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Modeling and Robostic Control of Reduction Car Using the Ultrasonic Satellite System

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Abstract: In this paper In this paper, which is one of the part of the development for the automation system in the navigation process, covers the car system. Local detection system based on pseudo-satellite was used to be able to detect the space coordinates and the absolute location with four ultrasonic transmitters and two receivers. Using this system wH_∞ e get the lateral dynamic model of a reduced car by using system identification methods and design a lateral controller. The system input is the steering wheel angle of the vehicle with constant speed and the output is the yaw of the vehicle. With system identification for a basis, to achieve a control objective, we design a controller using the model equation.

***Keywords*: USAT, localization, positioning, mobile robot**

I. INTRODUCTION

Research centered on ITS (Intelligent Transportation System), PATH (Partners for Advanced Transit and Highways) and AHS (Automated Highway System) has led to the development of the autonomous vehicle (Broggi *et al., 1999*) Although magnetoresistive (MR) and vision sensors play an enabling part in autonomous vehicle operation, they are not sufficient to permit operation under all conditions (Huei et al., 1992). For example, MR sensors require marked magnet points on the road and are susceptible to stochastic error. A disadvantage of vision sensors is that they are sensitive to weather conditions and light (Lee et al., 2002; Lee et al., 2006).

In this paper, as a part of this study we make a reduced car adopted H_∞ based on USAT(Ultrasonic satellite system) and design a controller. H_∞ control system as acontroller, which uses the feedback of the yaw angle error, was used to design a robust lateral control against modeling uncertainty (Shladover, 1991). The performance of this algorithm is compared to that of the PID controller. In order to obtain the system model equation, we use system identification.

2. ULTRASONIC SATTELLITE SYSTEM

The measurement of the distance using the ultrasonic waves is calculated with sound velocity and the delivering time. TOF (Time of Flight) is defined as the time difference between transmitter and receiver. Pseudo-satellite system(or Ultrasonic satellite system) consist of four transmitters and two receivers. Ultrasonic transmitters function as ultrasonic satellites and locate on the fixed places whose coordinates are known. So ultrasonic receivers receive ultrasonic waves transferred from ultrasonic satellites and the distance between ultrasonic receivers and ultrasonic satellites is calculated. The basic idea of U-SAT is similar to that of GPS. Although ultrasonic receivers exist in the ultrasonic satellites, the position of ultrasonic receiver is calculated respectively. We obtain the UCT position data from U-SAT and obtain the yaw data between prior position and present position.

3. SYSTEM IDENTIFICATION

Discrete time subspace system identification methods have attracted much attention during the past few years due to ability of identifying multivariable linear processes directly from the input-output data. Compared with the classical PEM and IVM, these subspace methods do not suffer from a parameterization and nonlinear optimization. Also, their properties and common features have been analyzed well (Van Overshee *et al.* [2]) and their extensions to closed-loop process data have been developed (Chou *et al.* [3], and Ljung *et al.* [4]). The objective of discrete-time subspace system identification methods is identifying the system matrices as well as the process order of the discrete-time state space model.

In general, linear time invariant system represented

$$x(t+1) = Ax(t) + Bu(t) \tag{3.1}$$

$$y(t) = Cx(t) + Du(t) + v(t) \tag{3.2}$$

System identification tool is used discrete state-space model. Discrete state-space equation is

$$x(kT+T) = Ax(kT) + Bu(kT) + Ke(kT) \tag{3.3}$$

$$y(kT) = Cx(kT) + Du(kT) + e(kT) \tag{3.4}$$

$$x(0) = x_0 \tag{3.5}$$

In order to design a PID controller, eq. (2), (3), and (4) is transformed the continuous state space equation

$$\dot{x}(t) = Fx(t) + Gu(t) + \tilde{K}\, w(t) \tag{3.6}$$

$$y(t) = Hx(t) + Du(t) + w(t) \tag{3.7}$$

$$x(0) = x_0 \tag{3.8}$$

The relation discrete time state matrices A, B, C, D have relation with continuous time state matrices F, G, H, D

$$A = e^{FT} \tag{3.9}$$

$$B = \int_0^T e^{F\tau} G d\tau \tag{3.10}$$

$$C = H \tag{3.11}$$

This relation accomplish when input is piecewise-constant in time interval. Where is state transition matrix. If the system has no noise, we approximate $v(t) \approx 0$, $K \approx 0$ and we rewrite the Eq. (3.6), (3.7), (3.8) as Eq. (3.1), (3.2).

A least squares problem to obtain the state space matrices solve Eq. (3.12).

$$\begin{pmatrix} \hat{A} & \hat{B} \\ \hat{C} & \hat{D} \end{pmatrix} = \min_{A,B,C,D} \left\| \begin{pmatrix} \hat{x}_{i+1} & \hat{x}_{i+1} & \cdots & \hat{x}_{i+j} \\ y_i & y_{i+1} & \cdots & y_{i+j-1} \end{pmatrix} - \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} \hat{x}_i & \hat{x}_{i+1} & \cdots & \hat{x}_{i+j-1} \\ u_i & u_{i+1} & \cdots & u_{i+j-1} \end{pmatrix} \right\|_F^2 \tag{3.12}$$

Where $\|\cdot\|_F$ denotes the Frobenius-norm of a matrix[5].

As soon as the order of the model and the state sequences X_i and X_{i+1} are known, the state space matrices A, B, C, D can be solved form

$$\begin{pmatrix} X_{i+1} \\ Y_{i|i} \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} X_i \\ U_{i|i} \end{pmatrix} \tag{3.13}$$

Where $U_{i|i}$, $Y_{i|i}$ are block Hankel matrices with only one block row of inputs respectively outputs, namely $U_{i|i} = \begin{pmatrix} u_i & u_{i+1} & \cdots & u_{i+j-1} \end{pmatrix}$ and similarly for $Y_{i|i}$. This set of equations can be solved. As there is no noise, it is consistent.

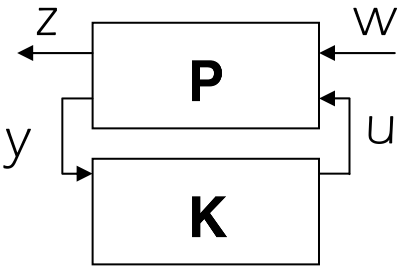

Fig 4.1. H_∞ controller block diagram

4. H∞ LATERAL CONTROL OF AUTRONOMOUS VEHICLES

Figure 1 shows the H∞ control block diagram. The components of w are all the exogenous inputs to the system (Kemin, 1998). These typically consist of disturbances, sensor noise reference commands and fictitious signals that drive frequency weights and models of the uncertainty in the dynamics of the system. The components of z are all the variables we wish to control, such as tracking errors and actuator signals. The inputs generated by the controller are denoted u. The sensor measurements used by the feedback controller are denoted y.

The generalized plant P, which is assumed to be linear and time-invariant, contains all the information that is favorable to incorporate into the synthesis of the controller, K. System dynamics, models of the uncertainty in the system's dynamics, frequency weights to influence the controller synthesis, actuator dynamics, sensor dynamics and implementation hardware dynamics are all included in P

$$z = P_{11}w + P_{12}u \tag{4.1}$$

$$y = P_{21}w + P_{22}u \tag{4.2}$$

$$u = Ky \tag{4.3}$$

The relationship between the variable z and the exogenous input is $z = T_{zw}w$. The H∞ control is represented as follows:

$$\| T_{zw} \|_\infty \le r\,. \tag{4.4}$$

Equation (4.4) motivates the design of a stable controller of P to maintain a less infinite norm of Tzw than the given scalar γ.

The H∞ control is represented as Equation (4.5) with the method of Glever and Doyle (John et al., 1989).

$$\left\| \begin{matrix} w_1 & s \\ w_3 & s \end{matrix} \right\|_\infty \le r\,. \tag{4.5}$$

In the mixed-sensitivity problem, W1 and W3 are weighting functions for improving the performance of the system. In addition, S and T are the sensitivity function and the loop transfer function of the system, respectively.

The selection of weighting functions for a specific design problem often involves ad hoc fixing, many iterations and fine tuning. It is challnging to generate a general formula for weighting functions that applies to every case. Based on the time domain performance specifications, the corresponding requirements in a frequency domain in terms of the bandwidth w_b and the peak sensitivity Ms can be determined. This assumes that the steady state error of the step response ε has to satisfy $|w_1(0)| \geq 1/\varepsilon$. A possible choice of w_1 can be obtained by modifying the weighting function as follows:

$$w_1 = \frac{s/M_S + w_b}{s + w_b \varepsilon}. \tag{4.6}$$

W1 is selected to improve the disturbance-reject and command-tracking, as follows:

$$w_1 = \frac{0.38s^2 + 15.5s + 1.38}{s^2 + 3s + 0.26}. \tag{4.7}$$

Additionally, the magnitude of $|KS|$ in the low frequency range is essentially limited by the allowable cost of control effort and saturation limit of the actuators;

hence, in general, the maximum gain MT of KS can be fairly large, while the high-frequency gain is essentially limited by the controller bandwidth (w_{bc}) and the sensor nois frequencies. A candidate weight w_3 would be

$$w_3 = \frac{s + w_{bc}/M_T}{\varepsilon_1 s + w_{bc}}. \tag{4.8}$$

for a small $\varepsilon_1 > 0$. Considering the roll off performance of the controller w_3 is selected to reject noise, as follows:

$$w_3 = \frac{s^3 + 600}{80000}. \tag{4.9}$$

Figure 4.2 is the frequency domain performance of each weighting function.

5. SIMULATION

To evaluate performance of controller reference path is set and a simulation performanced. To evaluate how the vehicle trace well to the designated point using Navigation algorithm PTP(point to point). Reference path is randomly set and base on state using system identification degree of tracing is evaluated. In real experiment performance fluctuates according to external condition nonlinealy system identification. Considering system identification method is designed on nonlinearty. Nonlinearty can be ignored in simulation to compare the performance of controller with disturbance and noise with the performance of controller without them.

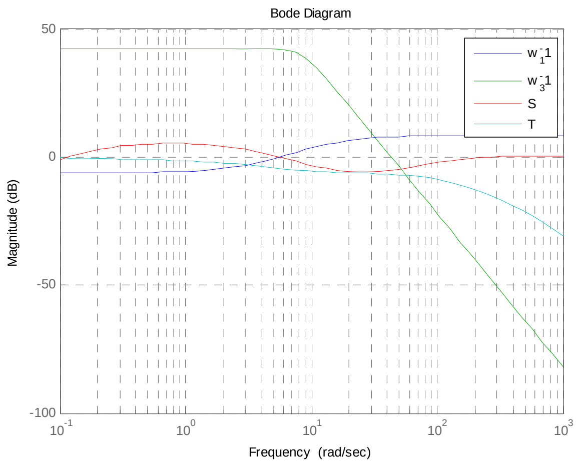

Fig 4.2 weighting function w_1, w_3 frequency domain performance

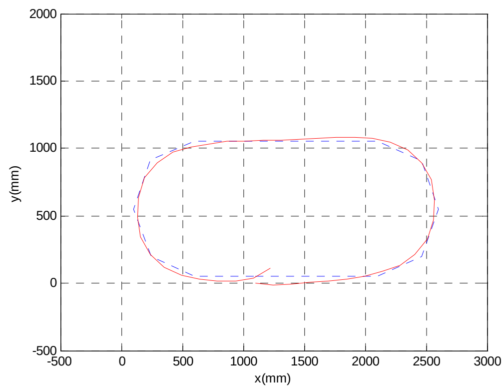

Fig 5.1 simulation result(0.3m/s)

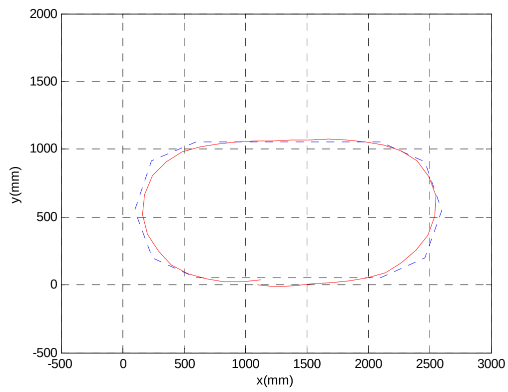

Fig 5.2 simulation result(0.35m/s)

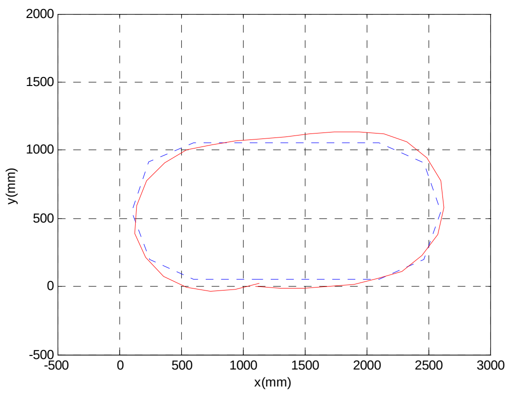

Fig 5.3 simulation result(0.4m/s)

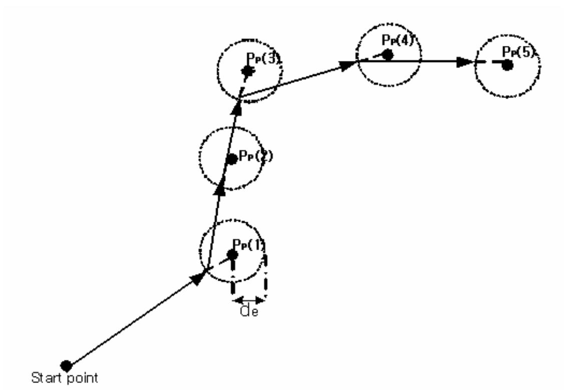

Fig 6.1 Navigation algorithm

6.NAVIGATION ALGORITHM

Fig. 6 represents the unmanned navigation algorithm. Navigation algorithm is PTP(Point To Point) method. UCT moves from the point on the reference path $P_p(i)$ to $P_p(i+1)$. If the reduced car arrives the target point, system continuously determined the next target point. And if the distance error between current position and $P_p(i)$ is smaller than d_e, system correct the next target point $P_p(i)$ to $P_p(i+1)$. d_e is selected by the velocity of reduced car and error of position measurement.

7. CONCLUSION

In this paper, we determined the system model of an autonomous vehicle for lateral control that is important to design parameter based controller in unmanned vehicle system. Using the subspace system identification method, we confirmed that the simulation is very accurate. It is important to design a controller that uses system parameters. We minimized the modeling error using system identification that using system input-output data. and we made a reduced car adopted H_∞ based on USAT(Ultrasonic satellite system) and design a controller. The performance of the compensated system that based on the system identification deserves satisfied. We will research the vehicle system identification with other dynamic and system condition. we design controller that is robust to system disturbance and parameter uncertainty.

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