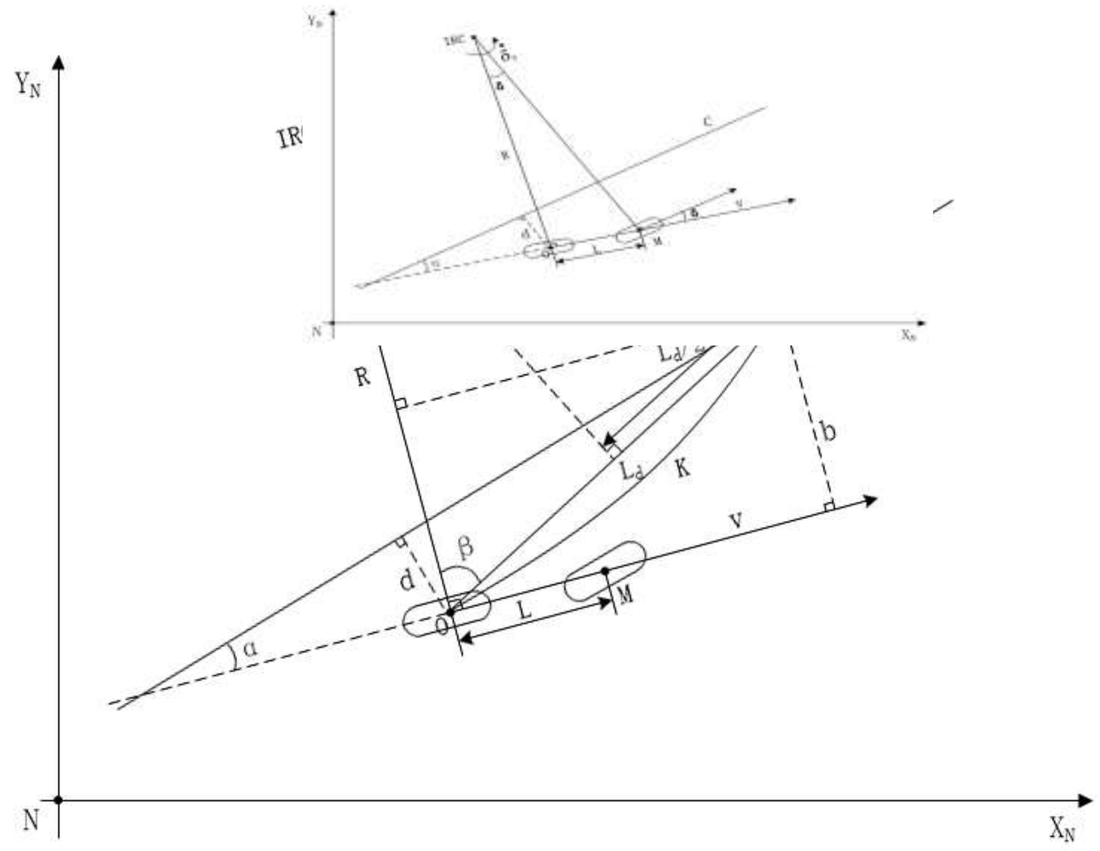
The path tracking control method proposed in this paper is to determine the agricultural vehicle steering wheel steering angle according to the lateral deviation, the heading deviation, the agricultural vehicle longitudinal speed and the target point on th expected path.

In view of assumption D,agricultural vehicle control vector can be written as:

$$U = \delta \qquad (2)$$

Assumption B implies that the linear velocity vector at a wheel center belongs to the wheel plane.Therefore, the linear velocity vector at point M presents an angle δ with respect to the centerline of the agricultural vehicle.And the linear velocity at point O is v ,along the centrerline of the vehicle.

According to assumption E,in every moment,the agricultural vehicle is either travelling straight line or going arc around the instantaneous center of rotation (IRC). The definition of IRC is described as the crossing point of the perpendiculars to the linear velocity vectors at any two points of the agricultural vehicle.The steering kinematic model of agricultural vehicle is depicted on Fig.2 :



on; $\dot{\delta}_t$ is

heading
he target
ehicle is

FIG 3. Path tracking kinematic model of agricultural vehicle.

On Fig.3, P is the target point chosen on path C ; L_d is the distance between point O and point P ; b is the shortest distance between point P and the centerline of agricultural vehicle; K is the curvature of the instantaneous rotating circle.

According to the basic geometric relations, we can obtain:

$$b = d\cos\alpha - \sqrt{L_d^2 - d}\,\sin\alpha \tag{6}$$

$$\cos\beta = \frac{b}{L_d} \tag{7}$$

$$\cos\beta = \frac{L_d}{2R} \tag{8}$$

Therefore,gathering (4), (6), (7) and (8),we can deduce:

$$\delta = \arctan\frac{2L\left(d\cos\alpha - \sqrt{L_d^2 - d^2}\,\sin\alpha\right)}{L_d^2} \tag{9}$$

Where,δ is the expected steering angle, L , d , α can be quantified by measuring and calculating; L_d ,target distance, the diatance between point O and point P , is determined by a method based on self-adaptive fuzzy control, which will be introduced below.

2.2.2 *Determine The Target Distance*

In the practical application of agricultural vehicle path tracking, the two factors of path tracking control, vibration and response time, must be considered. Only when the chosen target distance is appropriate, the control requirements could be well satisfied. When the value of the linear velocity of agricultural vehicle is constant, if the lateral deviation and heading deviation are large, a small target distance should be chosen, in order to achieve prompt control response;if the lateral deviation and heading deviation are small, a large target distance should be chosen, in order to descrease the vibration.When the deviations are constant,if the value of the linear velocity of agricultural vehicle is high,a small target distance should be chosen, in order to descrease the vibration; if the value of the linear velocity of agricultural vehicle is low, a large target distance should be chosen, in order to achieve prompt control response.

The input of the self-adaptive fuzzy control is the lateral deviation, the heading deviation and the linear velocity of the agricultural vehicle, and the output is the target distance L_d .The self- adjusting functions are used to adjust the fuzzy control rules, and then the the target distance is determined adaptively.

The fuzzy control expression:

$$D = \left\| \eta \left[\lambda (T - |G|) + (1-\lambda)(T - |H|) \right] \right\| \quad (\eta \in [0,1], \lambda \in [0,1]) \tag{10}$$

Where, D is the fuzzy variable of target distance; $\|\bullet\|$ denotes a integral function; η is the fuzzy control self-adjusting function based on the linear velocity of the agricultural vehicle; λ is the fuzzy control self-adjusting function based on lateral deviation and heading deviation; T is theory domain adjustment value of fuzzy control system; G is the fuzzy variable of lateral deviation; H is the fuzzy variable of heading deviation.

2.2.3 Determine the Self-Adjusting Functions

When the deviations are constant, if the value of the linear velocity of agricultural vehicle is high, the value of the self-adjusting funtion η should be large, in order to descrease the vibration;if the value of the linear velocity of agricultural vehicle is low, the value of the self-adjusting function η should be small, in order to achieve prompt control response. Therefore, the self-adjusting function η ,in our course,its equation is:

$$\eta = k_1 \left| \frac{v}{V} \right|^p \tag{11}$$

Where, k_1 is the proportional parameter, $k_1 \le \left(\frac{V}{v_{\max}} \right)^p$; V is the speed reference value; p is the power of self-adjusting function, $p > 1$.

When the value of the linear velocity of agricultural vehicle is constant, if the lateral deviation and heading deviation are large, the value of the self-adjusting function λ should be small, in order to achieve prompt control response;if the lateral deviation and heading deviation are small, the value of the self-adjusting function λ should be large, in order to descrease the vibration.Therefore, the self-adjusting function λ ,in our course,its equation is:

$$\lambda = k_2 \left| \frac{d}{W} \right|^q \tag{12}$$

Where, k_2 is the proportional parameter, $k_2 \le \left(\frac{W}{d_{\max}} \right)^q$; W is the deviation reference value; q is the power of self-adjusting function, $q < 1$.

2.3 The Path Tracking Controller

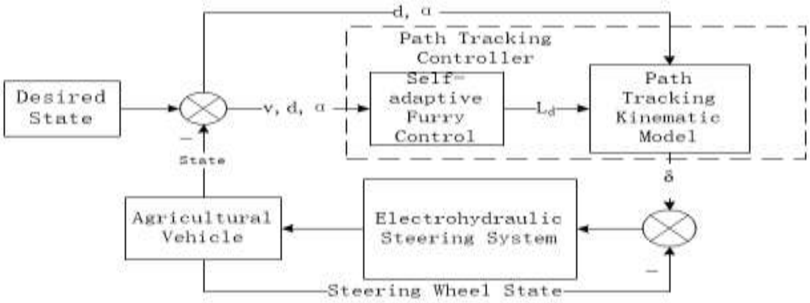


FIG 4. The control diagram with the path tracking controller.

According to equation (9),the desired steering angle is:

$$\delta = \arctan \frac{2L\left(d\cos\alpha - \sqrt{L_d^2 - d^2}\sin\alpha\right)}{L_d^2}$$

L_d is determined by adaptively by means of the self-adaptive fuzzy control method introduced above.The control diagram is shown in Fig.4.

III. EXPERIMENTAL VERIFICATION

3.1 Experimental Platform

The developed control method was verified by a series of experiments on a agricultural vehicle model car, as is shown in Fig.5.

Fig 5. The agricultural vehicle model car.

The agricultural vehicle model car was modified and quipped with the navigetion control system based on the path tracking control method proposed in the study.The navigation control system diagram is shown in Fig.6.

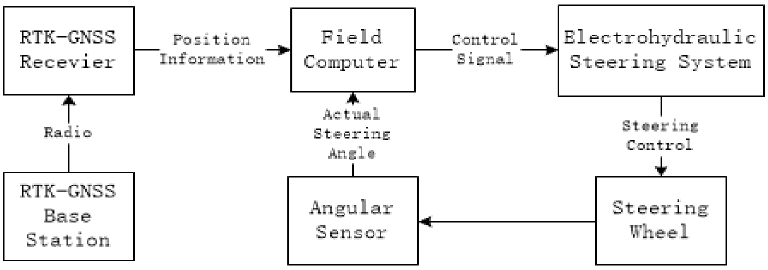


Figure 6. The navigation control system diagram.

As is shown in Fig.6, in the navigation system, we seleted the ComNav T300 GNSS Receiver as the RTK-GNSS base station and its accuracy of location measurement is 8mm + 1ppm. The RTK-GNSS Receiver installed in the model car is consisted of three parts:a GNSS receiver and two GNSS antennas. We chosen the ComNav M600 GNSS Receiver as the GNSS receiver and its its accuracy of location measurement is 10mm + 1ppm.The GNSS antennas we uesed were ComNav AT300 GNSS Antenna. MCGJ100A38BCF was the model number of the angular sensor we applied. The field computer and the electrohydraulic steering system were self-designed.

3.2 Path Tracking Experiment

3.2.1 Parameters Choosing

In this paper, the positive and negative signs of the lateral deviation and heading deviation are as follows: When the agricultural vehicle is located on the right side of the expected path,the lateral deviation is positive, and the left side is negative;When heading deviation is clockwise with respect to the expected path, it is positive, and the counter clockwise is negative;When the steering wheels turn right, the steering angle is positive, and the left is negative.

The parameters we chose is introduced below. The basic universe of the lateral deviation: $[-30cm,30cm]$,the quantization levels: {-15,-14,-13,-12,-10,-9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7, 8,9,10,11,12,13,14,15}; the quantization factor: $K_e = 0.5$. The basic universe of the heading deviation : $[-30^\circ,30^\circ]$, the quantization levels: {-12,-11，-10，-9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6, 7,8,9,10，11，12}, the quantization factor: $K_i = 0.4$. The basic universe of the desired steering angle: $[-12^\circ,12^\circ]$, the quantization levels: {-12,-11，-10，-9,-8,-7,-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10,11， 12}, the quantization factor: $K_u = 1$. $k_1 = 0.2$, $V = 2m/s$, $p = 1.2$, $k_2 = 0.6$, $W = 30cm$, $q = 0.7$.

3.2.2 Experimental Results and Discussion

In the horizontal, flat field, recording two positioning points by the high-precision ComNav M600 GNSS receiver, denoted as point A and point B, and the determined straight line was the expected tracking path. At one end of the path AB, start navigation control system. And the field computer will get the positioning data, process the data, convert it into lateral deviation, heading deviation and model car velocity.Carry out the experiments in the same initial conditions for several times, record the results, and analyze them.

Condition A: The initial lateral deviation was about $20cm$, the model car velocity was fixed at $1m/s$, the initial heading deviation was about 25°. The path tracking lateral deviation variation curve is shown in Fig.7.

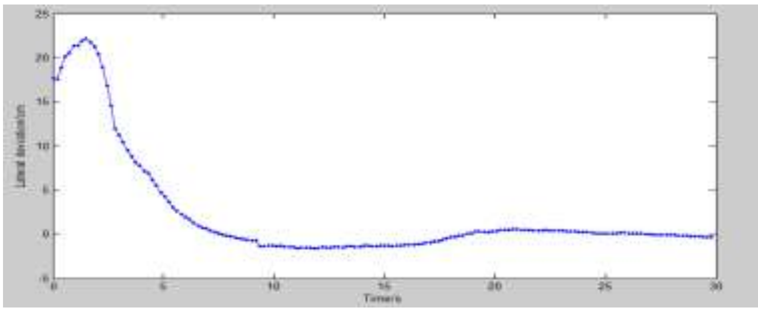


Fig 7. Experimental results at condition a.

Condition B: The initial lateral deviation was about $20cm$, the model car velocity was varies between $0.5m/s$ and $2.5m/s$, the initial heading deviation is about 0°. The path tracking lateral deviation variation curve is shown in Fig.8.

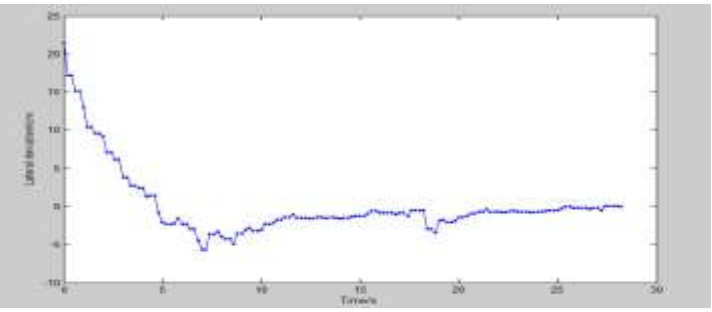


Figure 8. Experimental results at condition B.

The experimental results shows that, in the two runs,the good path tracking performance was obtained, and mean value of the lateral deviation was under 5cm, whether the velocity of the model car is fixed or not. And in different initial heading deviation conditions, 0° or 25°, with the same initial lateral deviation, the model car can track the path witin 5 seconds.

To sum up,we can conclude that the self-adaptive furry control method proposed in this paper has very satisfactory performance, high control precision and fast control response, and very satisfactory adaptability and robustness in different initial conditions.Therefore, the feasibility and effectiveness of this method were verified.

IV. CONCLUSIONS

In this study, a self-adaptive furry control method for straight path tracking was proposed. Firstly, from the perspective of the geometry, the study deduced a kinematic model of agricultural vehicle in the navigation control system frame. Secondly, the study deduced the desired steering angle from the kinematic model. Then, the study proposed a self-adaptive furry control rule to determine the target distance. Which will determine the target distance according to the values of lateral deviation, heading deviation and linear velocity. And the path tracking controller was designed correspondingly. Finally, in order to verify and test the proposed methond, the study carried out automatic navigation experiments of the agrcultural vehicle model car. The analysis results of the experimental data demonstrate that mean value of the lateral deveation is under 5cm, and the reponse time is within 5 seconds.The proposed method has very satisfactory performance, adaptability and robustness in different initial conditions.The feasibility and effectiveness of this method were verified.

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