AN ALGORITHM USING PREDICTIVE CONTROL THEORY FOR AUTOMATIC DRIVE

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Abstract:

In ITS (Intelligent Transportation System), automatic drive is a popular topic. This paper describes an algorithm using the predictive control theory based on a vehicle systematic dynamical model described in [1]. Under our simulation environment, one automatic car runs on the virtual roads. The car can change its velocity and other parameters to satisfy the need of safe automatic drive in time according to the circumstance of the fore road. The simulating results at the end of the paper show that this algorithm is suitable and the status of the moving car is accepted.

Keywords:

Automatic drive, intelligent transportation system, predictive control

1 Introduction

Automatic drive system is one important field in the Intelligent Transportation System. However, the main challenging problem lies in finding the suitable strategy for controlling the car. In recent years, some researches have been done on it [2][3].

Some other researches, how ever, are on modeling dynamic human control strategy. The aid is "teaching" the car to run itself just like under the control of human. Because human control strategy is a dynamic, nonlinear stochastic process, developing good analytic models of human control strategies tends to be difficult. Therefore, recent work in modeling it has focused on learning empirical models, through, for example, fuzzy logic and neural network techniques [4][5]. However, we should not ignore the extraordinary computation ability of the machine that is superior to human. It can play an important role on some complex situations under which human may not process easily.

In this paper, we used the vehicle systematic dynamical model defined by Michael [1]. This model is reasonable and widely used [5][6][7]. Firstly, we give the description of this vehicle model and our simulation for roads. Secondly, the application of predictive control theory is described. Finally, the simulation results are given and explained.

2 Model description

The following second-order nonlinear model gives the simulated vehicle's dynamics:

$$\dot{\omega} = (l_f \phi_f \delta + l_f F_{\xi r} - l_r F_{\xi r}) / I; \quad (1)$$

$$\dot{v}_\xi = (\phi_f \delta + F_{\xi f} + F_{\xi r}) / m - v_\eta \omega - (\operatorname{sgn} v_\xi) c_D v_\xi^2; \quad (2)$$

$$\dot{v}_\eta = (\phi_f + \phi_r - F_{\xi f} \delta) / m + v_\xi \omega - (\operatorname{sgn} v_\eta) c_D v_\eta^2; \quad (3)$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin g\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v_\xi \\ v_\eta \\ \omega \end{bmatrix}; \quad (4)$$

Where,

ω = Angular velocity of the car, (5)

v_ξ = Lateral velocity of the car, (6)

v_η = Longitudinal velocity of the car, (7)

$$F_{\xi k} = \mu F_{zk} (\tilde{\alpha}_k - (\operatorname{sgn}\delta) \tilde{\alpha}_k^2 / 3 + \tilde{\alpha}_k^3 / 27) \times \sqrt{1 - \phi_k^2 / (\mu F_{zk})^2 + \phi_k^2 / c_k^2}, k \in \{f, r\}; \quad (8)$$

$$\tilde{\alpha}_k = c_k \alpha_k / (\mu F_{zk}), k \in \{f, r\}; \quad (9)$$

$$\alpha_f = \delta - (l_f \omega + v_\xi) / v_\eta = front\_trie\_slip\_angle \quad (10)$$

$$\alpha_r = (l_r \omega - v_\xi) / v_\eta = rear\_trie\_slip\_angle; \quad (11)$$

$$F_{zf} = (mgl_r - (\phi_f + \phi_r) h) / (l_f + l_r);$$
$$F_{zr} = (mgl_f - (\phi_f + \phi_r) h) / (l_f + l_r); \quad (12)$$

$$\xi = body\_relative\_lateral\_axis;$$
$$\eta = body\_relative\_longitudinal\_axis; \quad (13)$$

$$c_f, c_r = cornering\_stiffness\_of\_front, rear\_tires = 50000 N/rad, 64000 N/rad; \quad (14)$$

$$c_D = lumped\_coefficient\_of\_frag = 0.0005 m^{-1}; \quad (15)$$

$$\mu = coefficient\_of\_friction = 1; \quad (16)$$

$$F_{jk} = frictional\_force\_on\_rear\_tires$$

$$= \begin{cases} 0, \phi_f > 0 \\ k_b \phi_f, \phi_f < 0, k_b = 0.34 \end{cases}; \quad (17)$$

$$\begin{aligned} m &= 1500kg; \qquad I = 2500kg - m^2; \\ l_f &= 1.25m; \qquad l_r = 1.5m, h = 0.5m; \end{aligned} \quad (18)$$

And the control parameters are given by

$$-0.2rad \le \delta \le 0.2rad; \quad (19)$$

$$-8000N \le Pf \le 4000N \quad (20)$$

Where Pf is the longitudinal force on front tires, and δ is the steering angle.

We randomly generated each individual segment to compose the whole road. Two kinds of segments are used: (1) straight-line segments, (l, 0), where l is the length of the segment. (2) winding segments, illustrated by (r, β), where r and β are the radius and angle of curvature. Each straight-line segment as well as the radius of curvature for each turn range in length between 100m and 200m and the absolute value of the angle, β , is from 20 degrees to 180 degrees. The positive value means turning right and the negative means turning left. Fig.1 shows part of our map.

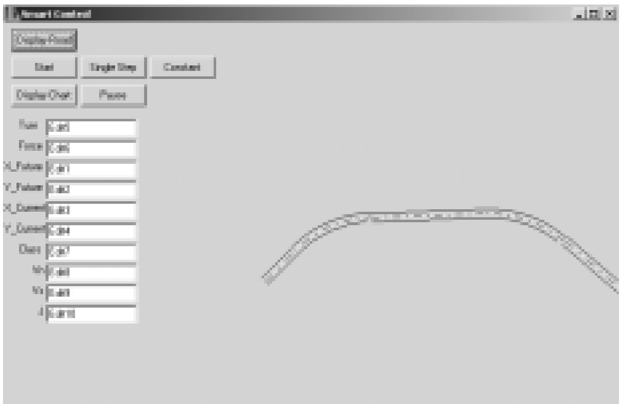

Fig.1 The environment of the automatic drive

3 Application of predictive control theory

In our earlier work, we found that it is difficult to control the car only according to the current circumstance of the road. For example, when the car was in the end of the straight road and just to enter the winding segment, it is already too late to turn the steering and change the longitudinal force. The safe automatic drive needs the prediction for the future road circumstance and changes its parameters earlier, so we choose the predictive control theory as the main method in our work.

Predictive control belongs to the class of model-based controller design concepts. That is, a model of the process is explicitly used to design the controller, as is illustrated in Fig.2 [8]. Usually, predictive controllers are used in discrete time. Suppose the current time is denoted by sample k, u (k), y (k) and w (k) denote the controller output, the process output and the desired process output at sample k, respectively.

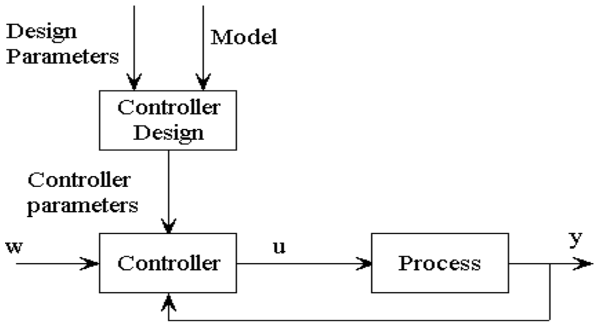

Fig.2 Model based control [8]

In our research, the process is modeled in [1], as shown above. The input of the process, **u (k)**, are two control parameters: Pf and δ. The output of the process, **y (k)**, represents these variations: the horizontal coordinate x, the vertical coordinate, y, the angle of the car body θ, the lateral and longitudinal velocity of the car, V_ξ and V_η, the angle velocity ω.

Normally, we hope the car can always run near the middle line of the road. At one given time k, no matter what is the current position of the car, the positions of the following time periods are expected on the middle line, as shown in Fig.3 and Fig 4. The coordinates of these expected positions could be attained easily. If we specify one longitudinal velocity V_η, the other two related velocities: V_ξ and ω can be computed. Then, we can get the desired output of the process, **w (k)**.

We choose 3 as the number of the predictive horizon. Define:

$$\begin{aligned} u &= [u(k+1), u(k+2), u(k+3)]^T \\ \hat{y} &= [\hat{y}(k+1), \hat{y}(k+2), \hat{y}(k+3)]^T \\ w &= [w(k+1), w(k+2), w(k+3)]^T \end{aligned} \quad (21)$$

The symbol ^ denotes estimation. Then, a predictive controller calculates such a future controller output sequence u that the *predicted* output of the process $\hat{y}$ is 'close' to the desired output w. This desired process output is called the reference trajectory and it can be an arbitrary sequence of points. In our research, 3 pairs of control parameters, Pf_i and δ_i, (i=1,2,3) are used as u, the computation results through the vehicle model are used as $\hat{y}$, and the parameters of the 3 expected positions are used as w.

Rather than using the controller output sequence determined in the above way to control the process in the next 3 samples, only the first element of this controller output sequence, in our background is Pf $_1$and δ_1, is used to control the process. This method is the receding horizon principle of the predictive control theory. According this principle, we use six control parameters to compute the predictive output and compare it with the desired output. However, only the first 2 are used and the result of the first step is the real result.

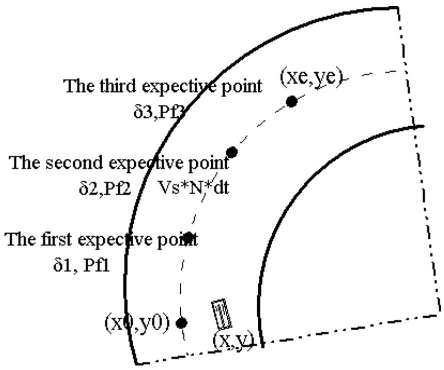

Fig.3 Expected position on the winding road

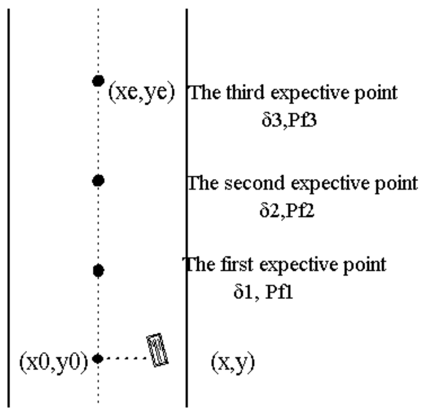

Fig.4 Expected position on the straight road

A criterion function is used to define how well the predicted process works:

$$J = \sum_{i=1}^{3} (\hat{y}(k+i) - w(k+i))^2 \qquad (22)$$

The optimal controller output sequence is obtained by minimization of J. The criterion function J in our problem is described in the next part of the paper.

The whole process for automatic control is shown in Fig. 5 below.

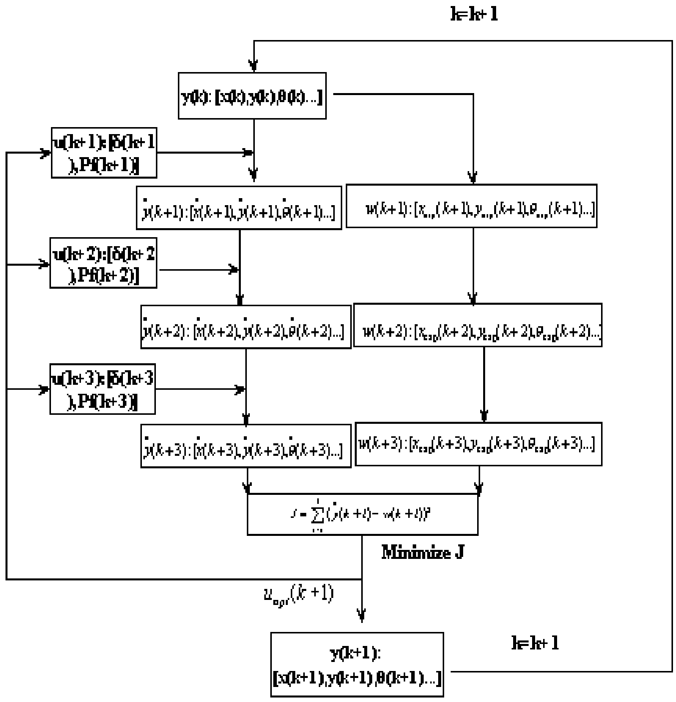

Fig.5 Flow chart of the algorithm

Because the vehicle model is not a linear model, minimizing J is not an easy problem. Usually, solving a minimization problem requires an iterative procedure. In this paper, we used the genetic algorithm[9], the result using this improved genetic algorithm is well accepted.

4 Experiment result and conclusion

The width of the car is 2m, and the width of the road is 10m. We specify the standard velocity of the car as 20m/s and the sample time is 0.2s.

As discussed above, we choose the number of predict horizon as 3, so the length of the road the car will pass is 12m. Then, 3 expected positions are located every 4 meters.

It is very important for the predictive control method to choose a suitable criterion function. Because our problem discussed is one multi-input, multi-output (MIMO) system, we should consider the features for all the output parameters. In our test, we choose the distance between the real position and the expected position Δd, the difference between the real driving angle and the expected angle $\Delta\theta$, the difference between the current control parameters and the parameters in the previous time, $\delta(k) - \delta(k-1)$, $Pf(k) - Pf(k-1)$. These four parts make up of the final criterion function to be optimized.

The dark line represents the trace of the car in our test. It can be seen that the automatic drive is safe. The car can travel near the middle line of the road steadily.

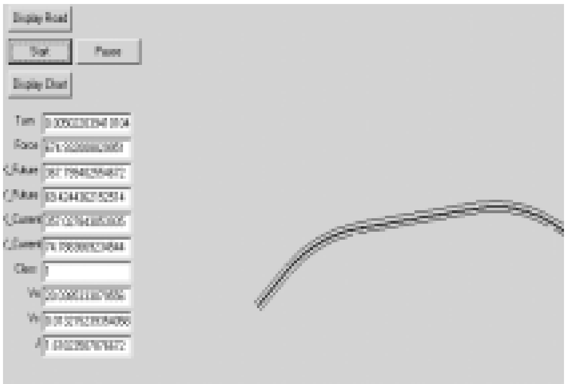

Fig.6 Trace of the car

Fig.7 shows the variation of the parameters in the driving process.

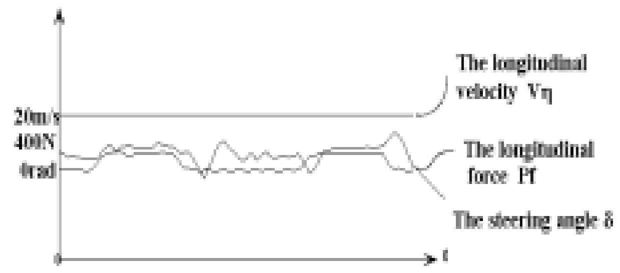

Fig.7 Curve of the parameters

Combing the Fig.6 and the Fig.7, we can see that the longitudinal velocity of the car is controlled under our algorithm with great veracity. The longitudinal velocity of the car nearly kept at 20m/s without any drastic difference. When the car passed from the straight road to the winding road, the steering angle is changed properly and gradually. At the first moment of this period, the longitudinal force damp has a clearly vibration, but it can achieve one steady value in a short time.

From the experiment results and the discussion above, this algorithm using predictive control theory is proved to be one qualified algorithm for automatic drive.

5 Discussion

The criterion function, J, is one of the most important factors that will affect the result. In this paper, the longitudinal velocity keeps at one constant value. However, this strategy is not always the best one. For example, the car may accelerate in the straight road and it may decelerate in the winding road or when it will enter the winding road. In this case, we should remove the longitudinal velocity restriction in the criterion function. In other cases, we need add some new restrictions into the criterion function. So, how to get the suitable criterion function and, at the same time, how to distribute the weight of every part of this function for different needs is one tough problem. Moreover, the computation amount of this algorithm also should be reduced in order to satisfy the need of real-time application.

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