Modeling of Steering System of High Speed Intelligent Vehicle by System Identification

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Abstract---Because of the complexity of the modern industrial plant, it is difficult to get the proper mathematical model of the system by using the traditional methods. This make us difficult in designing the best system controller. According to the control circumstance、the characteristics of control plant and the control aim, choose the proper system identification algorithm , is often a good measures to resolve this kind of problem. In this paper, we choose generalized least squares algorithm as system identification algorithm and get the differential equation model of the autonomous navigating intelligent vehicle system(ANIVS in short). Using this model in the experiment , we resolve the problem of the modeling and control of the steering system of ANIVS satisfactorily.

I .INTRODUCTION

In the recent years, people have paid more and more attention to the study of the Intelligent Vehicle System(IVS in short). According to the controlled method and autonomous degree, the IVS can be grouped into three kinds: remote controlled IVS, partly autonomous navigating IVS, autonomous navigating IVS. The last one, namely the autonomous navigating intelligent vehicle system(ANIVS in short), is an integrated system which consists of circumstance perception、planning & determination and autonomous navigation.

In the study of ANIVS, a very important premise is to establish the mathematical model of the steering system. Then by combining this model with the characteristics of kinematics and dynamics of the vehicle system, we establish the controller model, and finally realize the autonomous navigation of vehicle system.

Because of the complexity of modern industrial plants, when applying the purely theoretical analysis method, we need a lot of hypotheses and simplifications. These make the gained mathematical model inaccurate and certainly it is difficult to realize the optimal autonomous navigation of the IVS.

With the development of system identification theory, it is a good method to acquire the mathematical model of the system by applying the proper system identification method.

On the basis of the autonomous navigation model vehicle which we have designed and built by ourselves, We carry out our identification experiments by the following steps: 1) Design of the experiment system. 2) The selection of class and structure of model. 3) Estimation and verification of model parameters.

II. THE DESIGN AND REALIZATION OF COMPUTER MEASURE AND CONTROL SYSTEM OF STEERING SYSTEM OF ANIVS.

Showed in the Fig. 2-1, the whole control and measure of experiment system focuses on the industrial PC. Theoretically speaking , the steering angle and input pulses are precisely corresponding one by one . But in fact, because of the disturbance of stochastic noises introduced by the reducer and redirector, even if the input pulses number are same, the output steering angle is different, so we have to consider the stochastic noises into the mathematical model of the system.

III.THE SELECTION OF CLASS AND STRUCTURE OF MODEL

The selection of class and structure of model include two parts: the presupposition of class and structure of the model and the confirmation of the model parameters. Because there are a lot of differences between the steering system of the model vehicle and the steering system of the traditional vehicle, so we know the dynamic characteristics of the steering system of the model vehicle little.

In order to analyze the steering system, we carry out the following experiment first .

When the steering wheel are in the middle position , make the steering wheel run by outputting some pulses.

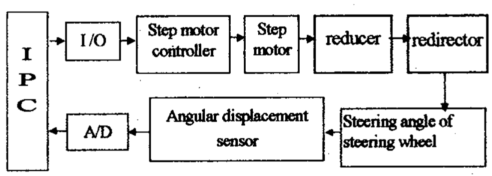

Fig.2-1 Steering system of ANIVS

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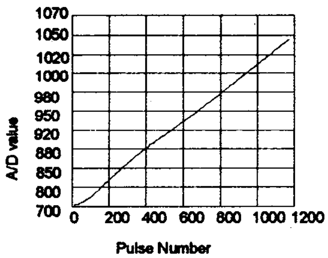

Fig.3-1 step response curve of steering angle of steering wheel

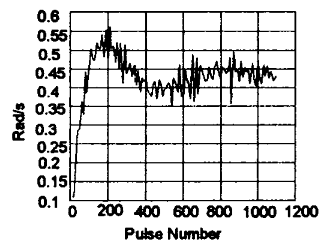

Fig.3-2 step response curve of angular velocity of steering wheel

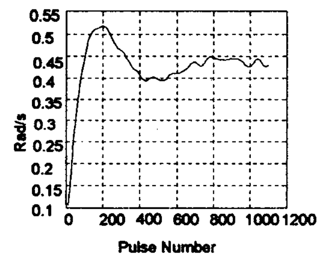

Fig.3-3 step response curve of angular velocity of steering wheel by filtering process

During the procedure , we sample the A/D value with sampling time 0.01s. The experimental data are showed as following Fig.3-1.

In the Fig3-1, we notice that the steering angle of the steering wheel goes into the stable state in a few seconds, which result in the difficulties in observing the dynamic characteristics. To avoid this ,we can transform the data by following equation:

$$\omega(k) = \pi \frac{\alpha[(k+1)T] - \alpha(kT)}{180T} \qquad (3-1)$$

where ω ——steering angular velocity

α ——steering angle A/D value

T ——sampling periods

k ——sampling series

After the transformation, the step response curve of angular velocity is showed in Fig3-2.

In order to reduce the disturbance of the high frequency noises, the experimental data should be pre-processed . In this paper, we filter the experimental data by five order Butterworth filter. The Fig.3-3 shows the step response curve of angular velocity of steering wheel by filtering process.

According to the step response curve, we can estimate that the adjust-time of the system is approximately 0.9s and the system order should be at least two order.

So we can assume system model is three order ARMAX model:

$$A(z^{-1})z(k)=B(z^{-1})u(k-1)+C(z^{-1})e(k) \qquad (3-2)$$

$$A(z^{-1}) = 1 + a_1 z^{-1} + \cdots + a_{na} z^{-na}$$

where $$B(z^{-1}) = b_0 + b_1 z^{-1} + \cdots + b_{nb} z^{-nb} \qquad (3-3)$$

$$C(z^{-1}) = 1 + c_1 z^{-1} + \cdots + c_{nc} z^{-nc}$$

$z(k)$ and $u(k-1)$ are the output and input of the system

$e(k)$ is the independent white noise series

$\max(na, nb) \le 3$

Ⅳ. THE ESTIMATION AND VERIFICATION OF THE SYSTEM MODEL

A. The Selection of the Identification Input Signal

If the selection of the model structure is proper, the precision of the parameters identification will directly depend on the input signal by Fisher information matrix. Although selecting the white noise as the input signal can get the best parameters identification results, it's difficult to realize the white noise in practice . So in practice, we often select the M series as the identification input signal. The characteristics of M series are similar to the one of the white noise and also can get the better parameters identification results.

In experiment, we use four order M series as the input signal ,so the $N_P = 15$. Δt is the period of shifting pulse , select $\Delta t = 0.2$s, so the period of the input signal T $=3$s.

B. Identification and Analysis of the Steering System

For the traditional least squares(LS) method, if the mathematical model of the system is :

$$A(z^{-1})z(k) = B(z^{-1})u(k-1) + e(k) \qquad (4-2-1)$$

We can transform equation (3-2-1) to the LS format[2]

$$z(k) = \mathbf{h}^{\tau}(k)\theta + e(k) \qquad (4-2-2)$$

where

$$\begin{cases} \mathbf{h}(k) = [-z(k-1), \cdots, -z(k-na), \\ \qquad u(k-1), \cdots, u(k-nb)]^T \\ \theta = [a_1, a_2, \cdots, a_{na}, b_0, b_1, b_2, \cdots, b_{nb}]^T \end{cases} \qquad (4-2-3)$$

for the $k = 1, 2, \cdots, L$,equation (3-2-3) make up of a linear equation group

$$\mathbf{Z}_L = \mathbf{H}_L \theta + \mathbf{e}_L \qquad (4-2-4)$$

where

$$
\begin{cases}
\mathbf{Z}_L = [z(1), z(2), \cdots, z(L)]^T \\
\mathbf{H}_L = \begin{bmatrix} \mathbf{h}^T(1) \\ \mathbf{h}^T(2) \\ \vdots \\ \mathbf{h}^T(L) \end{bmatrix} = \begin{bmatrix} -z(0), \cdots, -z(1-na), \\ u(0), \cdots, u(0-nb) \\ -z(1), \cdots, -z(2-na), \\ u(1), \cdots, u(1-nb) \\ \vdots\ \vdots\ \vdots \\ -z(L-1), \cdots, -z(L-na), \\ u(L-1), \cdots, u(L-nb-1) \end{bmatrix} \\
\mathbf{e}_L = [e(1), e(2), \cdots, e(L)]^T
\end{cases}
$$

for the above (4-2-4), we choose the lost function :

$$
J(\theta) = \sum_{k=1}^{L} [z(k) - \mathbf{h}^T(k)\theta]^2 \qquad (4-2-5)
$$

and get the parameter estimation of LS by making the $J(\theta)$ tend to the limit

$$
\hat{\theta}_{LS} = (\mathbf{H}_L^T \mathbf{H})^{-1} \mathbf{H}_L \mathbf{Z}_L \qquad (4-2-6)
$$

Only when the system noise is independent white noise , the LS estimation is the valid、non-bias and consistent estimation. Because we use the ARMAX model (3-2) as the experiment model, and the system noise is the color noise, so we should use the generalized least squares (GLS)method as identification algorithm , the GLS method consider the noise model into the system model, and correspondingly the equation group (4-2-3) is changed into:

$$
\begin{cases}
\mathbf{h}(k) = [-z(k-1), \cdots, -z(k-na), \\
\qquad u(k-1) \cdots, u(k-nb), e(k-1), \cdots, e(k-nc)]^T \\
\theta = [a_1, a_2, \cdots, a_{na}, b_0, b_1, b_2, \cdots, b_{nb}, c_1, c_2, \cdots c_{nc}]^T
\end{cases}
$$

because the data vector $\mathbf{h}(k)$ consist of the unmeasurable noises $e(k-1), \cdots, e(k-nc)$, we should replace it with the corresponding estimators , so

$$
\mathbf{h}(k) = [-z(k-1), \cdots, -z(k-na), u(k-1), \cdots, \\
u(k-nb), \hat{e}(k-1), \cdots, \hat{e}(k-nc)]^T
$$

where

$$
\begin{cases}
k \le 0, \hat{e}(k) = 0; \\
k > 0, \hat{e}(k) = z(k) - \mathbf{h}^T(k)\hat{\theta}(k-1)
\end{cases}
$$

at last , we get the recursive generalized least squares algorithm of system identification:

$$
\begin{cases}
\hat{\theta}(k) = \hat{\theta}(k-1) + K(k)[z(k) - \mathbf{h}^T(k)\hat{\theta}(k-1) \\
K(k) = P(k-1)\mathbf{h}(k)[\mathbf{h}^T(k)P(k-1)\mathbf{h}(k) + 1]^{-1} \\
P(k) = [\mathbf{I} - K(k)\mathbf{h}^T(k)]P(k-1) \\
P(k-1) = [\mathbf{h}^T(k-1)\mathbf{h}(k-1)]^{-1}
\end{cases}
\qquad (4-2-7)
$$

When we discussed the above algorithm ,we assumed that we had known the system order . However ,the fact is that we only estimated the system order as three order by the step response curve of the system . So, we need confirm the system order firstly before we carry out the final parameters identification. We choose the different system order and compare the matching degree between the experimental data and the simulated data, and then according to the matching degree to determine the system order. we select system order $n = 2,3,4$ respectively and get the matching degree respectively as showed in Tab. 4-1.

TAB 4-1

COMPARISON OF MATCHING DEGREE BETWEEN THE EXPERIMENTAL DATA AND SIMULATED DATA BY SELECTING DIFFERENT ORDER

(n_a, n_b, n_c, n_k)	The best matching degree
(2,1,1,1)	2.6269
(2,2,2,1)	0.64204
(3,3,3,1)	0.50057
(4,4,3,1)	0.51297

From the Tab.4-1 ,we know the best selection of system order is three order.

To carry out the system identification by applying the above algorithm, choose the sampling time T=0.01s, the Fig.4-2-1 shows the relationship between the input pulses signal and the output angular displacement signal during an entire input signal period. From the relationship curve , we notice that the output signal follows the input signal .

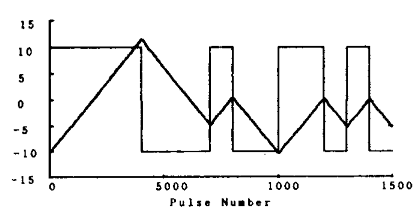

Fig.4-2-1 response curve of angular displacement of steel wheel

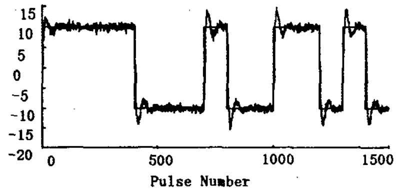

Fig.4-2-2 response curve of angular velocity of steering wheel

In order to reflect the dynamic characteristics more directly, we still transform the angular displacement to angular velocity. The Fig.4-2-2 shows the relationship between the input pulse signal and the output angular velocity signal.

Choose the length of the identification data L=1500,and we get the differential equation which describe the steering system:

$$\begin{aligned} z(k) = {} & 2.7597\, z(k-1) - 2.5486\, z(k-2) \\ & + 0.7870\, z(k-3) + 0.2007\ u(k-1) \\ & - 0.3766\ u(k-2) + 0.1779\ u(k-3) \\ & + e(k) + 2.6237\, e(k-1) \\ & + 2.5901\, e(k-2) + 0.9662\, e(k-3) \end{aligned}$$

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